WIRELESS PHONE USE BY YOUNG NEW ZEALANDERS: HEALTH AND POLICY IMPLICATIONS

By

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Abstract

Over the last decade the use of cellphones has increased dramatically among the young adolescent population. In New Zealand, most children of this age also use a cordless phone. With the rapid proliferation in children's use of these devices, there has been increasing concern about whether children are more vulnerable than adults to possible adverse outcomes if such effects do result from wireless phone radiofrequency exposure.

This is the first study of young New Zealanders' wireless phone habits, focusing particularly on the extent of use, and the relationship of that use with well-being. Two studies were undertaken: a census of schools with Year 7 and 8 classes in the Wellington Region of New Zealand to ascertain what rules were in place regarding cellphones at school, and a cross-sectional survey of students from the same region, using a representative sample of 373 students aged 10.3-13.7years. Both studies were conducted by the author independently from any research group.

The primary research appears in Part II. Chapter 5 presents wireless phone user-habits. The large majority of young adolescents were already using cellphones and cordless phones regularly in 2009, although use was generally light or moderate. A small group (5%) was using both phone types extensively (≥ 30 minutes cordless daily plus ≥ 10 cellphone calls weekly); almost a quarter used a cordless phone ≥ 30 minutes daily, and 6% reported, on average, 1¼ hours or more use daily. This extent of use over 4 or more years has been associated in several major studies with an increased risk of glioma. Both the MoRPhEUS data and this study's data (Appendix 1 and Chapter 5) showed that use of the two phone types is positively correlated, increasing the comparative and actual radiofrequency exposure in heavy users. Cellphone use during school was compared with school expectations, discussed in chapter 6, showing there was a considerably greater level of illicit use than that of which principals were aware. This use was adjacent to the lower abdomen, and a brief review of relevant fertility literature suggested that cellphone use, or even carriage, in that position may impair sperm quality and duration of use like this appeared consistent with reduced fertility.

A novel observation is explored in chapter 7. The mental process in recalling the extent of cellphone use was not linear. It parallels that found in many types of magnitude estimation, using a logarithmic mental number line. This carried implications for epidemiology methods that use recall data, particularly the need to record the geometric rather than arithmetic mean when a range of estimated use is provided. Not doing so put almost 5% of participants in an incorrect category when estimated use was split into tertiles.

Recall estimation has a large variance. Chapter 8 presents a Bayesian method of reducing estimation bias in recall data. It should be applicable for use by studies that conform to the method's requirements. Chapter 9 presents the results of logistic regression analysis of the participants' reported well-being with respect to their wireless phone use. A dose-response relationship with frequent headaches confirmed findings elsewhere. Tinnitus and tiredness results suggested that responses were different depending upon phone type. This is the first study to explore and demonstrate different well-being responses according to cordless phone frequency or modulation. There was a strong association between being woken by the cellphone in the night and being tired at school.

This research carries implications for young people's wireless phone use, including the advisability of limiting daily use to no more than 15 minutes daily. The relevance of researchers considering cellphone exposures, compared to that of cordless phones, is questioned. Further research on bio-sensitive frequencies, modulations and exposures is needed.

An important recommendation is for the inclusion of education about wireless technology in schools and school communities and for child-health practitioners.

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Abbreviations

2G	:	Second Generation
3G	:	Third Generation
ACRBR	:	Australian Centre for Radiofrequency Bioeffects Research
APC	:	Adaptive Power Control
ARPANSA	:	Australian Radiation Protection and Nuclear Safety Agency
BMI	:	Body Mass Index
CEHAPE	:	Children's Environment and Health Action Plan for Europe
CI	:	Confidence Interval or Credible Interval in Bayesian paper
cm	:	Centimetre
CNS	:	Central Nervous System
CTIA	:	The Association of the Wireless Telecommunications Industry
dB	:	Decibel
DECT	:	Digital Enhanced Cordless Telephones
DNA	:	Deoxyribonucleic acid
DPC	:	Dynamic Power Control
DSS	:	Digital Spread Spectrum
EC	:	European Commission
EE	:	Eastern Europe
EEA	:	European Environment Agency
EEG	:	Electroencephalogram
E-field	:	Electric field
ELF	:	Extremely Low Frequency
EME	:	Electromagnetic Energy
EMF	:	Electromagnetic Frequency
ERK	:	Extracellular-signal-regulated kinases
EU	:	European Union
FCC	:	Federal Communication Commission
FH	:	Frequency Hopping
FHS	:	Frequency Hopping System
GHz	:	GigaHertz
GSM	:	Global System for Mobile Telecommunications

HBSC	:	Health Behaviour in School-Aged Children
HEN	:	Health Evidence Network
H-field	:	Magnetic field
HSP	:	Heat shock protein
Hz	:	Hertz
IACHEEF	:	Interagency Advisory Committee on the Health Effects of Electromagnetic Fields
ICEMS	:	International Commission for Electromagnetic Safety
ICNIRP	:	International Commission on Non-Ionizing Radiation Protection
IEEE	:	Institute of Electrical and Electronics Engineers
IEGMP	:	Independent Expert Group on Mobile Phones
IRPA	:	International Radiation Protection Association
MHz	:	MegaHertz
MoRPhEUS	:	Mobile Radiofrequency Phone Exposed Users' Study
mW	:	mW
mW/cm^2	:	Microwatts per square centimetre
NRL	:	National Radiation Laboratory
NRPB	:	National Radiation Protection Board
NZS	:	New Zealand Standard
OR	:	Odds Ratio
psSAR	:	Peak Spatial average Specific Absorption Rate
RF	:	Radiofrequency
RNCNIRP	:	Russian National Committee on Non-Ionising Radiation Protection
ROS	:	Reactive Oxygen Species
SAR	:	Specific Absorption Rate
SCENHIR	:	The Scientific Committee on Emerging and Newly Identified Health Risks
SD	:	Standard Deviation
SES	:	Socio-Economic Status
SMS	:	Short Message Service (texting)
STUK	:	Finnish Radiation Authority
TV	:	Television
UMTS	:	Universal Mobile Telecommunications System
UNEP	:	United Nations Environment Programme
V/m	:	Volts per metre
W	:	Watt
W/kg	:	Watts per kilogram

WHO	:	World Health Organisation
WiFi	:	Wireless broadband
$\mu W/cm^2$	:	Microwatts per square centimetre

PART ONE

LITERATURE REVIEW, AIMS AND STRUCTURE

FOCUS ON CHILDREN'S VULNERABILITIES

INTERNATIONAL and NATIONAL POLICY

1 Introduction, Aims and Structure

> "Science often becomes ammunition in partisan squabbling, mobilized selectively by contending sides to bolster their positions. The scientific experts on each side of the controversy effectively cancel each other out and the more powerful political or economic interests prevail."
> p.80 (Sarewitz, 2000)

1.1 Introduction

Over the last decade the use of wireless technology has increased dramatically, with a cellphone rapidly becoming a 'must have' appendage in teenage and young adolescent life. As telecommunication companies market these phones to younger and younger children, ownership and use of this technology has grown among primary school students and even pre-schoolers (Davie et al., 2004a; Marsh, 2004). Research has confirmed what appears obvious – that many young people are addicted to their mobile phone (Yen et al., 2009; Walsh et al., 2008). From babyhood, our children are becoming encultured to the normality of electronically transmitted communication (Marsh, 2004).

Other wireless devices such as cordless landline telephones, WiFi, and Bluetooth have also become commonplace, surrounding most New Zealanders in a sea of radiofrequency electromagnetic radiation colloquially referred to as electrosmog.

This dissertation asks to what extent New Zealand adolescents are using cellphones and cordless landline telephones, thereby routinely being exposed to potentially adverse doses, frequencies, and modulations of non-ionising electro-magnetic radiation. If there is evidence of adverse effects on well-being or health, what policy (or other) responses (if any) are required to mitigate these risks?[1]

In the first chapter (Part I), I explore the topic broadly from an environmental studies perspective. In the next two chapters, I focus on technical considerations and the research literature firstly regarding concerns of children's greater vulnerabilities than those of adults, and then on international and national policy. The purpose for this extended introduction and literature review is to enable me to place my original research into an international and

[1] Cellphones and cordless landlines will be referred to collectively as "wireless phones". The radiation from them will also be referred to as "radiofrequency radiation" "RF" or "microwave radiation"

policy context. The original research is then presented in chapters 4 to 9, and the findings and policy implications are discussed in the final chapter.

The first half of this first chapter provides an introduction to the controversial topic of children's use of wireless phones. This is set it in a broad context which considers the scientific basis for the policy approach taken regarding radiofrequency exposure and reviews some research that has demonstrated bio-effects at lower exposures and proposed mechanisms for such effects. I provide a description of wireless phones, and outline the parts of the radiofrequency spectrum that they utilize. Personal and environmental exposures are described. I explain the challenges presented in conducting and replicating research in this field, review further research and describe the New Zealand policy context and approach.

1.1.1 Thermal exposure

Wireless-phone technology operates using radiofrequency (RF) radiation[2]. With sufficient intensity, this is known to damage living tissue through acute heating. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) developed guidelines in 1998 that sought to prevent injury from acute heating. This thermal interaction was, and still is, the only well-understood and universally accepted mechanism of physical harm. RF exposure maxima for 10 MHz to 10 GHz were calculated based on the exposures that led to a 1°C body temperature increase in a resting human after 30 minutes' exposure under moderate environmental conditions (ICNIRP, 1998). The selection of 1°C relies on a UNEP/WHO/IRPA paper (United Nations Environment Programme et al., 1993) in which this was "suggested as the upper limit of temperature increase that has no detrimental health effects" p.505 (ICNIRP, 1998). For public exposure, ICNIRP recommended a 50-fold reduction as a safety margin to allow for hot and humid climate, exposure when not at rest, and "potentially higher thermal sensitivity in certain population groups, such as the frail and/or elderly, infants and young children, and people with diseases or taking medications that compromise thermal tolerance" p.508. Basic restrictions are expressed by Specific Absorption Rate (SAR) and reference levels are given for power density (mW/cm^2) and electric field (E-field) strength (V/m). More information is given in chapter 3. The New

[2] They utilise the upper part of the radio frequency range called microwaves, but are generally referred to as radiofrequencies (RF). They are non-ionising: not carrying sufficient energy to knock ions off atoms or molecules as occurs with ionising radiation

Zealand Standard 2772.1:1999 (the NZ Standard) for radio frequency emissions is based on the ICNIRP guidelines.

1.1.2 Non-thermal exposure

Neither the ICNIRP guidelines nor the NZ Standard addresses possible biological effects of long-term exposure or energy levels which are too low to cause heating. These exposures are commonly referred to as non-thermal.[3] No mechanisms of interaction from such exposures are officially acknowledged, although the following pathways of interaction have been proposed. Lu et al. found that exposure to 900 MHz RF at a specific absorption rate (SAR) of approximately 0.4 W/kg for 2 or more hours induced a series of bio-effects through the mitochondrial pathway, stimulating oxidative stress through the generation of Reactive Oxygen Species (ROS) and a protein known as caspase-3 [4] (Lu et al., 2012). Friedman et al. described a detailed molecular pathway by which mobile phone frequencies induce short-term activation of extracellular-signal-regulated kinases (ERKs)) ((Friedman et al., 2007) [5]

Others have also demonstrated activation of the ERK cascade and increased heat shock protein (HSP) activation after non-thermal exposures (Goodman et al., 2009; Leszczynski and Joenväärä, 2002; Weisbrot et al., 2003; Friedman et al., 2007). Several studies have observed rapid activation of changes to protein expression including protein transcription and folding (De Iuliis et al., 2009; Agarwal et al., 2009; Friedman et al., 2007; Fragopoulou and Margaritis, 2012). Specific sequences of DNA in HSP 70 have been identified that respond to extremely low electromagnetic field exposures; removing this section eliminated the response (Blank and Goodman, 2009).

Other bio-responses to non-thermal exposure include changes in chromosomal material (Sarimov et al., 2004), alteration of cerebral blood flow (Huber et al., 2002; Aalto et al., 2006), and leakage through the blood brain barrier (Nittby et al., 2009; Vojtíšek et al., 2005).

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[3] The expression 'non-thermal' is not technically accurate. In the cellphone context, the expression is typically used to mean radiation exposure at intensities which are too low to result 1°C whole body heating after 30 minutes' exposure to 4 W/kg in a moderate climate

[4] A protein of the **c**ysteine-**asp**artic acid prote**ase** family. These and other caspase proteins are central to executing cell apoptosis (programmed cell death)

[5] ERKs regulate several biological functions including cell proliferation, differentiation, and regulated cell death (apoptosis)

Research has not consistently found these effects (Kundi and Hutter, 2009). There are several indications of why effects are not consistent across all studies. Researchers commonly assume a linear dose-response relationship although replicated research from the 1970s to the 1990s demonstrated 'windows' of effect with respect to both exposure intensity and frequency (Blackman et al., 1979; Bawin et al., 1975). These experiments indicated that increased intensity was not linearly associated with increased effect, or even likelihood of effect. The 'windows' of effect were like islands in a sea of frequencies or energy levels that showed no bio-response. An ion parametric resonance (IPR) model was developed which successfully predicted distinct magnetic field interactions with biological systems based on a selective relation with frequency and flux density of parallel magnetic field, the flux density of the static magnetic field and charge-to-mass ratio of ions of biological relevance (Blackman et al., 1995; Blackman et al., 1999).

Recent research on *Drosophila melanogaster* has demonstrated such 'windows' from typical 900 MHz and 1800 MHz cellphone exposures, indicating a significant decrease in reproductive capacity. This applied not to a specific distance from the source, but an exposure intensity of about 10 micro Watts per square centimetre ($\mu W/cm^2$) from the RF component of the exposure, or 0.6-0.7 volt per metre (V/m) and 0.10-0.12 milli Gauss (mG) Extremely Low Frequency (ELF) electric and magnetic fields components, respectively (Panagopoulos and Margaritis, 2010). The results were not linear, since higher exposures had less effect. This 'window' effect has not so far been demonstrated in other animals or people, so it is unknown whether the bio-effective 'windows' vary for other species. Panagopoulos and Margaritis' work does however imply that there are indeed 'windows' of intensity that are bio-active in vivo and that likelihood of bio-effects does not necessarily increase with increased intensity. In the Panagopoulos study, the most bio-active intensity of $10\ mW/cm^2$ $(0.6–0.7\ V/m)$ occurred at distances of 30 cm from a Global System for Mobile Telecommunications (GSM) 900, or 20 cm from a GSM 1800 cellphone antenna.

The response of biological cells has also been shown to depend upon the type of cell exposed to RF, the stage of the cell cycle, and the exposure duration (Gerner et al., 2010). Cultured human fibroblasts[6] showed the highest level of responsiveness to RF with an average protein synthesis increase of 128% +/- 22%. Previously insensitive white blood cells became sensitised to RF by inflammatory activation. The authors suggest that their findings

[6] Fibroblasts produce connective tissue

indicate that "proliferating cells with high protein synthesis rates are more sensitive to RF-EME than cells with lower protein production" p.696 (Gerner et al., 2010).

Elsewhere, proliferating T-cells[7] exposed to RF showed no differences from sham-exposed cells, while proliferating human peripheral blood lymphocytes[8] and proliferating Jurkat[9] cells showed a significant increase in caspase 3[10] activity 6 hours after 1hr of exposure to a 900 MHz GSM signal (Palumbo et al., 2008).

Further, a research group in Colorado has shown that a static magnetic field, such as that of the Earth, influences how cells react to radiofrequency exposure (Martino et al., 2010). As the authors explain, this has clear implications for laboratory conditions in in vitro research, and may explain the disparity of results in experiments which have sought to replicate others' work.

1.1.3 Personal versus environmental exposures: international responses

Personal RF exposure occurs when using RF-emitting technology. It is always highest for any given piece of equipment when the equipment is adjacent to the body. Exposure increases rapidly as the transmitting antenna nears the body.

Daily environmental exposure to RF is defined here as that which individuals have little or no choice about encountering (e.g. emissions from base stations, TV and radio transmitters). It is unavoidable in most urban settings, even for those who do not own cellphones, and mean exposure values are highest in public transport and airports (Frei et al., 2009). Environmental exposures are many times lower than personal RF exposures and are highly unlikely to pose any thermal threat in places readily accessible to the public. However, many people have reported experiencing changes in health and general well-being after the installation of equipment such as a base station nearby and have attributed these changes to the RF emissions. This has caused wide-spread concern in many communities. This was initially addressed by a drive for 'harmonisation' of RF Standards, which is outlined in chapter 3. Children's increasing use of RF technology and the growing body of evidence for

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[7] A type of lymphocyte that helps protect from infection. Lymphocytes are white blood cells.

[8] Mature lymphocytes found in the blood, comprising T-cells and two other types of lymphocyte

[9] An immortalised line of T-cells used in scientific research

[10] A protein of the **c**ysteine-**asp**artic acid prote**ase** family. These and other caspase proteins are central to executing cell apoptosis (programmed cell death)

biological and potentially adverse health effects from non-thermal RF exposure has led several radiation advice bodies overseas to issue cautions, and some countries, regions or cities to introduce more stringent exposure maxima.

Chapter 3 will address ways in which the international community has responded to children's environmental and personal RF exposure.

1.1.4 Cellphone versus cordless phone exposures

Cellphones and cordless phones are forms of two-way radios which operate using a radiofrequency carrier wave. This is modulated to carry the signal. They also emit extremely low frequencies (ELFs), which depend upon the battery refresh rate and the way the carrier wave is modulated. The antenna transmits in all directions allowing it to effectively communicate with the nearest base station in any direction; this energy also radiates into the body. The depth it reaches at any measurable intensity depends upon the frequency – the lower the frequency, the deeper it will readily penetrate. Antennae are located in a variety of positions in the phone, depending upon the style of phone. Early cellphones had antennae on top that could be extended when the phone was in use. These evolved to be internal (often even when there appeared to be a stubby one on top) and could be inside the top or the bottom, or parallel to the hinge in the hinged varieties. RF emissions are highest adjacent to the antenna.

Cellphones first acquired this name due to the nature of how the network was set up. A honeycomb of 'cells' across the country aimed to ensure good coverage by having a base station transmitter in each one to receive and transmit calls within and across cells. These were originally set on a hill, tower or tall building to maximise reach. As demand increases, the cells need to be smaller are smaller as each transmitter has a limited number of calls it can carry at any one time. This has necessitated more, lower-powered base-station transmitters. In urban areas, they are now commonly on top of street lamps or disguised within something else such as those within the artificial chimney in Figure 1.1. In this photo, the cover had been removed for servicing, so the antenna is visible.

Figure 1.1 Cellphone base stations in an urban setting

Photo: M. Redmayne

There are several different protocols on which cellphones operate, broadly classified as 1G, 2G, 3G or 4G. This stands for 1st Generation, and so on, and broadly indicates the carrier frequency range and the modulation type. The frequency range for any one generation of phone can vary by country and by provider as it will depend upon the spectrum allocation. A spectrum allocation chart is available at http://www.rsm.govt.nz/cms/pdf-library/policy-and-planning/spectrum_chart.pdf

There are several types of cordless phones in use in New Zealand. Those in the current survey covered the full range available: 30-40 MHz, 900 MHz, 1.8 and 1.9 GHz, 2.4 GHz, and 5.8 GHz.

Specific RF allocation for each type and the permitted output energy information is available at http://www.rsm.govt.nz/cms/licensees/types-of-licence/general-user-licences/cordless-telephones

The amount of energy output permitted from either a cellphone or cordless phone[11] is restricted with the intention of keeping exposure during use within the limits of the NZ Standard[12], as discussed above. Different models have different maxima as tested according to the method described in chapter 2. This is sometimes labelled on the packaging or in the handbook as the SAR rating. The way the SAR is determined is described in the next

[11] Other personal RF transmitting devices such as laptops are included in these limits

[12] Exceeding the limit is possible depending on how equipment is used. For instance, RF energy absorption from a laptop computer used on the lap against the abdomen may exceed the NZ Standard.

chapter. The lower the SAR rating, the lower the maximum energy output from the phone. For the general public, the maximum permitted SAR is 2 Watts per kilo (W/kg) for the head and trunk, 4 W/kg for the limbs, and 0.08 W/kg whole body average.

As manufacturers have sought to improve the efficiency of their products, the maximum output has tended to be reduced, extending the battery life. Many photos now have a maximum SAR of <1 W/kg (although the SAR is not generally readily available to New Zealand consumers as there is no SAR labelling requirement).

As well as the constraints of the particular cellphone, output energy will vary according to traffic load and the quality of reception. This tends to lead to higher power outputs in some circumstances. For instance, in rural areas individual phones' highest power levels have been recorded about half the time and the lowest only 3% of the time (Lönn et al., 2004). The reason for this is that there are fewer base stations rurally than in cities, therefore the cellphone has to work harder to make the connection. In the city, this study recorded between 25% and 22% maxima and minima of phones' maximum energy output.

Cordless landline telephones account for a large proportion of radiofrequency exposure in those who have one at home (Frei et al., 2009). Digital Enhanced Cordless Telephones (DECT) exposures have been demonstrated to be the dominant RF contributors indoors at 28.9%[13] (Joseph et al., 2012). In the same study, WiFi exposures were 0.04 Volts per metre (V/m) and 0.16 V/m (50^{th} and 95^{th} percentiles) while DECT provided 0.12 V/m and 1.50 V/m.

There are three important differences between the two phone types. The first is that modern cellphones have Adaptive Power Control, which allows them to automatically operate at the lowest efficient level of energy output while in use. This will increase as the quality of reception reduces[14]. Cordless phone handsets in New Zealand always operate on full power, whether or not they are being used[15]. The second is that cellphones commonly have the ability to automatically select from two or more carrier frequencies to enable the best possible reception according to traffic load, terrain, and other conditions at any given time, while cordless phones handsets transmit using only one particular modulation type, and just

[13] Compared with other RF emitting devices in the home (not compared with other cordless phones)

[14] Texts do not use the APC function but are sent on full power. The time it takes for a text to be transmitted depends upon the size and the amount of traffic being handled by the base station.

[15] In Europe, some types of cordless phone are available which only emit RFs when in use

one frequency band for transmitting and another (often adjacent one) for receiving. The third is that while they are turned on and not in airplane mode cellphones automatically make contact with the nearest base station from time-to-time. How often this occurs depends upon the phone, the provider and the circumstance at the last update, but is generally every few minutes. These updates take a few seconds at most and occur at full power of the particular phone. Cordless phones, on the other hand, only have a single cell and their base station is located in the house. The handset does not make contact with the base except when there is an incoming or outgoing call.

Digital Enhanced Cordless Telephones (DECT) handsets transmit their message on one of 24 time slots sending pulses at full power every 10 milliseconds leading to a 100 Hz ELF. The handset battery turns on and off every 5 milliseconds during a call, leading to a 200 Hz ELF (Swiss Federal Office of Public Health, 2010). Peak power outputs vary according to phone type. In Australasia, these are typically 1W, whereas a typical European DECT phone has a peak power output of 250 mW. Allowing for time averaging and discontinuous nature of the transmission the European DECT phone emission averages 10 mW delivered in 250mW bursts (Swiss Federal Office of Public Health, 2009). At 1 W maximum, this would be 40mW average delivered in 1W bursts.

Newer cordless phones transmit using Digital Spread Spectrum technology. One type employs Frequency Hopping which spreads the audio signal across a wider range of frequencies, hopping rapidly among them in a pseudo-random pattern. The other is Direct Sequence, which uses more power, substituting each bit of information with a longer data string, again transmitted across a spread of frequencies (Unified Networks Emerging Technologies, n.d.).

1.1.5 Difficulties in undertaking, replicating and comparing results of RF bio-research

There are many difficulties encountered in RF bio-research. Electromagnetic fields, how they behave in different types of tissue, and how different organs, tissues and cells respond are all exceptionally complex, with many factors that need to be controlled both in the RF/ELF exposure and in the bio-samples or participants. If any relevant aspects are not controlled by the researcher they can confound the results. This makes comparison of studies difficult as there are almost always some aspects of the methodology or analysis that vary. The following describes some of the problems researchers face.

1.1.5.1 Experimental conditions

Experimental results related to EMF RF exposure may vary depending upon:

- what frequency, or range of frequencies, is used,
- the power density
- the polarisation,
- the modulation,
- the angle of the handset,
- the duration of exposure,
- the static magnetic field (Martino et al., 2010),
- any other electromagnetic stray field, and
- the use of a replicateable setup designed to imitate a 'typical' cellphone exposure (excluding the variability)or the use of a real cellphone. The frequency and the power output can change frequently during the course of even a single call on a real phone (making it impossible to exactly replicate any one exposure period).

These factors, therefore, have to be controlled, as applicable.

Additionally, there are other factors related to the complexity of living beings and cells that the researcher must also take into account, such as:

- duration, timing and frequency of exposure,
- the particular stage of the cell-cycle the cells are in when tested (e.g. whether the cells are producing RNA, replicating DNA, or dividing),
- the inherited genetic form of the individual being exposed (genotype),
- the gender age of the participants,
- physiological and individual factors including health-status,
- how many cells are present during exposure (Belyaev et al., 2005),
- the composition of overlying and radiated tissue (skin, fat or ligament for instance),
- the ability to dissipate heat (Elder et al., 1989) (affected by climate and health status), and
- the place of residence (e.g. rural, town or city) (Hardell et al., 2005).

Finally, it has been demonstrated that subliminal noise might induce changes in blood flow in the brain (Hamblin et al., 2004), so for studies that assess blood flow this is a further variable to consider.

The large number of possible confounders explains why it is often hard, and sometimes impossible, to replicate earlier research. This is a problem for scientists (and, in the long run, for the general public) as it can lead to claims that the earlier research findings are invalid since they did not take a particular variable into consideration. There is, therefore, plenty of scope for weaknesses to be found by those wishing to downplay the significance of either positive or negative findings. This can result in the situation referred to by Sarewitz in the opening quote to this chapter. It is a situation which is further exacerbated if the study being replicated has not had the method written up with sufficient detail.

These aspects also make it difficult to reasonably compare results of different studies.

1.1.5.2 Assessment methods and measuring tools

The choice of measuring tool or test can affect the result. This may be a device such as a particular statistical method, a bio-assay, or it may be a piece of equipment. In the case of equipment, much of it is very costly and the best item may not be available in all laboratories. In some circumstances, many assays are available for testing biological material, but these can have different levels of sensitivity. This has been well described (Kumari et al., 2008). One outcome of this is that two studies carried out with the same exposure protocol, on sub-sets of the same sample, may report different outcomes due to the sensitivity of the test or equipment used in the analysis.

1.1.5.3. Accuracy in using the assessment method or tool

It is vital that assessment tools are used correctly and that the results are interpreted the right way. Clearly the assessor needs to be competent in undertaking the test and interepreting what they see. Members of the public are most likely to become aware of problems in this area when poor analysis from a particlar laboratory has led to many people receiving incorrect diagnoses of, say, breast cancer. These then receive considerable media attention. In research papers, such problems are likely to go undetected.

To ensure impartiality, biological testing should be blinded. That is, the person interpreting the results should not know whether they are examining the exposed or unexposed sample, but this is not always the case.

1.1.6 Tumour studies

As cellphone popularity grew, so did concern about possible carcinogenic effects. The earliest studies began when use was still very light by today's standards: median hours of use 2.4 hours monthly and mean duration of use 2.8 years (Muscat et al., 2000). Many other studies followed: cohort (Johansen et al., 2001) and case-control (Aydin et al., 2011c; Interphone Study Group, 2010b; Christensen et al., 2005; Hardell et al., 2011c; Lahkola et al., 2008; Sadetzki et al., 2007).

There have been several reviews and critical analyses of this body of research (Hardell et al., 2007; Levis et al., 2011; Levis et al., 2012), as well as pooled- meta-analyses (Hardell et al., 2011a; Han et al., 2009; Cardis et al., 2011).

One review of 18 epidemiological studies has shown the risk of acoustic neuroma[16] and glioma[17] increases with prolonged exposure (≥ 10 years) to cellphone radiation with the risk highest for ipsilateral exposure – that is, the tumour is on the same side of the head as that to which the phone is usually held (Hardell et al., 2007). More recently, tumours of the parotid gland[18] have received attention since the position of the antenna in hinged phones is generally parallel and adjacent to the hinge, thereby exposing the parotid to more radiation than the brain while the phone is in use; a 58% increased risk correlated to ≥ 10 years' ipsilateral use in the highest 'call-duration' and 'years' use' user-group was observed (Sadetzki et al., 2008).

Tumour studies are discussed in chapter 5 with relation to my findings on adolescents' extent of cordless phone use.

1.1.7 Other health concerns

Although various bio-effects have been demonstrated, as described above, it has not been generally acknowledged that these result in health effects. According to the ICNIRP guidelines, "An adverse health effect causes detectable impairment of the health of the exposed individual or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect" p.494 (ICNIRP, 1998).

Despite extensive research into bio-effects and other studies focussing on health effects, there has been little discussion of how regularly observed bio-effects may lead to health effects. Here I propose one way this is feasible. One of the most commonly observed bio-effects of RF exposure is increased production of Reactive Oxygen Species (ROS). Oxidative stress reported as a result of RF exposure has been deduced from changes in ROS levels, protein expression, and increased levels of 8-hydroxyguanine (a common biomarker

[16] Acoustic neuromas are slow-growing, usually benign tumours, first affecting facial nerves or hearing

[17] Gliomas are fast-growing malignant tumours

[18] The parotid gland is a salivary gland in the neck.

of DNA oxidative damage) (Naziroglu et al., 2012; Naziroglu et al., 2013; Lu et al., 2012; Fragopoulou and Margaritis, 2012; Kesari et al., 2011; Xu et al., 2010; De Iuliis et al., 2009; Agarwal et al., 2009; Aynail et al., 2013; Hamzany et al., 2013).

The normal metabolism of oxygen produces ROS as a by-product. These are chemically reactive molecules which contain oxygen. They have some positive roles [43], and normal levels are handled by the body. However, when the body is exposed to environmental stressors it rapidly produces excess ROS which can lead to oxidative stress and several types of cellular damage.

Melatonin is a powerful free-radical scavenger and one of the body's main defences for fighting oxidative damage (Karasek, 2004). A limited number of studies suggest that RF exposure reduces production of melatonin. This has been noted in the pineal melatonin in exposed rats (Kesari et al., 2011), and in nocturnal melatonin metabolite 6-hydroxymelatonin sulphate in utility workers who used a cellphone for >25 minutes for each of 5 days a week (Burch et al., 2002). Other research has found that melatonin pre-treatment prior to RF exposure reduced or eliminated oxidative damage compared with the non-treated animals (Naziroglu et al., 2013; Aynail et al., 2013; Oktem et al., 2005).

Could a combination of oxidative stress and a reduced ability to repair that damage lead to or exacerbate disease?

In 2010, the WHO identified areas most in need of research into effects of RF exposures on young people. They placed a high priority on the following outcomes and actions:

- Behavioural and neurological disorders
- Cancer
- Monitoring brain tumour incidence trends
- Identifying neurobiological mechanisms underlying possible effects of RF on brain function, including sleep and resting EEG
- Effects of early-life and prenatal RF exposure on development and behaviour (World Health Organisation, 2010)

1.1.8 Research involving young people

There are far fewer studies of any type involving children than adults, although there is broad agreement that children are likely to be more susceptible to bio- or health effects from cell-phone use (Hardell et al., 2007; Vecchia, 2005; Carpenter and Sage, 2008; Ahlbom et al., 2004). Hardell's findings (Hardell, 2008) show a strong correlation between age of first use of a mobile phone and incidence of glioma, with a 5-fold increase after 10 years in those who start using them before reaching the age of 20. Due to there still being rather few young people who had used cell phones for 10 or more years when this study was done, the sample number was small. Further research with this age group will be necessary as time passes and numbers are greater.

There has only been one cellphone brain tumour study of adolescents published to date (Aydin et al., 2011c). The authors reported that they "did not observe that regular use of a mobile phone increased the risk for brain tumors in children and adolescents" despite tabulated data indicating several significant dose-response relationships. This study is discussed further in Chapter 5.

Other epidemiological studies are discussed in Chapters 5 to 9 in the context of the current research. Research comparing responses to RF exposure in different age-groups is addressed in Chapter 2.

1.1.9 Differing parties' priorities and their impact on research and Standard-setting

The major priorities of the various parties provide clues to the drivers and problems inherent in policy and standard setting with regard to the regulation of public exposure to radiofrequencies. Governments/economists look first to the short term, public health bodies are concerned for the long term, the telecommunication industry is a business where profit for the shareholders is foremost, the courts seek primarily to avoid false condemnation, and the scientific method seeks to eliminate false negatives and false positives. Outcomes of scientific research can be influenced by the level of funding, such as through the acuity of affordable assay equipment, the study design, and the experience of the researchers, and also appear to be influenced by the source of funding (Pearce, 2008). Comparison of these differing priorities highlights their incompatibility.

Policy-setters typically prefer certainty upon which to base policies. However, the scientific method is intrinsically cautious about drawing definite conclusions. Since it is impossible to prove the absence of risk, providing policy-makers with scientifically certain parameters is also frequently impossible. As Repacholi (Chairman of ICNIRP and the World Health Organisation Electromagnetic Field Project at the time) pointed out in a 1998 review of demonstrated biological effects of low-level radiofrequency exposure, no definitive affirmation of safety can be made, because it is not possible to prove the negative in hazard-evaluation studies (Repacholi, 1998).

As Standards have been set to prevent damage from the only accepted mechanism of harm, the burden of proof has been illogically inverted so that the technology is assumed to be safe if it conforms to these Standards unless harm can be proven. This means that the holders of 5.9 billion current cell phone subscriptions worldwide (Whitney, 2011) are exposed to levels of microwave radiation for which there is insufficient scientific evidence to support the WHO, ICNIRP and International Committee on Electromagnetic Safety's claims that present safety standards on the radiation emitted by mobile phones protect all users (Leszczynski and Xu, 2010).

Furthermore, reviewing bodies such as ICNIRP seem to keep raising the required level of proof of harm as proposed 'non thermal' mechanisms of biological damage are better described, and their effects more robustly demonstrated. For instance, the 2009 ICNIRP review of studies using the most recent and powerful techniques for identifying changes in genes and proteins sums up assorted findings with statements such as, "which might have occurred by chance" and "may be of little functional significance" and "heating may account for some of the positive effects reported" (p.148) and concludes that "these advances in molecular studies are promising, but not yet decisive in risk evaluation. The microarray technology, for example, can be very important … but, on their own, results from such studies are not yet sufficiently understood and the methodologies not sufficiently standardized and validated to provide decisive data on RF (and other) health effects" (pp. 148-149) (ICNIRP, 2009). This suits the telecommunication industry whose priority is their shareholders.

Some scientists in the field are no longer able to conduct research as the industry has withdrawn much of its funding (Hansson Mild et al., 2008). This has been remarked on by the Director of the European Environmental Agency (European Environment Agency, 2009) who noted that, historically, "'early warning scientists' frequently suffer from discrimination, from loss of research funds, and from unduly personal attacks on their scientific integrity" and considered it would be surprising if this were not already the case in the EMF controversy.

1.1.10 New Zealand's policy approach

In the New Zealand policy setting arena there are two tools that take risks with 'low probability but high potential impact' into consideration. The first is the Precautionary Principle which formed part of the 1992 Rio Declaration on Environment and Development that New Zealand ratified in 1993 (Ministry for the Environment, 2010). Principle 15 states: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". The second is New Zealand's Resource Management Act (New Zealand Government, 1991) which states that: (2) …sustainable management means managing the …development… of … [e.g. wireless] resources in a way, or at a rate, which enables people and communities to provide for their …health and safety while – (c) avoiding, remedying, or mitigating any adverse effects of activities on the environment. 'Environment' includes: …people and communities (2)(1), and 'Effect' includes: 3(f) any potential effect of low probability which has a high potential impact.

These requirements have one acknowledgment in the policy approach to RF in New Zealand. It is found in NZS 2772:1 which is the Standard recommending the maximum safe level of RF exposure, and is found in the precautionary clause at 10(d). This requires, "Minimizing, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided that this can be readily achieved at modest expense." According to a member of the standards committee (Gledhill, 2002) this was included due to acknowledged holes in the scientific data regarding biological effects of exposures typical of wireless phones and cell phone base stations. In practice, it appears to make no or little difference in several situations. For instance, the power output of cordless phones in New Zealand is not tested and their manufacturers are not required to reveal the power output or the Specific Absorption Rate (SAR) rating of the phones. The information is regarded as commercially sensitive and is not available even on request (personal communication, Mark Sole, Development Manager, Uniden, 8 February 2010).

New Zealand's National Radiation Laboratory (National Radiation Laboratory, 2008) and that of Australia (Australian Radiation Protection and Nuclear Safety Agency, 2012) consider research shows no long-term health hazards, and New Zealand's Interagency Advisory Committee on the Health Effects of Electromagnetic Fields (IACHEEF)[19] place heavy reliance on the WHO stance (IACHEEF, 2004). Contrary to the many countries that now issue precautionary advice regarding children's exposure to RFs,[20] the New Zealand NRL considers that our exposure standard takes sufficient account of children.

New Zealand has therefore taken no special precautionary action regarding children. Marketing to children is unrestricted, there are no requirements for warning labels on product packaging, there is no public education programme, and there is no uniform policy or health advice about cell-phones in schools, and no education about RF with relation to wireless technology required by the school science, health or technology curricula. New Zealand is thus at a standstill compared to the move toward precaution in many countries.

There are however New Zealand standards for the Wellbeing of Children and Adolescents Receiving Healthcare (The Paediatric Society of New Zealand, 2002). Standard 2 states, "All attendances for healthcare shall be used to promote, and advocate for …wellbeing of children, adolescents, and their families/whanau[21]....Activities to improve health status e.g. … behavioural guidance or accident prevention advice should be part of models of care across all settings."

1.1.11 Research question

It is now commonplace for teenagers and children to use, or own, cell-phones, but there is little data on the extent or type of New Zealand children's cell-phone use. Awareness of the broad range of research findings, overseas trends, and the extent and nature of children's cell-phone use is integral to science-informed decision-making. The purpose of the current research therefore is to explore these, thereby providing a broad, evidence-based foundation to guide policy formulation.

This brings me back to the overarching research question:

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[19] IACHEEF's function is to provide the Director General of Health with advice on potential health effects from exposures to extremely low or radiofrequency fields, and provide copies to the CEOs of MfE and MED. They also report to the Ministers of Health, the Environment, and Economic Development from time to time.

[20] International responses will be explored in Chapter Three.

[21] Maori for 'extended family'

To what extent are New Zealand adolescents using mobile and cordless landline telephones, thereby routinely being exposed to potentially adverse doses and frequencies of non-ionising electro-magnetic radiation. If there is evidence of adverse effects on well-being or health, what policy or other responses (if any) are required to mitigate these risks?

In the remainder of this chapter, comprising sections 1.2 to 1.7, I present the research motivation, objectives and instruments; an introduction to the research methods; the significance of the study; the structure of the thesis; and aspects this thesis will not address. Finally, there is an authorship statement.

1.2 Research motivation, objectives and instruments

1.2.1 Research Motivation

In 1991, I happened upon a book that set me on the path that eventually led to the research presented in this dissertation. This book was *Cross Currents* by Robert Becker (Becker, 1990). In it, Becker introduced his research on the electrical nature of healing and growth, and explored some possible mechanisms whereby exposure to nonionizing radiation may impact on us biologically. Much of what he said struck a deep resonance in me; it made sense and seemed something worthy of learning more about. I therefore read what research I could access from the public domain. I trained in measuring electromagnetic fields, followed by a few years running a private consultancy. I came back to this area of research in 2008, exploring it this time from an academic perspective.

1.2.2 Research Objectives:

1) **Ascertain the spread of behaviour patterns associated with wireless phone use among adolescents in the target population by answering the following questions:**
   a) What approach do the Wellington Region's schools take towards cell phones and their use at school?
   b) How, and to what extent, do Wellington Region's adolescents use cellphones and cordless phones?

2) **Review and evaluate policy frameworks relating to this extent and type of exposure by answering the following questions:**
   a) On what scientific basis are radio frequency (RF) Standards set in the international community?
   b) What are the scientific assumptions made by the international community on issues that may have a significant public health impact in the long term; are they supported by the full range of relevant peer-reviewed scientific evidence?
   c) What spread of recommendations are being made internationally regarding young people's RF exposure and on what basis are these recommendations being made?

3) **Evaluate existing evidence for health consequences arising from this extent and type of wireless phone use by young people by answering the following questions:**
   a) What biological differences are there in children compared to adults, and in what ways do radiofrequencies interact differently with children than adults, that might make them more susceptible to health effects?
   b) What biological or health effects (that are likely to impact on those under 20 years) have been demonstrated to have an association with wireless phone radiation exposure?
   c) What association (if any) is there between NZ adolescent wireless phone use and self-reported well-being?

4) Analyse and evaluate the overall data to assess the necessary policy direction, if applicable, through:

1.2.3 Research instruments

Objective 1 research instruments:

- Telephone or email census of schools in the Wellington Region to establish what approach is taken with cell phones in the region;
- A questionnaire survey of Year 7 and 8 students in the Wellington Region to find out about adolescent wireless phone user habits and compare with self-reported sleep patterns, headaches, tinnitus and feeling down or depressed;
-Statistical analysis of census and survey data to compare school cellphone rules and student behaviour.

Objective 2 research instruments:

- Literature review of international responses and policy regarding young people's use of wireless telephones;
- Examination of differing approaches to RF Standard-setting and their scientific underpinning.

Objective 3 research instruments:

- Literature review of biological and health effects and susceptibilities peculiar to children's RF exposure;
- Logistic regression analysis of well-being and wireless phone use data;
- Comparison of the extent of wireless phone use by participants with that of participants in cellphone brain tumour studies.

Objective 4 research instrument:

a) . Synthesis and discussion of the research and its implications in terms of the relationship between science and policy, with particular reference to the New Zealand policy context.

1.3 Introduction to research methods

The methodology combined qualitative and quantitative design, being complementary approaches of systematic inquiry (Borland, 2001). Greene et al. (Greene et al., 1989) proposed five purposes for using both research approaches. Within the original research section I used two of these:

- developmental reasons, wherein the first method is used sequentially to help inform the second method,
- expansion reasons, wherein the mixed methods add scope and breadth to a study.

In some areas, these approaches were implemented within an iterative design, allowing "progressive reconfiguration of substantive findings and interpretations in a pattern of increasing insight" (Caracelli and Greene, 1997). For instance, the qualitative aspects of the data collection included pilot studies of questionnaires with discussion over their merits and shortcomings. This informed the development of a well-tuned quantitative research tool to provide the needed data. Once questionnaires were completed and quickly checked on-site, obvious misunderstandings, ambiguities and missing responses were able to be queried individually.

Further, the descriptive data on adolescents' wireless phone use was used to inform additional, targeted, literature review such as that in *Adolescent in-school cellphone habits: a census of rules, survey of their effectiveness, and fertility implications* (Redmayne et al., 2011). The literature review, which explored how health implications of young people's wireless phone use are being handled overseas provided a framework within which to integrate my survey findings. The resulting picture informed the discussion around a suitable policy approach for New Zealand.

The census involved all schools with year 7 and/or 8 classes in the Wellington Region. It involved firstly ringing the Principal or Deputy Principal of 10 schools to ascertain rules or policies regarding use or location of cellphones during the school day. This served as a pilot study. A very short set of questions with multiple choice answers based on the pilot study responses was then prepared to assess whether cellphone rules were in place in schools and what they were; and to get permission to use that information in my thesis. This also served as the initial approach for the survey, with likely participants then being sent a letter with additional information.

The survey sample was drawn from Year 7 and/or 8 classes in the Wellington Region. Schools were placed in three groups according to decile level and school type. The appropriate proportion of schools was selected from each group to provide a representative stratified cluster sample survey. This theoretical framework is similar to that taken in an Australian study also evaluating adolescent cell phone user-habits (Abramson et al., 2009).

The literature review in the introduction was based on published, peer-reviewed journal articles (research and reviews), along with some conference proceedings and reports. There is a very extensive body of literature investigating effects of wireless phone RF.
When writing original research chapters, the results of Objective 1 were used to identify the most relevant sub-topics to search. For instance, the paper examining cellphone use in schools reviewed the literature on RF and fertility as most exposure in school was from within a pocket or against the lower abdomen.

The literature reviews in chapters 2 and 3 were based on a search of national policy documents; meeting minutes, reports and papers published by national and international organisations researching and advising on cellphones and their health effects; peer-reviewed, published journal articles; hearings; parliamentary and conference proceedings; and technical papers.

Searches originally focused on developments since 1998 when the ICNIRP guidelines that New Zealand conforms to were published. Due to finding impacts on well-being that appeared to be due to radiofrequency or modulation, later literature reviews included some historical perspective, checking publication from 1970s to 1990s during which a considerable amount of research was undertaken which identified 'windows' of effect related to frequency and energy intensity.

The full research methodology for the original research is at Chapter 4.

1.4 Significance of the study

1.4.1 Setting and approach

My research has taken place in an Environmental Studies setting within a Science Faculty. This has offered me the opportunity to take a holistic approach to a complex topic. Research related to the effects of RFs and extremely-low frequencies (ELF) involves a wide variety of disciplines including epidemiology; cell biology; biophysics; neuroscience; public health; electrical, computer and energy engineering; health and risk policy. Other than the blend in biophysics, these disciplines do not generally overlap and researchers' knowledge tends to be focused in their own field, and therefore follows its own priorities. This perhaps feeds into the controversy running through this field, with considerable disagreement among scientists about the science. By taking a broader approach, I have been able to integrate different 'scenes' to describe a larger part of 'the picture' than found in any one approach. This has been further enabled by working independently of any established research group.

1.4.2 Focus

This dissertation focuses on children. I will refer to all those under 20 as young people, those in my study as adolescents, and adolescents plus those who are younger as children. I chose this segment of society for several reasons. I believe a healthy childhood today is fundamental to a healthy society tomorrow. Children are recognised to be more vulnerable to environmental pollutants and stressors than adults (Faustman et al., 2000). Particular known and suspected vulnerabilities and ways children differ from adults will be discussed in chapter 2.

1.4.3 Health and society

Uptake of wireless technology has grown exponentially among young people since about 2005, with the age of first use reducing year by year. By 2012, it was not unusual to see even toddlers using a cellphone and knowing how to operate various functions. Such widespread use means that even a low risk of impairment to well-being or long-term health from regular and extended exposure could have serious implications if substantiated. These could impact not only on individuals' ability to maximise their childhood development and education opportunities (Jacobsen et al., 2002), but, as they grow, also affect society especially in terms of public health (Cardis and Sadetzki, 2011) and the related direct and indirect costs.

1.5 Structure of the Thesis

The thesis takes the approach of incorporating papers published during the PhD research period along with traditional components such as the literature review and one chapter of original research results not yet published. The thesis is presented in two parts. Part I is principally three chapters of literature review, each with a different focus. It also introduces the research question, approach and methodology. Part II presents the original research resulting from the two studies I undertook. This takes the form of five chapters, four of which are published papers. A few contain minor subsequent additions or clarifications; the original versions are available on the accompanying CD. The structure of the thesis is illustrated at Figure 1.1 and elaborated further below.

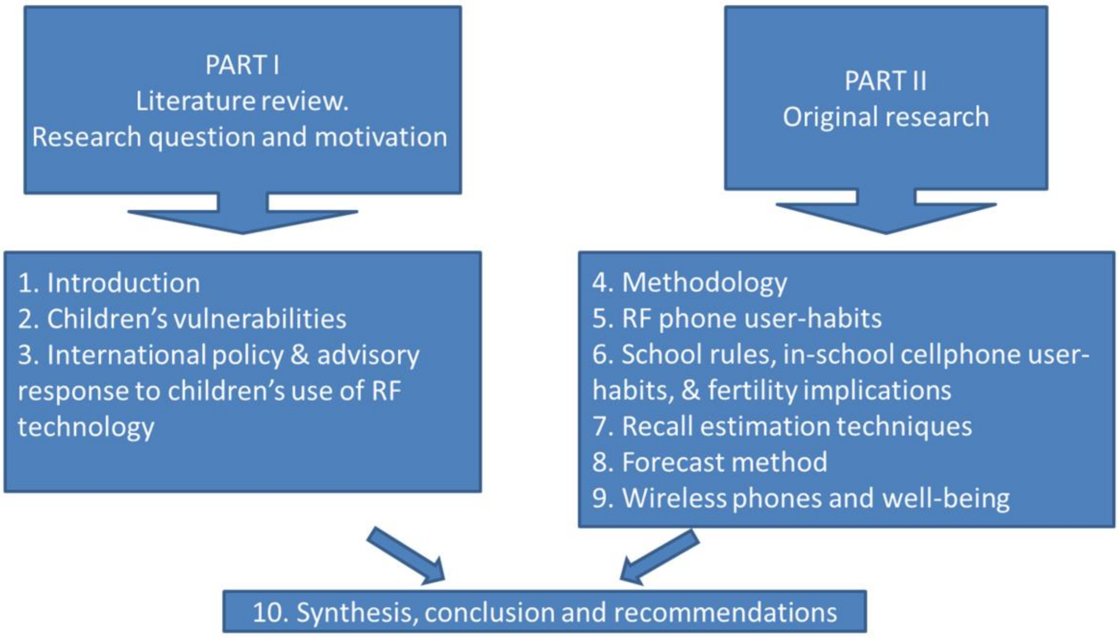
Part I – Research question, thesis structure and a three part literature review

Chapter One presents the research question. It then places this question in context with the main issues surrounding the use of radiofrequencies for communication technology through a broad-ranging literature review. It goes on to outline the research motivation, objectives and instruments and then gives an overview of the research methods, the significance of the research and the structure of the thesis.

Chapter Two explores physiological differences between children and adults, and reviews the literature demonstrating some ways in which RF exposures differentially affects different age groups. It then discusses how these are likely to make children more susceptible to biological and neurological insult from RF than adults.

Chapter Three is a discussion of the approaches being taken and advocated internationally regarding children's use of wireless phones and precautionary action.

Figure 1.2 Thesis structure



Part II – Original research

Chapter Four gives a full description of the methodology for the two studies undertaken as my original research. These were a census of cellphone rules in schools with year 7 and/or 8 in the Wellington education region, and a cross-sectional survey of 16 classes from schools throughout the region.

Chapter Five discusses the wireless phone user-habits of the New Zealand survey participants. The analysis is largely descriptive and includes comparison of the extent of cellphone and cordless phones use, for comparison with the Australian results. The discussion considers the students' extent of phone use with relation to results of published case-control brain tumour studies. It particularly focuses on the heaviest reported extent of cordless phone use. This chapter is presented in its final form prior to publication and after peer-review.

A large part of adolescents' life is spent at school so Chapter Six considers cellphone use in this setting and some implications of this. Chapter Six is a paper published in *Reproductive Toxicology*. It compares and contrasts the results of the census on school cellphone rules and students' reported cellphone behaviour at school. Due to the findings about the way cellphones were used at school, the paper takes an unusual approach of doing a *post hoc* review of the fertility literature about effects of RF exposure on sperm.

The next two chapters take a sideways step from presenting participants' wireless phone user habits. It draws on the participants' recalled and billed data to address some of the problems faced by those doing epidemiological studies that rely on recall data. These problems have led some to regard recalled cellphone use as unreliable. However, some of the difficulties lie in the ways the data are treated. Chapter Seven is a paper published in *BMJ Open*. It presents serendipitous new findings about the mental process whereby numbers of events are recalled (in this case the number of texts sent daily, weekly, and monthly). The observations provide empirical support for log transformation of recalled numerical data, and I provide recommendations to reduce introducing bias to recall data. This is especially relevant if continuous data are to be categorised.

Chapter Eight is a paper published in the *Journal of Exposure Science and Environmental Epidemiology*. This paper presents a Bayesian method of reducing estimation bias in recall data. I hope it will be applicable for use when analysing continuous data by studies that conform to the method's requirements.

Chapter Nine presents the results of logistic regression analysis of the participants' reported well-being with respect to their cellphone and cordless phone use and whether or not they have WiFi at home. The method presented in chapter eight is applied to some of the analyses in this chapter for comparison.

Chapter Ten considers the results of Parts I and II of the thesis and discusses them with relation to young people's use of radiofrequency technology (cellphones and cordless phones in particular). Implications for the policy approach in New Zealand are discussed and recommendations made.

Appendix 1

Prior to undertaking the survey and census described in the Chapter 4, I spent a few weeks in Melbourne where the Mobile Radiofrequency Phone Exposed Users' Study (MoRPhEUS) was in progress. I undertook an analysis of the cordless phone data which consisted of whether or not students had a cordless phone at home, and if so the estimated number of calls made and received on it by the participant each week. This resulted in a paper published in the *Journal of Environmental Monitoring*. As it is relevant to the current study and was undertaken during the study period, it is available at Appendix 1. It presents an analysis of comparative cellphone and cordless phone use from the MoRPhEUS study.

1.6 Aspects this thesis will not address

There are both acute risks and insidious changes related to cellphone use that this thesis does not address. There is an established increased risk of having a traffic accident while using a cellphone (Ship, 2010). While the research appears limited to driving a motor vehicle, it is not uncommon to see young people talking or even texting on a cellphone while cycling or using a skateboard (Figure 1.2). Research on whether or why people indulge in this highly risky behaviour is outside the scope of this study.

Figure 1.3 Uses of a cellphone that pose acute danger

a. Goldner (2009) http://www.brassmagazine.com/blog/texting-kills b. Hess, B. (2010)

There has been a very noticeable evolution over the last decade in how the young communicate and interact socially, and in the apparent need of many for constant affirmation. Also, there have been troubling reports of bullying and violence by young people on their peers that has sometimes even been touted on social networking sites.

Another cellphone activity that some young people are involved in is sexting. This is especially worrying if they are still too young to cognitively understand the full implications of such actions. Many of our participants said that they paid for their own text plans (although this was not formally asked), which substantially increases the likelihood of their partaking in sexting (Lenhart, December 2009). These changes in social and interpersonal interactions have had an insidious and significant impact on societal values that provide a rich opportunity for psychosocial research. The addictive nature of cellphones and interactive social media generally is also of interest. Again, these areas are outside the scope of this dissertation.

1.7 Authorship statement

Four chapters in Part II of this thesis are co-authored publications (3 in print and 1 under review). One other chapter is also published under my authorship only. These papers all use the plural personal pronoun, the first three because of multiple authorship, the last out of convention. The chapter that is not yet published uses the singular personal pronoun.

The following is a statement of author contributions for published papers having multiple-authorship:

The papers sourced data from my two studies in the Wellington Region of New Zealand. The cross-sectional survey used questionnaires which I developed based on the MoRPhEUS study questionnaires, which were developed by Michael Abramson. These were, in turn, based on the Interphone questionnaires.

1. Redmayne M, Smith A, Abramson M: **Adolescent in-school cellphone habits: a census of rules, survey of their effectiveness, and fertility implications**. *Reproductive Toxicology* 2011, **32**:354-359.

Euan Smith: provided supervisory guidance
Michael Abramson: advised on statistical methods
Mary Redmayne: analysed data, developed figures, designed visual abstract, and wrote the paper.
All authors discussed the interpretation, contributed suggestions to improve the text, and approved the final version.

In addition, Professor Ken McNatty, Victoria University of Wellington, checked the accuracy and interpretation of the fertility literature review.

2. Redmayne M, Smith A, Abramson M: **Patterns in wireless phone estimation data from a cross-sectional survey: what are the implications for epidemiology?** *BMJ Open* 2012, **2**(5).

Euan Smith: had extended conversations with me on use of first digit analysis.
Michael Abramson: supervisory comment
Mary Redmayne: analysed data, developed tables, researched history of research on magnitude estimation, and wrote the paper.

All authors discussed the interpretation, contributed suggestions to improve the text, and approved the final version.

3. Redmayne M, Smith E, Abramson M: **A forecasting method to reduce estimation bias in self-reported cell phone data**. *Journal of Exposure Science and Environmental Epidemiology* 2012 (advance online publication 18 July 2012; doi: 10.1038/jes.2012.70).

Euan Smith: developed the Bayesian forecast model and wrote the section of the paper titled "Development of a regression model and Bayesian method", developed figures 3 and 4, provided supervisory comment and advice
Michael Abramson: supervisory comment and advice
Mary Redmayne: analysed data; developed figures 1, 2 and 5; and wrote the paper.

All authors discussed the paper, especially the application of the model; contributed suggestions to improve the text; and approved the final version.

In addition, Dr Richard Arnold, Victoria University of Wellington, commented and provided suggestions on using a Bayesian approach

4. Redmayne M, Smith A, Abramson M: **The relationship between adolescents' well-being and their wireless phone use (under review by Environmental Health).**

Euan Smith: supervisory guidance, Pearson Chi^2 analysis of all variables using MatLab
Michael Abramson: guidance and advice on doing and interpreting logistic regression

Mary Redmayne: analysed data, developed tables, and wrote the paper.

All authors discussed and agreed on the approach for selecting the 'best model', contributed suggestions to improve the text, and approved the final version. The version in this dissertation is a longer, fuller version than that submitted for publication.

2 Are children more vulnerable than adults to RF effects?

"They aren't children so much as what I like to call evolving consumers"
Quote from Eliot Ettenberg, CEO Prism Communications (Heap, 2011)

2.1 Introduction

This chapter is a combined desktop study and literature review that explores some physiological differences between children and adults that make, or are likely to make, children more vulnerable than adults to bio- or health effects from RF exposure. It also reports how RF absorption is calculated and reviews research that has specifically compared impacts of RF exposure in different age groups or in biological material from different age groups.

There are a few regularly given reasons why young people are considered likely to be more susceptible than adults to detrimental effects of radiofrequencies (RF).The most commonly voiced of these were first outlined in the Stewart Report, commissioned in 1999 by the British Minister for Public Health, and published the following year (Independent Expert Group on Mobile Phones, 2000). These were:

- the probable increased vulnerability of their nervous system to potentially hazardous agents;
- the smaller size of their head, along with their thinner skull and more highly conductive tissue;
- the possibility of their absorbing more of the wireless phone's energy than adults; and
- the longer period of use over a lifetime due to starting earlier

The report concluded these would lead to an accumulated greater risk if detrimental effects exist.

The published clarification of issues raised in the Stewart Report considered that these greater risks apply until the age of 16 years as the "density of synapses reaches adult level around puberty and skull thickness and brain size reach adult levels around ages 14 to 15" (Independent Expert Group on Mobile Phones, 2000, 16 June).

These reasons have been picked up and repeated by many official bodies, including those in Australia and New Zealand (Australian Radiation Protection and Nuclear Safety Agency, 2012; National Radiation Laboratory, 2012), organisations (Environmental Working Group, 2009; European Environment Agency and WHO Regional Office for Europe, 2002; SCENHIR, 2009), and research scientists (Schüz, 2005; Martens, 2005; Maisch, 2003; Tillman et al., 2010) . Official websites often add statements such as, "there is insufficient evidence in the science to substantiate the hypothesis that children may be more vulnerable to RF [electromagnetic energy] emissions from mobile phones than adults" (Australian Radiation Protection and Nuclear Safety Agency, 2012)or "to date no special risks for children have been found, although only limited research specifically investigating effects of exposures on children has been carried out" (National Radiation Laboratory, 2012). These were issued by the Australian Radiation Protection and Nuclear Safety Authority and New Zealand's National Radiation Laboratory, respectively.

This chapter will describe some developmental changes in the central nervous system and age-related changes in dielectric values of various tissues. It then reports how RF energy deposition in living tissue is calculated, and explores the research on how dielectric tissue values and the distance from the source of RF exposure result in age-dependent differences in RF absorption. Children's RF absorption, as determined by their size, is then explained. Other age-dependent research is very limited, but will be reviewed last.

2.2 Central Nervous System

2.2.1 Development of the CNS and myelin sheath

Humans are born with scant electrical insulation of their central nervous system (CNS), an intrinsically electrical system. During human development, a sheath of fatty myelin develops around neurons. Once developed it acts as electrical insulation and prevents the electrical signalling from the brain along the neuron from leaking out through the walls of the neuron. Its purpose is to enable efficient, speedy conduction of electrical nerve impulses. The major development of this sheathing begins during the fourth and fifth months of gestation, continuing from the 25th week of gestation until the age of two (Rathus, 2010), but there are age-related changes to axon thickness and white matter density visible in MRI scans suggesting that it continues throughout childhood and adolescence (Paus et al., 1999). Myelination follows a particular order, beginning with the brain stem and cerebellar regions progressing through to the frontal lobes during adolescence (Yakovlev and Lecours, 1967). Recent research suggests that myelination repeats this cycle of reinforcement, and later repair and replacement until late middle age, coating smaller and smaller diameter axons in increasingly thinner layers until the process degenerates through vulnerability to environmental or genetic insult (Bartzokis, cited by Wheeler (Wheeler, 2009)). Being fatty, myelin does not contain free ions. Keshvari et al (Keshvari et al., 2006) reason that this means that as the myelin sheath develops there will also be a reduction in electrical conductivity of brain tissue. The reverse side of this coin is that there is a higher overall electrical conductivity in the foetus, infant and young child's brain. Myelin deposition is delayed in malnourished children (Rodier, 2004), thereby possibly leaving some of lower socioeconomic status more vulnerable yet.

Synaptic connectivity in the CNS develops in parallel with that of myelin sheathing. Excessive production of synaptic connections during foetal development is followed by heavy pruning perinatally; a second round, in the prefrontal cortex, occurs later with a huge increase in synapses at the onset of puberty (Huttenlocher, 1979) followed by pruning and reorganisation during adolescence (Blakemore and Choudhury, 2006a). This process is not complete until early adulthood.

Rodier suggests that because the CNS and myelination developmental processes are vulnerable to interference by agents that adult physiology can cope with, it is reasonable to expect that the later stages of brain development present particular risks (Rodier, 2004).

2.2.2 RF Research

There are two ways in which RF exposure could potentially affect the CNS of young people with relation to myelin sheathing. The first is by directly affecting the integrity of the myelin, the second is by affecting the CNS during periods of rapid growth and change prior to myelination and the insulation it provides.

Very little research on effects of radiofrequencies on myelin sheathing itself is available in the Western literature. Baranski (Baranski, 1972) exposed animals to intensities of RF typically encountered during cellphone use at 3 GHz, for 3 hours daily for 30 days (guinea pigs: 3.5 mW/cm^2, SAR 0.53 W/kg), and rabbits 5 mW/cm^2, SAR 0.75 W/kg). He found myelin degeneration and glial cell proliferation in the exposed group. These effects were greater when the RF was pulsed at 400 pulses per second. Despite the methodology being carefully reported, it does not appear that this research has been followed up.

Deterioration of the myelin sheath is related to multiple sclerosis and some forms of dementia in which loss of myelin is instrumental, but whether this deterioration may be triggered or aggravated in humans by RF exposure has not been explored.

My concern, with regard to young children, is whether the lack of myelin leaves the poorly insulated intrinsically electrical central nervous system vulnerable to outside electrical interference. Studies examining differences in CNS responses between young and old populations could perhaps reveal whether this is the case. There have been studies that have compared reaction times that fall in this category and will be discussed at 2.5.

2.3 Dielectric values of brain tissue and other tissues

The dielectric values of body tissues refer to their intra- and extra-cellular conductivity and permittivity. Within cells these depend on the proportion of intra-cellular electrolytes, principally water or saline solution (Keshvari et al., 2006). At birth, total body water of humans is high due to more extra-cellular fluid. This increases the internal organs' conductivity (Keshvari et al., 2006). Loss of much of this extra-cellular fluid largely accounts for the typical weight-loss of new-borns, but children continue to have a higher total body water level than adults until approximately two years old (Keshvari et al., 2006).

Comparative dielectric values of adults and children have not been explored but porcine tissue is regarded as a suitable substitute for human tissue (Peyman et al., 2009). A study by Peyman et al considered the dielectric values in 10kg piglets as equivalent to those in 1 to 4 year old children, 50kg pigs as equivalent to 11 – 13 year old humans, and 250kg pigs equivalent to those of adult humans. Measurements were taken using probes in tissues of freshly killed animals. Ten of fifteen tissues tested had systematic variation in dielectric properties as a function of age. Bone marrow had the greatest difference with permittivity almost 7-fold greater and conductivity 15.4 times greater in the tissue of 'children' than 'adults' (900 MHz exposure). The same systematic trend existed to a lesser extreme in cortical bone, dura, intervertebral disc, periosteum, skin, skull, spinal cord, and white brain matter (refer to table 2 in (Peyman et al., 2009)).

Children have a higher number of ions in their tissue than adults and it has been proposed that this increases their absorption rate in specific tissues compared to adults by increasing conductivity (Schönborn et al., 1998; Independent Expert Group on Mobile Phones, 2000). The age at which conductivity in children's tissue reduces to that of adult levels is disputed. Anderson argues that it is approximately one year old based on the percentage of total body water reducing to a constant level by then (Anderson, 2003). However, experimental research indicates it is considerably later, as discussed above (Peyman et al., 2009) and demonstrated elsewhere (Gabriel, 2005), albeit using animal tissues, unless ion levels and dielectric values are not correlated.

Other factors that affect measured dielectric values are the mass over which they are averaged (1g or 10g, the smaller mass resulting in higher values), and the thickness and composition of exposed tissue layers (Keshvari et al., 2006), the latter changing with age and weight.

2.4 Magnitude of exposure in children

The dielectric values of tissues are needed in order to calculate microwave energy deposition (Peyman et al., 2009). New models of cellphone are tested to conform to a maximum permitted Specific Absorption Rate of radiofrequency energy inside the head in Watts per kilo (W/kg). As discussed, this is entirely based on preventing sufficient heating to cause damage. The FCC (US) set this at 1.6 W/kg, measured in a 1g cube of tissue, while European countries and New Zealand set the maximum exposure at 2.0 W/kg based on absorption in a 10g cube of tissue (Sargent and Zombolas, n.d.). The measurement cannot be done using a live person as it requires a probe inside the head. Therefore a mannequin is used (Figure 2.1). The one generally used in western countries is called SAM (Specific Anthropomorphic Mannequin) and was modelled on the 90th percentile of anthropometric data for male US Army heads (Beard and Kainz, 2004), which is clearly not representative of a child's physiology. To test a phone, the mannequin is filled with a fluid of a particular dielectric value selected according to the radiofrequency range of the phone being tested (Figures 2.2 and 2.3). Measurements are therefore based on a homogeneous, average 'tissue', not on the variety of bone, brain, sinew and other tissues found inside real heads.

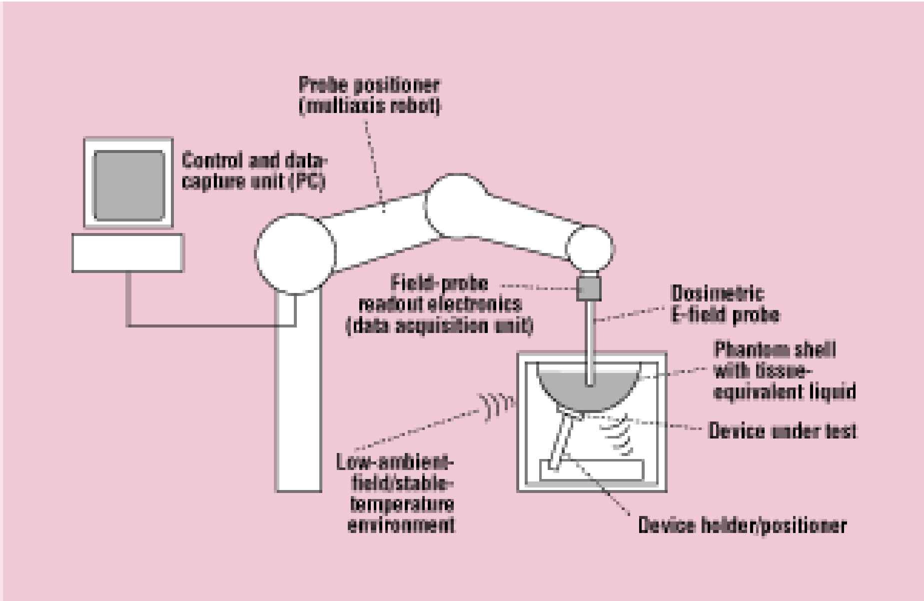
Figure 2.1 A phantom shell with phone in place, as used in the SAR system shown in image 2.3

(Image retrieved from CST - Computer Simulation Technology http://www.cst.com/Content/Applications/Article/218 21 March 2013)

Figure 2.2 A typical commercial SAR system, the DASY4, from Schmid & Partner Engineering

(Image retrieved from Sargent and Zombolas, SAR testing of IEEE 803.11a/b/g devices http://www.ce-mag.com/archive/05/07/zombo2.html 24 September 2012)

Figure 2.3 A diagram of the SAR system shown in figure 2.1



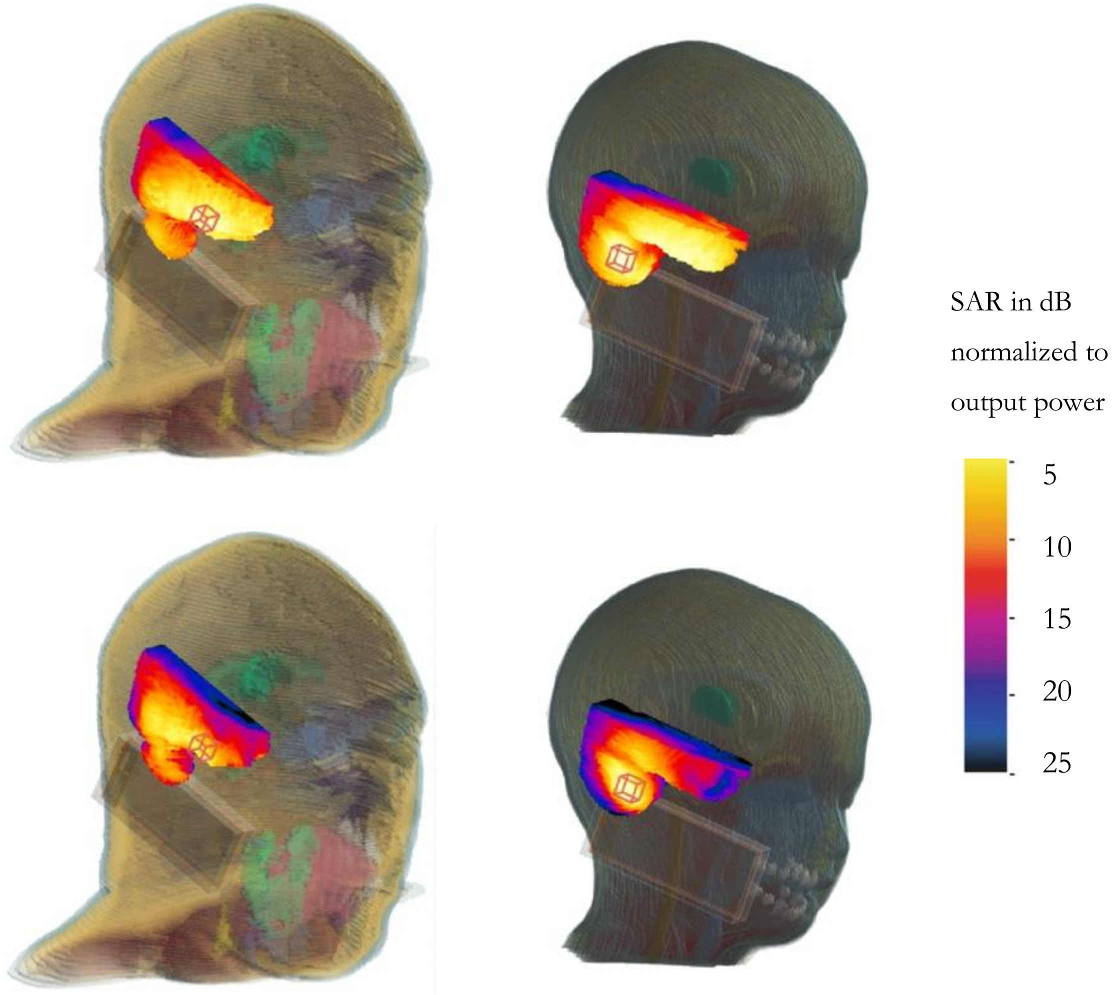
(Image retrieved from Sargent and Zombolas, SAR testing of IEEE 803.11a/b/g devices http://www.ce-mag.com/archive/05/07/zombo2.html 24 September 2012)

A probe is inserted into the fluid to measure the amount of absorbed energy from any specific exposure and the phone being tested is attached at a specified angle to and distance from the mannequin's head. The mannequin is fitted with a plastic, non-conductive pinna (outer ear) which has been criticised for reducing conduction and thereby lowering the measured energy absorption in the brain (Gandhi and Kang, 2004; Gandhi et al., 2012).

Compliance with New Zealand's standard is assessed from the peak spatial average specific absorption rate (psSAR), described by the ICNIRP guidelines (ICNIRP, 1998). The maximum field intensity is read at a distance of 2.2 cms from the antenna (European Environment Agency and WHO Regional Office for Europe, 2002). This is to allow for the distance to the brain through the ear, the space behind it, the hair and the skull. Radiofrequency intensity decreases in proportion to the inverse square of the distance from the antenna, it therefore increases rapidly with proximity. In children, the cartilage in the pinna tends to be softer making it easier for the phone to be pressed closer to the head than for adults. This brings the antenna closer to the head leading to higher exposure in peripheral brain tissue in children (Wiart et al., 2011). One study has suggested that the softness of the child's pinna did not result in the phone being closer to a child's head as the tissues compacted to the same extent (Christ et al., 2010b). This study used computer models from the Virtual Family (Duke, Billie and Thelonious) which, while based on magnetic resonance images of healthy volunteers, represent comparison of only three individuals.

Christ et al. have demonstrated that exposure to radiofrequencies in the brain from cellphone calls is higher in toddlers and children than adults (Christ et al., 2010a). They found several "major age-dependent changes" (p.1780), ultimately due to the distance between the radiation source and the respective brain region. These included increased energy absorption (SAR) in young children of 2 dB to 5 dB in some brain regions, such as the hippocampus and hypothalamus; absorption in bone marrow 10-fold higher than in adults; and greater absorption in the eyes of children than adults. The latter did not cause heating, although the calculations were based on use of the phone by the ear, not in front of the face as commonly used by children for games, when taking self-portrait photographs, and when texting in bed (see Chapter 5). The study by Christ et al. (2010a) also demonstrated different areas of peak exposure in the heads of children and adults, with the cerebellum most exposed in children (using child-models aged 3 and 7) while the temporal lobes were most exposed in adults (adult models Duke and Visible Human). These differences in the location of the maximum energy from the phone occurred because the position of areas of the brain changed to some extent during growth with respect to the location of the ear (Figure 2.4): the angle at which the phone sits between the ear and the mouth is more horizontal in a child. The tested cellphones did not all have their antenna located in the same part of the phone; this made a difference to the extent and location of peak energy absorption. These parameters also varied according to the radiofrequency emitted by the phone (Christ et al., 2010a).

Figure 2.4 Comparative location of maximum exposure in the child and the adult brain



The small cube in these illustrations indicates the areas of highest exposure. In adults, this is the temporal lobes and in adults, the cerebellum. This results from the mouth becoming lower with relation to the ear as the human head grows from childhood to adulthood (Figure 7 from (Christ et al., 2010a) © IOP Publishing)

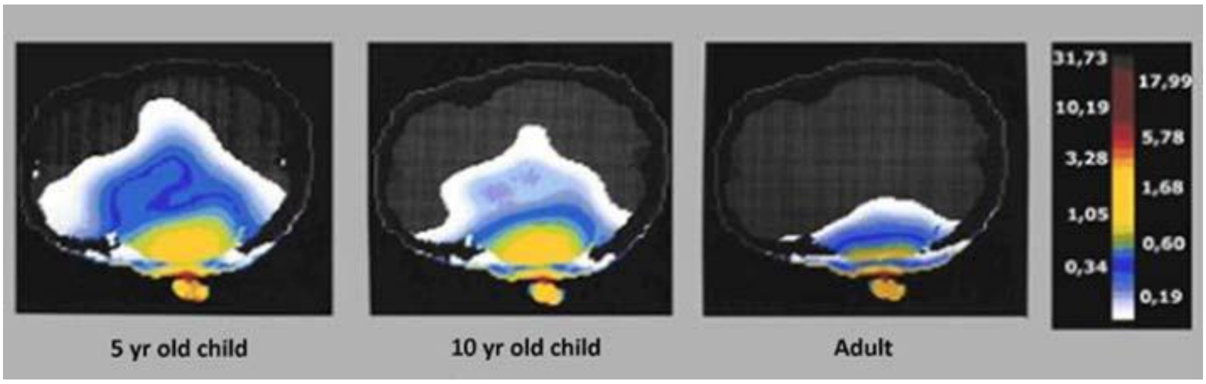
At the cellular level, RF absorption may be affected by other considerations. It has been claimed that the energy absorbed by different body cells is affected by field values within cells, which in turn depends on "the polarisation and relative orientation of the neighbouring cells" p.213 (Sebastián et al., 2001).

The researchers conclude that due to this the cellular values vary from those typically calculated for a tissue type which is based on dielectric values.

Whole body specific absorption rate (SAR_{WB}) increases with the reducing weight of the person (Joseph et al., 2009). This indicates that children absorb comparatively more RF than adults under the same exposure conditions.

For all ages, lower RF frequencies (that is, longer wavelengths) penetrate further than higher ones. However, the same frequency penetrates comparatively more deeply and has a proportionally greater spread within a child's brain than an adult's (Gandhi et al., 1996) (Figure 2.5).

Figure 2.5 Depth and spread of absorption 900 MHz cellphone emissions

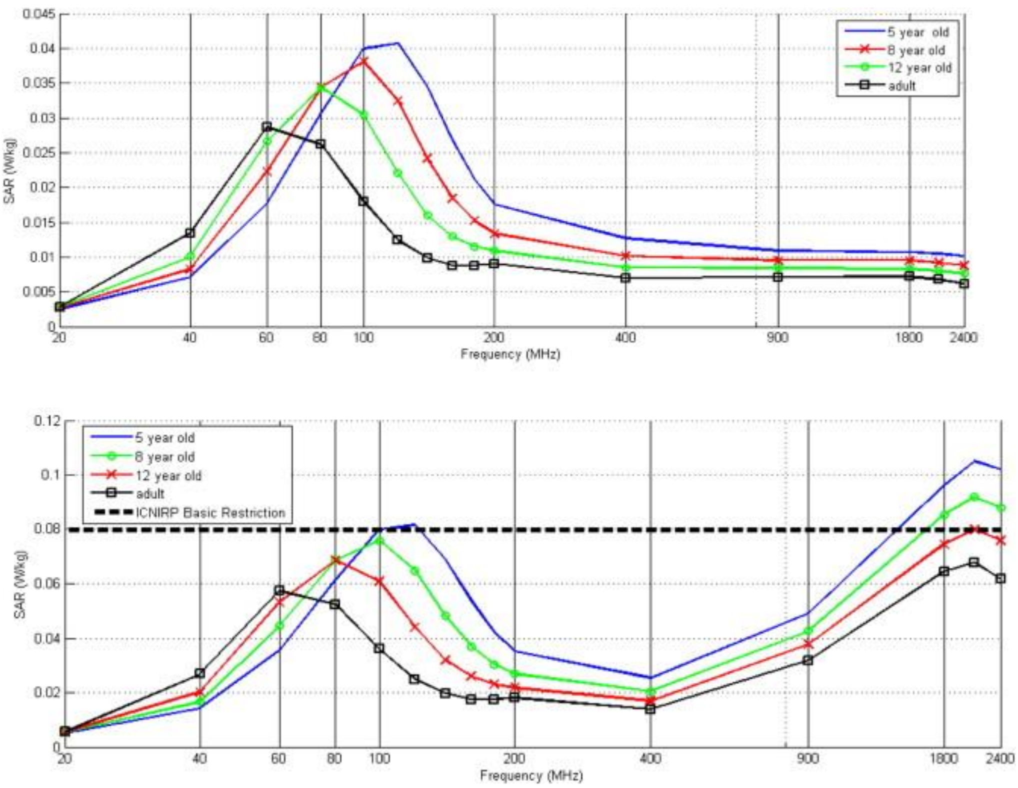


A dorsal view (top down) of the brain with the left ear at bottom of picture. Depth and spread of absorption 900 MHz cellphone emissions within the head of a 5 year old, 10 year old and adult. The colour scale indicates SAR in Watts (Figure 4 from (Gandhi et al., 1996)© 1996 IEEE).

2.5 Resonance and RF absorption

Whole body RF absorption in humans is maximal when the person's height is at peak resonance. As a person's size reduces, the peak for whole body resonance is at an increased frequency; the amount of energy absorbed (SAR) also increases (Figure 2.6) (Wiart et al., 2011). Whether or not the person is grounded also makes a difference. Resonance occurs when the height of the body is between 0.46-0.4 the wavelength in air (Gandhi, 1980; Durney et al., 1986). A person standing on ground has an electrical image in the ground which effectively doubles their electrical length. In that case, resonance for a standing grounded person occurs around 0.2 of the wavelength (λ) (personal communication, Vitas Anderson, Swinburne University, 13 March 2009) (Figure 2.7). This means that peak whole body resonance for a person of 1.5 metres occurs at 40 MHz, when standing. This is the average height of a girl of 11.5 years and a boy of 12.25 years (CDC National Center for Health Statistics, 2006). Cellphones do not operate in the range of whole body peak resonance frequencies, but some cordless phones operate at 30 – 41 MHz.

Figure 2.6 The whole body SAR using Virtual Family models of 5, 8, and 12 years olds.

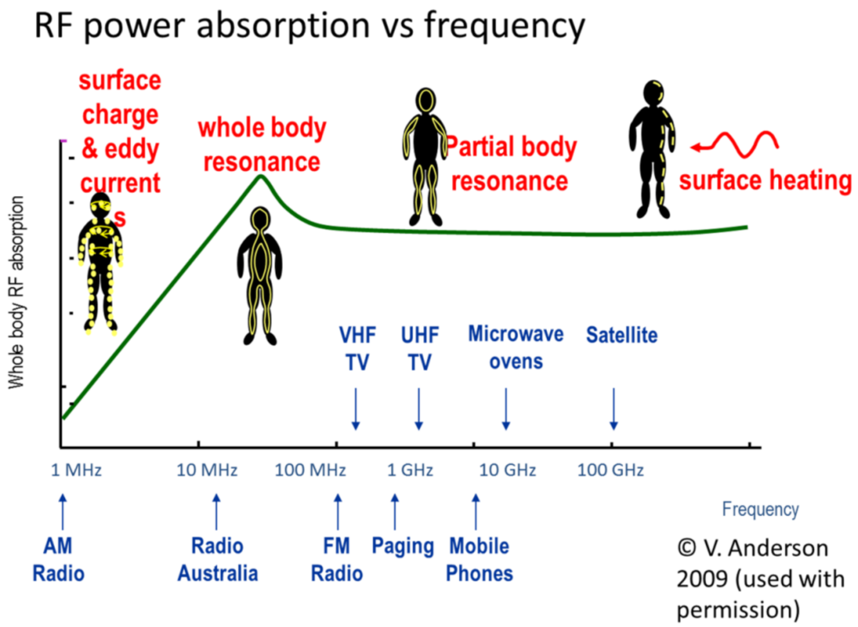


The whole body SAR induced by a vertical polarized plane wave in the Norman model and piecewise deformations using Virtual Family models of 5, 8, and 12 years olds. The top figure shows results of a constant amplitude over the frequency band. The bottom figure shows results with amplitude over frequency equal to the ICNIRP reference levels (i.e. maximum recommended exposure). The figure appears as figure 6 in (Wiart et al., 2011) (used with permission)

Differences in absorption of RF by adults and children depend on several factors, so reports have not been consistent. Some claim there is no significant difference in absorption in the near field of sources, such as when holding a phone to the ear (Schönborn et al., 1998; Bit-Babik et al., 2005), whereas others report increased absorption in children: up to 60% (Martinez-Burdalo et al., 2004; de Salles et al., 2006) or 50-55% (Gandhi et al., 1996). One telecommunication company-funded study reported such varied results that individual head geometry and anatomy were regarded as having a greater influence than age (Keshvari and Lang, 2005).

Body mass index also impacts on the amount of absorbed energy. One study using computer models found that at 2.4 GHz, RF absorption was positively related to body mass index (BMI); that is, the highest absorption occurred with the highest BMI (Chahat et al., 2011). The same paper reported that 5.5 GHz with layered tissue structure did not absorb the energy as efficiently.

Figure 2.7 Diagram showing approximate frequencies for peak power absorption.



The distribution of RF absorption inside the body also varies with frequency:

1. [*sub resonance*] At low frequencies, E[22] does not penetrate well leading to surface charge accumulation. H[23] fields penetrate easily and cause eddy currents near surface.
2. [*resonance*] Deepest and maximal penetration at resonant frequencies. E & H fields are much more closely coupled than at other frequencies.
3. [*partial resonance*] Partial body resonance of smaller body parts (like the head) occurs at higher frequencies. BTS antennas operate in this range.
4. [*supra resonance*] Surface heating effect occurs at very high frequencies (> 6GHz), like infra-red heating

   (personal communication, Vitas Anderson, Swinburne University, 13 March 2009).

2.6 Age-related research

There have been remarkably few studies done which directly compare the effects of RF exposure in the different age-groups although several have explored brain activity. This is related to the sensitivity of the CNS, discussed earlier in the chapter.

[22] The E field is the electric field

[23] The H field is the magnetic field

RF exposure studies have generally found a significant increase in brain alpha activity (spectral power) after exposure to RF. This occurs in awake (eyes open) (Croft et al., 2008b; Croft et al., 2010; Leung et al., 2011), awake (eyes closed) (Curcio et al., 2005; Vecchio et al., 2010) and sleep studies. Increased low frequency delta activity (2-4Hz) has also been observed (Kramarenko and Tan, 2003; Curcio et al., 2005), although not to a significant level in the latter case.

Not all these studies compared different age groups, but in those that did age-dependent response was a common feature. Croft et al (2010) found 2nd generation (2G) exposure resulted in enhanced alpha activity (spectral power) in young adults, but not adolescent or elderly groups. Using the same participants, change in alpha power onset was delayed in all age groups who were undertaking cognitive tasks during both 2nd and 3rd generation (3G) cellphone technology exposure (Leung et al. 2011). Only Vecchio et al (2010) compared the activity in different brain areas; they found the frontal alpha power was increased in the young compared to older adults, while the opposite was true for the temporal areas.

These three studies all had a rigorous design and the methodology was thoroughly reported. While not directly comparable due to slightly different exposures or exposure conditions and because they evaluated slightly different outcomes, they do help build a picture of age-related changes in the impact of RF exposure on the brain's alpha power density. They each used a Second Generation (2G) signal (≈ 900 MHz) or a Third Generation (3G) signal (≈ 1.9 MHz) and the associated extremely low frequencies from modulation and the battery.The Croft and Leung studies imposed white noise during all exposure conditions to provide a consistent background noise. The impact of this on EEG is not discussed, however this has been shown to inhibit changes that occur without it (Litovitz et al., 1994).

Inter-hemispheric coherence is another aspect of brain activity that has been explored across ages. An Italian group exposed two age groups (20-37 year olds and 47-84 year olds – young and older adults) to GSM (2G)[24] (Vecchio et al., 2010). In this cross-over, double blind study, 2G exposure induced age-dependent results reported as an increase of event-related inter-hemispheric coherence (ERCoh) of frontal and temporal alpha rhythms in the older compared to the young group, indicating a GSM effect of increasing inter-hemispheric synchronisation of the dominant alpha EEG rhythms with increasing age. Although not reported, the ERCoh of the

[24] Part of the same study reviewed above

dominant alpha rhythms (frontal area) in the younger group was significantly reduced in comparison to that of the older group by exposure to GSM. The response in the frontal areas was consistent with that of a similar earlier study by this group using only the younger group where the ERCoh was significantly reduced in the same two areas (Vecchio et al., 2007). The alpha temporal response in the two experiments is harder to interpret since in the first ERCoh increased whereas in the age-comparative study it reduced in the younger versus older group. It may be that they *both* increased, with that in the older group doing so more, but this is not interpretable from the reported data.

An EEG study from 2003 (Kramarenko and Tan, 2003) had some unexpected results. They developed EEG equipment that removed noises caused by the cellphone when recording an EEG. As a result they observed slow-wave activity (2.5-6.0 Hz) in the contralateral frontal and temporal areas. This activity occurred briefly approximately every 20 seconds and gradually disappeared after the exposure stopped. They observed similar, but more marked, changes in adolescents (10-20).

Adolescent cognitive function tests have indicated differences in reactions and accuracy after RF exposure, both as a dose-dependent effect (Abramson et al., 2009) and compared with exposure of an older group (Preece et al., 2005). It was not clear whether this was the result of RF exposure.

An experiment exposing adolescents, young adults and seniors to 2G and 3G phones found some age-dependent effects on cognitive function. Participants performed tasks tailored to their abilities to avoid Type II errors. Accuracy in N-back tasks (cognitive/behavioural) was reduced during 3G exposure, significant only in the adolescent group when groups were analysed separately. The authors suggest that adolescents' reduced performance in some tests indicate that 3G exposure may affect their working memory performance and brain function (Leung et al., 2011).

An animal study investigated the effects of typical cellphone exposures, 1 hour daily, on amino acid neurotransmitters in the midbrain, cerebellum and medulla of adult and young rats (Noor et al., 2011). There was a neurochemical inhibition after 4 months in the older group, whereas this occurred after only 1 month in the younger group. In the latter group, the inhibited state converted to excitation after 4 months as a result of increased glutamate levels.

Finally, concerning different responses in different age groups, stem cells are very sensitive to RF (Markova et al., 2009) and more active in children (Williams et al., 2006). Stem cells showed an increased inhibition of DNA repair after both acute (up to three hours) and chronic (1 hour 5 day/week for 2 weeks) exposure. Unlike some cells which appear to adapt to exposure thereby overcoming susceptibility to damage, stem cells did not (Markova et al., 2009).

2.7 Discussion and conclusion

In 2009, ICNIRP published a review of the scientific evidence on dosimetry, biological effects, epidemiological observations, and health consequences concerning exposure to RF (ICNIRP, 2009). The closing words were,

> Another gap in the research is children. No study population to date has included children, with the exception of studies of people living near radio and TV antennas. Children are increasingly heavy users of mobile phones, they might be particularly susceptible to harmful effects (although there is no evidence of this), and they are likely to accumulate many years of exposure during their lives.
> p. 337

There is a well-established inverse relationship between age of exposure to environmental damage and many types of cancer (Kleinerman, 2006; Asomaning et al., 2008; National Cancer Institute, 2013), although a link with respect to non-ionising radiation is still tentative. It is considered that this increased risk from early exposure is related to the gross changes taking place at the cellular level in young people. As the US Environmental Protection Agency put it, children are more sensitive to radiation, "because [they] are growing more rapidly, there are more cells dividing and a greater opportunity for radiation to disrupt the process" (US Environmental Protection Agency, 2013).

There are differences in proportion, size and development (especially of the CNS) between children and adults. These can mean that for each group exposures from the same source can be deposited in different brain areas, to a different extent and at a different intensity.

When using a wireless phone against the head, the most exposed area in a child's brain is the cerebellum (which is one of the first areas myelinated). But as the head size nears adulthood and depending upon head geometry the most exposed area becomes the temporal lobes. This suggests that during adolescence the temporal lobes may be more susceptible to RF interference not only because this region is not yet fully myelinated at that age, but because of increased vulnerability during the very active synaptic rearrangement and pruning in progress at that age.

At any given wavelength, RF penetrates further into the brain of children and has a broader spread. The RFs for whole body resonance and peak limb resonance differ with height and length, so that children's shorter limbs will be at peak resonance at higher frequencies than those of adults. The lower carrier frequencies used for wireless phone are resonant for children (and small adults).

The comparative prevalence of stem cells in foetuses and children suggests increased risk of inhibition of DNA repair from RF exposure, and the higher water content in foetal and child tissues increases tissue conductivity, particularly so in bone marrow.

Several studies, some of which compare different age groups, indicate cognitive/behavioural effects and reduced accuracy possibly indicating impaired working memory in adolescent brains. Young adults exhibit increased power density in the frontal alpha compared to the response in older people. For those who are older again, there was increased temporal alpha power density and increased interhemispheric coherence suggesting some possible benefit from RF exposure, at least in this respect, for the elderly. This may only be in comparison with younger people though.

The activity observed in the brain's delta range by Kramarenko and Tan may be of importance. Intermittent, rhythmic or persistent delta activity is abnormal when awake, but has been associated with temporal lobe epilepsy (Gennaro et al., 2003) and childhood brain tumours (Blume et al., 1982). As a stand–alone study the Kramarenko and Tan approach needs to be trialled elsewhere as the result could signal an important potential health effect, particularly for younger people.

In summary, there are differences between a child's and an adult's physiological development that impact on how much RF they absorb, at what depth and in which part of the brain. Overall, these differences suggest that children are more vulnerable to RF bio-effects than adults.

3 International policy and advisory response to children’s use of wireless phones

> “The year 2006 was the turning point when the industry started focusing not just on teenagers and adults but also on tweens — children between middle childhood and adolescence, about 8 to 12 years old — and even children as young as 5.”
> Doreen Carvajal, New York Times, 8 March 2012

3.1 Introduction

This is the final literature review chapter. In it, I examine both New Zealand and international responses of policy and advisory bodies to children’s use of wireless phones.

The international response to children’s exposure to RF has been varied. The number and sources of recommendations for caution regarding children’s exposure to cell phone radiation, whether from base stations or handsets, have grown and evolved in the last decade. After their publication in 1998, the ICNIRP guidelines were widely adopted in Europe and Australasia, which may in part have occurred due to the timing of the publication. The cell phone industry was growing rapidly by then and these guidelines provided a ready-made solution for the many countries that did not have the expertise to develop RF exposure Standards, as was the case in New Zealand (Gledhill, 2002).

Since then, many Western countries’ radiation or health authorities have continued to advise that, from a non-thermal perspective, “there is no clear indication of risks from cellphone use” (National Radiation Laboratory, 2012) and that the only proven mechanism of harm is from heating. This is driven largely by advice from the World Health Organisation EMF Project, the International Commission for Non-Ionising Radiation (ICNIRP), the Institute of Electrical and Electronics Engineers (IEEE), and the European Commission (Research Directorate-General, 2005).

The EMF Project, which was initiated by the WHO at about the time the ICNIRP guidelines were published, sought to evaluate "the biological effects and assess possible health risks from EMF exposure" and "cover" risk perception and risk communication. It also sought to 'harmonise' standards across all member countries in accord with the ICNIRP guidelines. The declared purpose of 'harmonisation' was to protect public health and reduce public anxiety (Repacholi, 2001) and was supported by the Council of the European Union who issued Recommendation 1999/519/EC (12 July 1999) for member states to adopt guidelines exactly in line with those of ICNIRP. This resulted in authorities in some countries which had applied to join the EU increasing the leniency of their Standards e.g. the Czech Republic and Hungary. It has been pointed out that this is a counter-intuitive approach which should not require standards to be 'harmonised' to become more lenient but that ICNIRP guidelines should, rather, become more protective (Levitt and Henry, 2010).[25]

However, several governments, major organisations and independent researchers are now expressing concern, especially with regard to children using wireless phones.

For those that consider special steps are necessary for surer protection of children, one avenue has been through introducing legislation or guidelines specifying more stringent maximum environmental exposures. Another has been through rules or advice about the use of RF-emitting equipment by young people, or via advice through a variety of media.

This chapter presents and discusses policy actions and advice from around the world regarding children's exposure to RF and their use of RF equipment.[26]

3.2 Consideration of young people in RF exposure guidelines and legislation

The ICNIRP reference levels for E-field exposures (400-2000 MHz) are 41 - 60 V/m and for power flux density exposures are 450 - 1000 μW/cm^2, varying according to the particular frequency being emitted. The reference levels for frequencies higher than this are 61 V/m and

[25] Discussion of this counterintuitive approach to reducing public concern about RF safety is outside the scope of this thesis.

[26] Material on this is very extensive. The aim of the chapter is provide a cross-section of policy and advisory responses.

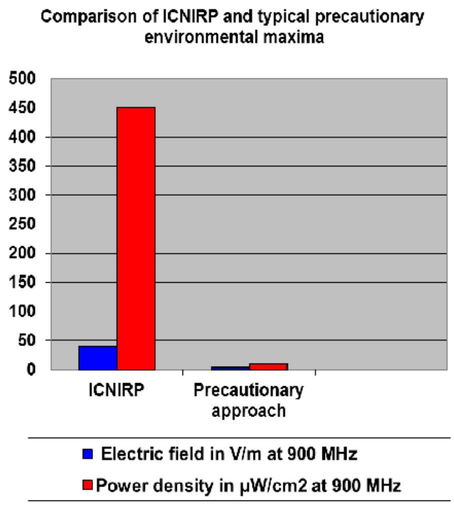
1000 μW/cm². Devices such as cellphones are also required to conform to a Basic Restriction measured as the Specific Absorption Rate (SAR), testing for which was discussed in chapter 2. Referring to the built-in safety factor of 50 for SAR in the general public[27], the ICNIRP guidelines state that they, "take into account the fact that their age and health status may differ from those of workers" (p.509), for whom the safety factor is 10 (ICNIRP, 1998) (Table 3.1).

Eastern European countries typically permit maximum levels approximately 10 and 100 times lower respectively[28], with exposure to an E-field of 6 V/m and a power density of about 10 microwatts per square centimetre.

Some countries and cities have recommended levels that are up to 10 times more stringent again for either outdoors or indoors.

Switzerland led the move in Western countries to lower environmental RF exposure maxima on a precautionary basis to one tenth that of ICNIRP. The Ordinance (which was actioned on 1 February 2000), specifically considers sensitive places, including children's playgrounds (The Swiss Federal Council, 1999).

Table 3.1 Comparison of ICNIRP and typical precautionary exposure values



[27] Known health effects are consistent with an increase of 1°C body temperature which occurs after approximately 30 minutes whole body SAR of 4 W/kg. The basic restriction for the public is 50-fold lower.

[28] The different scaling of the power density and the electric field is because the power intensity is proportional to the square of the electric field

That year the city of Salzburg adopted a policy recommending 0.1 μW/cm^2. This was ten-fold lower than the Swiss Standard. Within a year or two, the providers indicated that compliance was unattainable "in urban areas at reasonable cost" if service was to be of the quality being demanded by customers (Coray et al., 2002). The Austrian Federal Office of Communications undertook environmental measurements and concluded that typical urban exposures near transmitting equipment were between 10 and 200 mW/m^2 and "It would probably be very difficult to achieve exposure values lower than 100 mW/m^2 without substantial economic consequences"[29] (p.10).

Countries which have subsequently introduced or incorporated precautionary reference levels include Luxembourg, Italy, Republic of China & Hong Kong, Poland, Russian Federation, France, Peru, Liechtenstein, Brazil, Israel, Monaco, and Bulgaria (Table 3.2). Regions and cities that have done so include the Plenum region of Spain, Brussels and Walloon regions in Belgium, and several regions/cities in Brazil.

Although not for the benefit of vulnerable groups, the United States changed their method of calculating SAR in 2006[30] which had the effect of lowering the permitted energy output of RF equipment such as cellphones.

In Italy's case, the law sets a lower precautionary maximum for places where people spend extended periods (Italian House of Deputies and the Senate of the Republic, 2001). The law specifies that priority should be given to reducing emissions at sites where children spend more than four consecutive hours.

Brazil has several recommended Standards, varying by region. The Federal Agency of Telecommunications recommends one that is similar to the ICNIRP guidelines, while several areas including the city of Porto Allegro recommend the same levels as Switzerland (personal communication, Alvaro de Salles, 2 November 2012). This includes restricting base-stations from being closer than 50m from sensitive sites such as schools and day-care facilities.

Bulgaria, which was accepted into the EU in January 2007, base their guidelines on the EU recommendation but include different zones including sensitive sites. As of 2011, there was a

[29] 100 mW/m^2 = 10 μW/cm^2

[30] Averaging SAR over 1g rather than 10g.

new two-tier draft for public exposure limits, with the public space level including a precautionary zone for frequencies between 850 MHz and 2150 MHz (Israel, 2011). The Ministry of Health anticipates a limit of 0.1 μW/cm^2 will be approved in early 2013 applicable inside homes and public buildings where children congregate (personal communication, Michel Israel, 2 November 2012).

Table 3.2 Places and years when precautionary environmental Standards were adopted

Year	**Country**	Limit in either μW/cm^2 (power density) or V/m (E-Field)
1996	Ukraine	3 V/m and 10 μW/cm^2
2000	Salzburg Switzerland Toronto Health Board, Canada	1 μW/cm^2 4-6 V/m (900-1800 MHz) 4.5-10 μW/cm^2 (in areas accessible to the public)
2001	Turkey	15 V/m and 250 μW/cm^2
2003	Italy Republic of China & Hong Kong Poland Russian Federation#	6 V/m and 10 μW/cm^2 3 V/m and 40 μW/cm^2 10 μW/cm^2 300MHz-300GHz 10 μW/cm^2 300MHz-300GHz
2004	Paris	1-10 μW/cm^2
2005	Peru Monaco	20-30 V/m (400-2000 MHz) in sensitive sites including primary and secondary schools 6 V/m and 10 μW/cm^2
2006	US (method of calculation)	
2008	Liechtenstein	4-6 V/m (900-1800 MHz)
2009	Brazil (some regions/cities) Israel Plenum region, Spain	6 V/m and 10 μW/cm^2 4-6 V/m (900-1800 MHz)
2010	Brussels region, Belgium Wallonia region, Belgium Flanders region, Belgium	3 V/m at 900 MHz 3 V/m per antenna 3 V/m
2011	Bulgaria	10 μW/cm^2 for 300 MHz-300GHz
2012	India	4.5-10 μW/cm^2 900 MHz-300 GHz
2013	Bulgaria*	1 μW/cm^2 for 900-2100 MHz inside dwellings, kindergartens etc.

* In discussion; Bulgarian Ministry of Health hopes it will be legal in a few months (personal communication, Professor Michel Israel, Bulgarian National Program Committee, 1 November 2012).

The Russian Federation had had stringent Standards for many years, but first mentioned young people specifically in 2003.

N.B. Some countries increased the leniency of their Standards in line with the drive for harmonisation and the requirements of the EC

In Israel, the exposure thresholds were split into two categories (Ministry of Environmental Protection, 2005). Firstly, the health threshold, which aligns with ICNIRP; secondly, the environmental threshold which allows a maximum 10% of the ICNIRP levels for long term exposure. Regulations were supplemented in 2007 to include "safety distances from cellular base stations, including distances from sensitive sites, such as schools" (Ghelberg, 2006). During 2009, Israel set new maximum exposure levels based on what was regarded as the minimum level that still permitted a good level of coverage and capacity (Ghelberg, 2009). The more lenient standard that had been in line with ICNIRP, is now 10% of that.

Liechtenstein adopted a new law in 2008 that would oblige the telecommunication companies to reduce environmental exposure to 6 V/m by 2012. A referendum in late 2009 on reducing it to 0.6 V/m was lost, with the result being 57% in favour of keeping their standard in line with that of Switzerland and 43% in favour of reducing it to 0.6 V/m on GSM and UMTS (personal communication, Kurt Bühler, Director, Office for Communications, Liechtenstein, 31 October 2012).

For the last thirty years, Russia's radiofrequency legislation has been set at stringent levels. Grigoriev, Chairman of the Russian National Committee on Non-Ionising Protection (RNCNIRP) explained that the premise upon which their rules are based considers real conditions, normally faced by populations in situations of chronic influence. Consequently, their reference levels take account of epidemiological findings from chronic exposure to real situations over the last 60 years (RNCNIRP, 2008).

Other Eastern European (EE) countries have traditionally also followed the stringent approach taken by the Russian Federation, some of whom continue to review their reference levels. Poland is one that for several years has been debating whether to introduce even lower maxima relating to children (Szmigielski, 2010). This has been debated within the Commission for Bioelectromagnetic Problems at the Polish Society for Radiation Research since 2005 without reaching 'reasonable consent' (personal communication, Prof. Szmigielski, Department of Microwave Safety, Poland, 3 December 2009). Szmigielski explains that the Commission considers the current level satisfactory but the Department of Microwave Safety has been advising a reduction by about 50% for places where children spend four or more hours at one time. However, in Poland it is the Society for Radiation Research that issues resolutions to the

Ministries of the Environment and Health, who are responsible for setting EMF safety guidelines.

China and Hong Kong also set very low RF exposure maxima. They report that between 1994 and 2004 there were 109 controlled epidemiological Chinese studies evaluating chronic health effects of exposure to low levels of EMFs that resulted in papers (plus a few non-health categories and one referred to as containing "People's Liberation Army secret information")(Cao, 2006b). Only one of the published studies on electromagnetic field health effects had found none. Cao reports that they concluded that RF lower even than 10 $\mu W/cm^2$ might affect human neurobehaviour, neurasthenia, and cataract and sperm development. Various other projected health outcomes are also given, along with an expression of serious concern that some of these were due to exposures below even their current low maxima (Cao, 2006a). Clearly the Chinese definition of a health effect differs from that of the ICNIRP guidelines which exclude long-term effects.

As with the West's generally higher reference levels, Russia and China's are science-based. A major reason for the vast difference in their approach from that in the West is their different understanding of what constitutes 'health effects' and 'disease' (Foster, 2001). The scientific criteria for standard setting in the EE countries does not appear to have been published, a point that has provided fuel for the Western perspective to claim that their limits are based on "unknown scientific criteria for establishment of the health hazards" (Gajšek et al., 2002). However, in the same paper Gajšek et al. (2002) cite a statement by Grigoriev that their standards are based on the requirement that "EMF exposure should not affect homeostasis or activate protective and adaptation-compensatory mechanisms either acutely or in the long term" (p.475). In conference, it has also been reported that at wireless communications frequencies the Russian exposure limits are based on findings that the threshold for harmful physiological effects in experimental animals was 3 hours per day at 240 $\mu W/cm^2$ (Grigoriev et al., 1998). In other words, the Russian approach includes consideration of non-thermal effects.

Renewed concern engendered by the BioInitiative Report (see 3.3) was expressed in a mid-term review of the European Environment and Health Action Plan 2004-2010 by the EU Parliament, whose Members of Parliament represent the citizens of their countries. As a result, they voted 522 to 16 to recommend tighter standards "for all equipment producing emissions in the 0.1

MHz to 300 GHz frequency range used by cell-phones".[31] They considered "the current standards are now "obsolete" in the face of the growing body of scientific evidence and expressing concern especially for "vulnerable groups, such as pregnant women, newborn babies and children" (European Parliament, 4 September 2008).

The response of the European Commission, which carries out a Cabinet function with Commissioners representing the EU's interests, has consistently followed the more conservative, physics-based approach which considers that the ICNIRP guidelines are quite sufficient. The EU's own science advisory group (Scientific Committee on Emerging and newly Identified Health Risks) agreed with this conclusion in 2009 rejecting the need for the EU to change their ICNIRP-based recommendations in document SP(2009)3508 (European Parliament, 2009b).

During 2008, the New Zealand Government received three petitions calling for changes to legislation regarding the placement of cell phone base stations and for proper consultation. Due to the Government having other priorities in the lead up to a general election, the process of responding to this was deferred. However, the Local Government and Environment Committee took up these matters during 2009. With Green Party input, this also led to consideration of the issues regarding the adequacy of the NZ Standard for Radiofrequency Fields (NZS 2772:Part 1:1999) and the composition of the Interagency Committee of Health Effects of Non-Ionising Radiation.

The petitioners filed a report with House of Representatives recommending, among other things, Parliament's consideration of whether a review of the NZ Standard for Radiofrequency Fields (NZS 2772:Part 1:1999) was needed to ensure it was still aligned with international best practice. It also recommended a review of the Interagency Committee's membership, "to ensure better community representation and expertise in risk assessment" (Local Government and Environment Committee, November 2009) (p. 5). Both of these requests were deemed unnecessary (New Zealand Government, 2010).

In 2009, Victoria University of Wellington, New Zealand, set a reference level of 3.0 $\mu W/cm^2$ with antennae "positioned at the maximum possible distance from occupied spaces" that applies to university property (Information Technology Services, 2009). The purpose was "to provide a

[31] As part of the *European Environment and Health Action Plan 2004-2010*

safe environment" for students and staff. This appears to be the only private institution in New Zealand to have set its own reference level.

3.3 Recommended maximum exposure levels from independent sources

In 2000, Associate Professor of Environmental Health at Lincoln University, New Zealand , Neil Cherry (Cherry, 2000), presented results of his research to audiences in Italy, Austria, Ireland and to the European Parliament in Brussels. In it he conveyed his professional opinion that there would be a rapid increase in serious health effects unless mean residential exposures were reduced to $0.01\mu W/cm^2$ – that is approximately 100,000 times lower than New Zealand allows.

A 610 page independent review of the literature was published in 2007. The BioInitiative Report (BioInitiative Report, 2007) provided a major stimulus to the debate about cell phone safety. It set out to provide evidence of a wide range of health and biological effects from electromagnetic fields and concluded that considerably lower maxima needed to be set. In the radiofrequency range relevant to wireless phones the report recommended a precautionary limit of $0.1\ \mu W/cm^2$ (compared to ICNIRPs maximum of $1000\ \mu W/cm^2$) and 0.614 V/m (compared with 61 V/m). The report aimed to demonstrate the inadequacy of Western rationale in EMF standard-setting, and as such has received criticism decrying its approach as non-scientific and selective (Croft et al., 2008a; Health Council of the Netherlands, 2008). It has also received critical support (Khurana, 2009; Vienna Medical University, 2009).

3.4 A brief history of international advice regarding children's use of cellphones

3.4.1 Advice from official bodies

Public concern about mobile phones carrying health risks, especially for children, was noted in 1998 pamphlet by the WHO (World Health Organisation, 1998). The pamphlet explained that perception of risk (right or wrong) led to the WHO establishing the EMF Project. Several Governments thereafter called for their own evaluations, leading to a substantial number of reviews.

The British Minister of Health formed a research group called the Independent Expert Group on Mobile Phones (IEGMP) headed by their Chief Scientific Advisor and Chairman of the National Radiological Protection Board (NRPB), Sir William Stewart. In 2000, the group published what became known as the "Stewart Report" (Independent Expert Group on Mobile Phones, 2000). This was the first report from a Western country to recognise that if health effects were found to be related to cell phone use then children were likely to be more vulnerable than adults due to, "their developing nervous system, the greater absorption of energy in the tissues of the head, and a longer lifetime of exposure" (p.8, chapter 1). Their recommendations included advice that widespread, non-essential use of mobiles by children under 16 should be discouraged and the industry should not promote cell phone use by children.

This marked the beginning of precautionary advice from official bodies in Western countries regarding children's use of cell phones or their proximity to base stations. The same year the WHO published a fact sheet adhering to their stance that current scientific information did not suggest any special measures were needed, but suggesting that people could "choose to limit their own or their children's RF exposure by limiting the length of calls, or using 'hands-free' devices" (World Health Organisation, 2000). The following year the Singapore government issued the same advice (Singapore Health Sciences Authority, 2001). Similar advice from the same standpoint was issued by other organisations e.g. (British Medical Association, 2001; Canadian Partnership for Childrens' Health & Environment, 2005).

More than twenty reports from national and international committees, and expert groups and agencies followed in the next few years (Sienkiewicz and Kowalczuk, 2005). Many of these recommended precaution regarding children's use of cell phones as well as calling for research focussed on children. The Health Council of the Netherlands did not reach the same conclusion (Health Council of the Netherlands, 2002), considering that major changes in brain sensitivity to electromagnetic fields after the age of two were unlikely, and therefore there was no special need to limit children's use of cell phones.

Two major reports not commented on by the British National Radiation Protection Board review (Sienkiewicz and Kowalczuk, 2005) were the Stewart Report and a French one released in 2001 (Zmirou, 2001). The latter recommended that parents should ensure that children with cell phones should only make 'reasonable use' of them, supporting this with the suggestion that information explaining necessary steps to reduce RF exposure should be supplied with all mobile phones. They also advised that schools and other 'sensitive' buildings closer than 100 metres from a base station should not be in the path of its highest intensity beam. They suggested that this does not preclude putting transmitters on the rooves of these buildings due to the low exposure level beneath the transmitter. Their opinion was that this proposal would help calm parental concerns, but it seems unlikely this would be effective as it is counter-intuitive for those without information on the pattern of RF distribution around a base station.

Despite repeated assertions from the WHO and many other official bodies in the West that there was no consistent evidence of children's greater vulnerability or proven mechanism of damage, concern and publishing scientists' calls for further research involving children continued to grow. A COST281[32] workshop held in 2002 concluded that children's heads absorb more energy from wireless phones than adults although this did not necessarily signify a greater vulnerability (Repacholi, 2004).

In June 2004, the WHO called a symposium on "Sensitivity of children to EMF" in Istanbul. Issues covered were broad, but overall the reported conclusion was that there was insufficient relevant research to decide whether precaution was necessary or not. This led the WHO to call for research related to children's user habits and exposure as well as for them to be included in epidemiological studies (World Health Organisation, 2004). In a parallel conference, the WHO European Member States 4th Ministerial Conference on Environmental Health adopted the previously mentioned Children's Environment and Health Action Plan for Europe (CEHAPE). One of its objectives was to reduce children's exposure to non-ionising radiation by educating children, their caregivers and teachers about the desirability of limiting young people's exposure to mobile phones (Martuzzi, 2005). This very general recommendation uses the word 'educate' with no clear guidance that this should include explanations about *why* particular actions to reduce exposure do so.

The Russian Federation has demonstrated that they consider there is need for caution as evidenced by their long history of setting low exposure maxima. However they only specifically mentioned children from 2003 when they introduced within their legislation a recommendation that mobile phone use by children under 18 should be limited (Grigoriev et al., 2004).

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[32] A branch of the European Cooperation in the Field of Scientific and Technical Research which coordinates research to evaluate the potential health implications of mobile telecommunications

Turkey has included an education programme about EMF and health effects for medical students since 2001 (Seyhan, 2007).

In 2006, the Swedish Radiation Protection Authority (Swedish Radiation Protection Authority, 2006) decided there was a need to issue warnings on reducing exposure to microwaves from cell phones as a precautionary measure. This was taken due to studies indicating an increased risk of acoustic neuroma. The primary advice involves the use of wired, hands-free devices. They also printed a small booklet which is offered free for distribution through cell phone sale outlets. The booklet emphasises that it is particularly important for children and adolescents to take precautions.

Two years later the Russian radiation authority tightened its approach, publishing the strongest warning to date about the perceived risks of children using cell phones (Grigoriev, 2008). Titled, “Children and mobile phones: The health of the following generations is in danger”, the committee explained that the decision to issue this warning was based on 40 years’ research and supported by the members of Committees of health protection of both chambers of Russian Parliament" (p.1). It states,

> **health hazards** are likely to be faced by the children mobile phone users in the **nearest** future: disruption of memory, decline of attention, diminishing learning and cognitive abilities, increased irritability, sleep problems, increase in sensitivity to the stress, increased epileptic readiness. **Expected (possible) remote health risks**: brain tumors, tumors of acoustical and vestibular nerves (in the age [range] of 25-30 years), Alzheimer’s disease, “got dementia”, depressive syndrome, and the other types of degeneration of the nervous structures of the brain (in the age [range] of 50 to 60).
> pp.3-4 (RNCNIRP, 2008) original emphases

In early 2009, an independent report by the Belgian MEP Frédérique Ries (*A6-0089/2009* European Parliament B Series) supported the 2008 resolution of the European Parliament (European Parliament, 2009b) which included concern that the European Council’s radiofrequency exposure recommendation did not address vulnerable groups “such as pregnant women, new-born babies and children” (Para. 22) and added several specific points regarding children. Ries also suggested funding awareness campaigns for the young on good mobile phone techniques and condemned aggressive telecommunication company marketing of phones and call or text plans aimed at teenagers (*A6-0089/2009* European Parliament B Series). The European Parliament took the step of officially supporting SAR labelling on personal and home RF devices providing there was also accompanying information to help the consumer manage risks(European Parliament, 2009b).

In the previous year, 2008, the French Ministry of Health, Youth and Sport issued a recommendation for cellphone use to be minimised, especially by young people; advice included avoiding use when reception is poor or when travelling at speed, and to keep the phone away from sensitive body areas by using hands-free kit (Gitlin, 2008).

Soon afterwards, in France, research by TNS Sofres found that half of 12-17 year old French students used their cellphone during school lessons, regardless of the rules (Ecologist, 2009). The Ecologist reports that during later October 2009 this stimulated debate in the French Senate, which subsequently voted to ban cellphones in schools for students under 15. They also approved a move to ban cellphone advertising aimed at that age group. The following points were ratified by the National Assembly in May 2010, under Articles 72 (Assemblée Nationale de France, 2010):

1) All cellphones must be sold with a device limiting head exposure to EMF.
2) Any advertising campaign promoting the use of cellphones by children below 14 years is banned.
3) Providing radio equipment designed for children under 6 may be banned by ministerial order.
4) In kindergarten, primary school and junior high, the use of cellphones is banned for children during all teaching activities in locations listed in School rules.
5) For all cellphones sold on the French territory the SAR must be indicated clearly and in French. Possible risks resulting from excessive use must also be mentioned.

Also in 2009, the Finnish Radiation Authority (STUK) issued a position paper advising that children's use of mobile phones should be restricted, such as by favouring texting over calls. They recommended this for children "as not all the effects are known" (Heitenan, 2010).

This trend in the West towards a more precautionary stance continues (Table 3.2). Changes in stance have sometimes occurred in stages. For instance, in 2008, Australia EME series Fact Sheet 11 stated, "if individuals are concerned, they should choose to limit their own or their children's RF EME exposure" (Australian Radiation Protection and Nuclear Safety Agency Committee on

Electromagnetic Energy, 2008). By 2010, this was updated with a press release recommending that "parents encourage their children to limit their exposure" (Australian Radiation Protection and Nuclear Safety Agency, 2010).

Germany has followed a similar path. The Federal Office for Radiation Protection now recommended that, due to "uncertainties regarding risk evaluation for high-frequency electromagnetic fields that could not be completely resolved by the German Mobile Telecommunication Research Programme … it [is] especially important to minimise as far as possible the fields mobile phone users are exposed to" (The Federal Office for Radiation Protection, 2009).

Health Canada has also recently adopted a more precautionary stance, moving from, "Since children are typically more sensitive to many known environmental agents, parents who are concerned about possible long-term risks from RF exposure may wish to take extra precautions by limiting their children's use of cell phones" (Health Canada, 2009) to stating "Health Canada also encourages parents to take these measures to reduce their children's RF exposure from cell phones…" (Health Canada, 2011). They also recommend practical measures to reduce exposure (limit call duration, use [wired or speaker] 'hands free', text rather than call).

Some countries still taking the Australian 2008 approach are the Netherlands and New Zealand. These countries' radiation authorities do not consider special precautions necessary for children and consider the issue of whether children are more sensitive to radiofrequencies than adults as not yet established (The Federal Office for Radiation Protection, 2009; National Radiation Laboratory, 2012). At the time of writing (2012), New Zealand's National Radiation Laboratory states that, "Use of cellphones by children should be a matter for informed choice by parents" (National Radiation Laboratory, 2012).

In November 2009, the New Zealand Green Party called for the Government to require telecommunication companies to include information on the maximum level of radiation emitted by each model of phone on its packaging and in advertising (Kedgley, 2009). This did not eventuate.

3.4.2 Advice from independent organisations and individual scientists

With the uptake of wireless technology by the younger generation, some independent organisations and other scientists have spoken out on the advisability of restricting children's use of RF emitting equipment. In some cases this is prefixed with a disclaimer that the scientific evidence is still not clear enough so the advice is precautionary. In others the warnings accompany assertions that there is sufficient epidemiological or experimental evidence. The examples are extensive, so the following is a sample.

The International Commission for Electromagnetic Safety (ICEMS) was established in 2003 by a body of deeply concerned scientists working in this field. Its purpose is "to promote research to protect public health from electromagnetic fields and to develop the scientific basis and strategies for assessment, prevention, management and communication of risk, based on the precautionary principle" (International Commission for ElectroMagnetic Safety, 2003). Members of the Commission are signatories to a series of resolutions with each new one expressing greater concern about guidelines that only guard against thermal effects of radiofrequencies. The two most recent are the Venice Resolution of 2008 (International Commission for ElectroMagnetic Safety, 2008) and the Porto Alegre Resolution the next year (International Commission for ElectroMagnetic Safety, 2009). The Venice Resolution, which had 55 scientist signatories, strongly advised children and teenagers to limit their use of wireless phones and similar devices. The Porto Alegre signatories (69 scientists) agreed that children under 16 years should only use cell or cordless phones for emergency calls.

Regardless of growing caution and scientific research indicating a wide variety of health implications from cell-phone technology, the World Health Organisation (WHO) was slow to acknowledge such findings as sufficiently significant to warrant precautionary action. In 2006, the WHO's Health Evidence Network (HEN, 2006) considered that the research showed small and reversible biological and physiological effects that "do not necessary [*sic]* lead to diseases or injuries."

However, in 2010, the International Agency for Research on Cancer (another part of the WHO) met to assess the carcinogenicity of RF. After evaluating the available research, the committee rated "radiofrequency electromagnetic fields, such as, but not limited to, those associated with wireless phones" as a 2B carcinogen. This means "The agent (mixture) is possibly carcinogenic to humans. The exposure circumstance entails exposures that are possibly carcinogenic to humans (Baan et al., 2011).

Several countries' law and policy-setting bodies have held hearings that have called in expert witnesses to give evidence about the safety of children's use of wireless phones. What follows is an outline of one such hearing:

September 2008, the US House of Representatives Domestic Policy Oversight Subcommittee, Hearing: *Tumors and cell phone use: What the science says* (US House of Representatives, 2008). The expert witnesses and a summary of their testimony follow:

- Julius Knapp, Chief of the Federal Communication Commission's Office of Engineering and Technology, whose expertise was in spectrum allocation, technical rules for RF devices, and policy. Knapp stated that the FCC sets exposure guidelines "based on the advice of Federal agencies and groups with expertise in health-related areas and standard setting". He stressed that FCC staff were "not sufficiently qualified to speak with authority to the science of health effects of RF absorption in the body".
- Dr David Carpenter, the Director of the Institute for Health at the University of Albany's School of Public Health, who has been involved in research on the effects of electromagnetic fields for 25 years. Carpenter regarded the issue under discussion as "a critical public health issue". Carpenter's evidence stated that observations demonstrate that the assumptions on which the exposure standards are based are "simply wrong" p.2 (US House of Representatives, 2008) and ignore the complexities of biology; he called for federal agencies to issue "health-based warnings, especially designed to protect children" p.3 (US House of Representatives, 2008).
- Dr Ronald Herberman, a leading oncologist and founding director of the University of Pittsburgh Medical Cancer Centers, treating 27,000 new cancer patients annually. Herberman first remarked that he was not an expert on cellphones and cancer risk, but had reviewed the literature and spoken with many leading scientists in the field. He expressed concern about children's growing use of cellphones. Herberman reported that his concern led him to issue an advisory to his physicians, scientists and staff recommending that children should not be allowed to use cellphones except in emergencies due to the sensitivity of developing organs. Within a week, he said, his recommendation had been endorsed by the Israeli Health Ministry and translated into German, Portuguese and Spanish (Herberman, 2008a).
- Dr Robert Hoover, Director of the Epidemiology and Biostatistics Programme of the Division of Cancer, Epidemiology and Genetics at the National Cancer Institute. Hoover began by stating that RF radiation from cellphones was "billions of times lower than the

energy of x-ray photons” and “at this time” its effect appeared too small to produce cancer-causing genetic damage, alternative proposed mechanisms were not clearly linked to cancer development and the National Cancer Institute showed no increase in the “incidents [sic] of brain or other nervous system cancers from 1987 through 2005”. As no childhood cancer studies had been published, he reported that childhood exposure risks had not been assessed.

- The CTIA (the association of the wireless telecommunications industry) declined an invitation to testify.

These responses indicate the direction in which advice is heading, but also demonstrates that research results are interpreted differently by different experts.

A small selection of other specific expert advice follows:

- Jacqueline McGlade, Director of the European Environmental Agency: all reasonable measures should be taken to prevent children using cell phones for calls in which the phone is held to the head (European Environment Agency, 2009).
- David Carpenter: Children should be prohibited from using mobile phone except in emergencies. Phones should not be kept in pockets or on belts while turned on, nor kept nearby while sleeping (President's Cancer Panel, 2009).
- Siegal Sadetzki, Director, Cancer and Epidemiology, Chaim Sheba Medical Centre, Israel: until definite answers are available, some public health measures, with special emphasis on children, should be instituted....The question is not whether we should use cellphones, but how we should use them. That is very easy to address... taking action to ensure the safe and responsible use of cellphones (Sadetzki, 2009).
- Elizabeth Cardis, co-ordinator of the Interphone study: "as far as children are concerned, mobile phones should not be used beyond reasonable limits" (European Parliament, 2009a).
- Cardis and Sadetzki: young people particularly are advised to take precautions to reduce their exposure during cellphone use, due to indications of possible brain-tumour risk in mobile phone studies (Cardis and Sadetzki, 2011).
- Dariusz Leszczynski, Research Professor, Radiation and Nuclear Safety Authority, Finland: the current safety standards are not reliable in the context of the lack of studies on children (among others). Everyday steps should be taken to limit body exposure to cellphone RF (Leszczynski, 2009).

- Mike Dolan and Jack Rowley, Mobile Operators Association, London: mobile communications are inherently precautionary and the precautionary principle should not be applied. "Commonsense measures can be adopted by individuals, governments, and industry to address public concern while ensuring that mobile networks are developed for the benefit of society" (Dolan and Rowley, 2009).

During the first few years of the new millennium, the telecommunications industry began including cautionary advice in cellphone manuals. It is now usual practice for these to include statements such as, "keep the mobile device and its antenna at least 2.5 centimeters from your body when transmitting" (Motorola, 2006), and position the phone "at least 2.2 centimeters … away from the body when carrying" to ensure guidelines are met (Nokia, 2007). They continue, "Ensure the above separation distance instructions are followed until the transmission is completed".

3.5 Summary

Among many countries whose guidelines did not acknowledge non-thermal effects and among researchers in this field, there has been a groundswell of change. This began as routine addenda to the recommendations at the end of scientific papers. Typical wording expressed, "the need for further research, especially with regard to children who are likely to be more susceptible than adults if health effects are found to exist." A small body of scientists and medical doctors researching in this area went out on a limb and signed resolutions expressing their concern and calling for change. This progressed into more specific warnings from governmental reports such as that in the Stewart Report of 2000. In the last few years, this has expanded further to include the European Parliamentarians' concern, the US Senate and the US President's Cancer Group holding special RF hearings with expert witnesses, and the heads of some radiation control bodies issuing strong warnings. While many governments have cooperated with 'harmonising' with the ICNIRP guidelines, with some even making their Standard less stringent, several have added a second, more stringent, precautionary tier.

Some countries and researchers continue to consider that Standards based on ICNIRP or IEEE provide sufficient protection in the absence of a 'credible non-thermal mechanism", but many research scientists and medical professionals have specifically called for children to reduce their use of cell phones or keep them only for emergencies.

Several governments, national radiation laboratories, organisations and research and health professionals have issued statements advising reduced use of cellphone by children and promoting a number of methods for reducing exposure to cellphone radiofrequencies. Although the frequencies and the radiation are very similar, there have been few such calls regarding use of cordless phones.

PART II

ORIGINAL RESEARCH

4 Methodology of census and survey

4.1 Overview

The original data used for chapters 5 to 9 comprised two studies: Study 1 - a **census** of all schools in the Wellington Region with year 7 and/or year 8 students and a Study 2 - **survey** involving students (and parents) of one class from each of 16 of these schools. This chapter describes the methodology for them both and describes the survey's preliminary parental and student pilot studies.

Since my role has involved research design, data collection and input, analysis, interpretation and writing, an iterative process has helped minimize subjective bias and maximize the reliability, as outlined by Borland (Borland, 2001).

Ethical considerations are discussed first. Each of the following sections begins by explaining the rationale behind the approach, and goes on to describe the data sources, the questionnaire design, the sampling method and participant selection. The survey section continues with how non-participation and non-response were handled, and finishes by describing administration of the survey, data handling, and analytical approaches.

4.2 Ethical considerations

Ethical approval is required by the Human Ethics Committee of Victoria University of Wellington for all research involving human subjects. Human ethics approval was sought early in the planning stages and granted on 19 March 2009 (Appendix 2), prior to contacting schools.

School principals or deputy principals were called regarding the census. A pre-selected group (described at 4.3.3) was also told about the survey. The principal of all schools who said that that their schools may be interested in participating in the survey also were provided with written information about the research and its purpose and approach, a science lesson being offered in

conjunction with the survey, and background information about myself and my relevant qualifications and experience. They also received a copy of the information letter and consent form that would be sent home for parents.
The written informed consent of all parents and assent of participants was required. If permission to participate was denied, the only information that was recorded (if provided) was whether or not they owned a cellphone.

At the beginning of the survey data collection/lesson session, students were provided with a brief outline of what would happen and could ask questions if they wished. They were entitled to withdraw; only one did so. Those who participated were considered to have given assent.

Schools taking part in the survey were assigned a two digit number. Once class lists were provided, all participants and their questionnaires were assigned a number beginning with the school number followed by their own two digit number e.g. 1101. Each student and his/her parent/caregiver shared a number, so that questionnaires could be collated correctly when returned. Although potentially identifiable through class lists, numbering assured participant, parental and school anonymity when I or my advisors interacted with this material. Class lists which tied the names of schools and participants to their assigned numbers were stored separately and were only available to the researcher. Neither names nor pseudonyms of individuals or schools have been used in any written or orally presented work including presentations, publications and this dissertation.

4.3 Study 1: School rules census

4.3.1 Rationale

The census was for all schools in the Wellington education region with pupils enrolled in years 7 and/or 8. The rationale for compiling a basic record of their approaches to cellphones at school was two-fold.

Firstly, from a broad perspective, it enabled me to see whether the approaches of schools that participated in the survey were representative of the others in the region addressing assumptions of generalisability (Table 4.1). To a large extent, this was the case. Exceptions mainly lay in "what happens to cellphones brought to school?" and the first consequence for not following the rules.

The sample group were more likely than the rest of the region to be allowed to choose where to keep their phone during the day. After breaking the rules, they were less likely to have the phone removed until a parent collected it, and more likely to have it confiscated for the day or have no specific consequence.

Table 4.1 Comparative approaches to cellphones at school : census results

Rule	Schools Participating in the Survey % (N = 16)	Other schools in the region % (N =121)
Do you have cellphone rules?		
No	0	5.8
Yes, formal	62.5	59.5
Yes, informal	37.5	34.7
Are cellphones allowed at school?		
No	0	4.3
Yes	93.8	88.9
Yes, with parental permission	6.2	4.3
In emergencies, with a note		2.5
What happens to cellphones brought to school?		
Hand in for the day	50	53.2
Not allowed in class	12.5	18
Student choose location but switched off	37.5	24.3
No cellphone at school	0	4.5
Is use at school allowed, and when?		
Not in school hours	87.5	87.3
Not in class times	6.25	11.8
Yes, under some conditions	6.25	0.9
Consequence for 1st offence?		
Cellphone removed – parent to collect	18.8	33
Cellphone confiscated for day	43.8	30.5
Cellphone confiscated for week	6.3	7.8
Other	6.3	15.7
Depends/Not specified	24.8	13
Consequence for 2nd offence?		
Confiscated and parent to collect	25	16.5
Cellphone confiscated ≥ a week	6.3	8.7
Cellphone confiscated ≥ a month	0	0.9
Cellphone confiscated rest of term	6.3	4.3
Cellphone banned at school	6.3	5.3
Other	18.8	20
Not specified	37.3	44.3

The census questions and response options are in the left column. The distribution of responses for each question is divided into those of the 16 school classes that participated in the survey in the middle column and the responses of all the other that participated in the census in the right column.

From a narrower perspective, the extent to which schools allow cellphones in the students' possession during school hours was expected to affect the extent and method of daytime use. For instance, if one is being used clandestinely in class, it is likely it will be held close to the body under cover of the desk. The consequences of being caught ignoring the rules also seem likely to play a part in further covert use or lack of it.

Secondly, knowing the schools' rules regarding cellphones enabled me to analyse students' responses regarding their cellphone behaviour at school in light of the required behaviour.

4.3.2 The sample region for the census

There were 139 schools in the Wellington Region with pupils enrolled in year 7 and/or 8 classes in early 2009. The Wellington Region was selected for several reasons: it is where I am based, it is a manageable size, and it includes the full spectrum of schools listed by the Department of Education. This included all school types, all deciles,[33] and main urban areas through to remote rural ones.

4.3.3 Census procedure and questionnaire design

Before conducting the census, I calculated the types and number of schools I would need for the survey, as outlined at 4.4.3 and ear-marked schools that fitted the requirements in order to obtain a representative sample. I then called all the schools with year 7 and 8 students in the Wellington Region.

Census data was sourced through a telephone questionnaire directed to the Principal or Deputy Principal. If neither was available after three or four calls, it was sent in email form.

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[33] New Zealand schools are allocated a decile number by the Ministry of Education indicating the proportion of students drawn from low socio-economic communities; the indicator is based on socio-economic census data for households with school-aged children in each catchment area MINISTRY OF EDUCATION. 2010. *What are deciles?* [Online]. Wellington: Ministry of Education. Available: http://www.minedu.govt.nz/NZEducation/EducationPolicies/Schools/SchoolOperations/Resourcing/ResourcingHandbook/Chapter1/DecileRatings.aspx [Accessed 31 March 2010]. Decile 1 schools have the highest proportion of these students.

On contacting the Principal or Deputy Principal by telephone, I introduced myself, my background and the study I was undertaking[34]. If it was not one of the schools ear-marked for possible involvement in the survey, I asked if s/he would be prepared to take part in a very brief survey about cellphones at school that would take 3 or 4 minutes. If they agreed, I asked the questions. If it was not a convenient time, I arranged a time to call back later.

The first ten Principals or Deputy Principals contacted were asked open questions about the school's approach to cellphones at school, the rules and the consequences for breaking them. This served as a pilot-study, enabling me to finalise the question wording and to formulate best-fit categories (shown in Table 4.1). The remaining respondents were asked these questions and asked to select one of the following proffered response categories, which were recorded with an assigned number.

When ringing schools that were ear-marked for possibly taking part in the survey, I added that I would be conducting a survey about intermediate students' cellphone use and was making preliminary enquiries to see whether they may be interested in a Year 8, or combined years 7 and 8 class taking part in the study. I explained that I planned to collect questionnaire data within the context of a 1½ to 2 hour lesson which I would prepare. The lesson was about wireless phones and non-ionising radiation and was based on the requirements of the science and technology curricula. I explained I would be happy to discuss ways that topics they had already planned could be linked to this and that I was a registered teacher. The lesson component was provided on a complimentary basis.

4.4 Study 2: Wireless phone user-habits survey

4.4.1 Survey data sources

The survey was to find out about adolescents' cell and cordless phone ownership and user habits. It comprised two questionnaires: one for the parents (Appendix 3) and one for each student participant (Appendix 4). Additional data for this part were provided through observational notes taken by myself, and brief interviews with some participants to clarify questionnaire answers

[34] At that stage, it was for a Master's qualification. I upgraded to a PhD at the end of that year

which were illegible, inconsistent or provided the wrong type of information, such as words rather than a number.

4.4.2 Survey questionnaire design and pilot studies

The main study questionnaires were both primarily modelled on those used by the Mobile Radiofrequency Phone Exposed Users Study (MoRPhEUS) which was carried out at Monash University under the auspices of the Australian Centre for Radiofrequency Bioeffects Research (ACRBR). Their questionnaires were based on and validated by those of the Interphone study. I was familiar with the MoRPhEUS study's design and dataset having been involved in some data analysis at Monash in early 2009 which resulted in a paper (see chapter 5). Questions were adapted to make them relevant to New Zealand's circumstances and the somewhat different goals of the current study.

The main thrust of the current study was to thoroughly explore adolescents' extent of cellphone and cordless phone use, the cellphone functions that were most popular, and where it was stored by day and night. This meant adding several more questions. Two adaptations were related to texting. New Zealanders send texts much more than Australians, probably due to differences in billing systems. Also, New Zealanders refer to text messages or texting, whereas Australians commonly refer to sending an SMS (Short Message Service) message.

The current study gathered more information on cordless phone use. This was prompted by findings from the MoRPhEUS study (Redmayne et al., 2010).

On the other hand, this study was examining subjective well-being rather than cognitive effects, so the computerised cognitive test and STROOP test were omitted and fewer personal lifestyle questions were included. Instead, three of the symptoms measuring general well-being that were included were drawn from the WHO Health Behaviour In School-aged Children (HBSC) checklist (headache, feeling low, sleeping difficulties) (Haugland and Wold, 2001). Tinnitus was added as there were claims that it was related to RF exposure (Davidson and Lutman, 2007). The question about a painful texting thumb was a novel addition prompted by the extent of rapid texting observed among young people.

The four response categories were based on those of the HBSC (Haugland and Wold, 2001). We omitted 'about every month' as that was the period under consideration. Respondents could therefore choose from: No, hardly ever, once or twice a week, more often weekly, most days/nights. There was also the option to provide written comments regarding the health questions and responses.

The parental questionnaire needed more adaptation. I excluded the questions on birth place, languages spoken, medical conditions and medication as my study did not cover the cognition and hearing test components of MoRPhEUS. However, I added questions relevant to this study's objectives. These were about phone types in the house, the nearest base station, and extent of actual cell phone use if the child had a cell phone on a parental post-paid account.

The student questionnaire was quite long, so questions were presented in a variety of ways to maintain interest (Litwin, 1995). Images of a cellphone, cordless phone and corded landline were displayed on a large screen to clearly illustrate the phone types under consideration.

Once the final drafts were completed, I ran a pilot study of each to pre-test the questionnaires which were the main research instruments. These helped identify errors and unclear wording (Litwin, 1995). Participants were not randomly selected.

The student pilot group was selected from a decile 7 intermediate school that would be participating in the survey; this combination represents the second largest group by decile and school type in the Wellington region (Table 4.2), and being a mid-range decile group was more likely to be representative of a broad spectrum of backgrounds than the largest group which was decile 10.

It involved a non-random group of 14 articulate students who were hand-picked by the deputy principal, representing different ethnic backgrounds and both sexes. Fourteen were invited and 13 took part. In order to provide good internal consistency in the questionnaire, I largely followed the process outlined below (Peat et al., 2002):

- administer the questionnaire as it will be carried out in the main study
- ask the participants for feedback to identify ambiguities and difficult questions
- note how long it takes
- remove unneeded or ambiguous questions

- assess the range of responses, and adjust as needed
- ensure the replies provide information necessary for the research questions
- check that all questions are answered
- re-phrase questions that elicited irrelevant responses
- review questionnaire and re-run pilot if possible.

The main variation was that I allowed the participants to talk and to ask me questions as they completed the questionnaire. This served to highlight areas that may need clarification. Afterwards we discussed ways they thought it could be improved. This was to maximise the opportunities for identifying areas that needed adjusting in the 1.5 hours available.

Points covered included the length and layout of the questionnaire, whether relevant categories had been selected for answers, whether wellbeing-related questions were intrusive, and what period of time was most likely to elicit accurate recall of texting frequency. The latter point led to a suggestion from the group that I provide three options (per day, per week, and per month). This inadvertently led to some valuable and unexpected data being collected which led to the paper presented in Chapter 8. Students who took part in the pilot study were not invited to participate in the main survey. Further piloting confirmed that the length was suitable, and other issues had been satisfactorily addressed.

The parents' pilot used a group of six well-educated, low- to mid-income parents whose children attended a decile 2 primary school. It was not representative as I found once I was there, that the participants' intermediate-aged children did not own cellphones, however their older children did. This was a semi-structured session in which the participants read the draft package to be sent home for parents which was then discussed.

Once they had read through the letter, consent form and parents' questionnaire, we discussed changes they thought were needed. This led to several changes, the most notable being that everything was shortened and simplified due to strong feedback that parents receive a lot of 'stuff' and would not read a lengthy, formally worded request. They requested informal, everyday language and bullet points in the letter.

Finally, the questionnaires were reviewed by Dr Richard Arnold, Victoria University of Wellington, who is a biostatistician, and Dr Mark Wilson, Victoria University of Wellington, a senior psychology lecturer. Both are experienced in survey design and use, and were asked to comment on the questionnaires' structure, wording and layout for best practice and likelihood of providing the required data. Some changes were made, as suggested.

I also consulted a psychiatrist, Dr Giles Newton-Howes, about how to address the possibility of participants thinking that having told someone about a daily problem, especially feeling depressed, some help would be forthcoming. He recommended the phraseology to explain that I would not be able to find help for them if they had indicated they had a chronic problem due to their information being confidential. I included advice on how to find help both orally and alongside the well-being questions.

4.4.3 Survey sampling method and participant selection

The survey type was a cross-sectional, stratified cluster sample, chosen to maximize uniformity in implementation and accuracy of the data collected with the time and resources available. Sample surveys offer explanatory power and are used when goals need quantitative data, when information is specific and familiar to the respondents, and when the researcher is aware of the likely range of responses (Warwick and Lininger, 1975).

A possible drawback to a cluster approach is the tendency for an increase in sampling error compared to a simple random sample [Warwick and Lininger (1975)]. Ideally each cluster should be representative of its stratum. Keeping the sampling error low then lies in each strata, say decile 2 full primary schools, being similar in composition to each other within the region under study.

The most recent count of year 7 and 8 students was dated 1 July 2008. At that time the year 7 and 8 population in the Wellington Region was 13,002, with a decile and school type profile shown in Table 4.2 (personal communication, Tereza Rieglova, Education Counts, 11 May 2009). These data were used to calculate the required number and distribution of participants. About 88.5% of year 7 and 8 students attended schools in main urban areas (population of 30,000 or more), 6.5% were in secondary urban areas (population of 10,000 – 29,999), 4% in minor urban areas (1000 – 9,999) and 1% in rural areas (under 300 - 999) (personal communication, Ryan McFarlane, analyst with the Ministry of Education, 11 May 2009).

A sample size of 3% of the Year 7 and 8 population was drawn from schools with year 7 and 8 classes. I grouped them as 'low' deciles 1 – 3, 'mid' deciles 4 – 7, and 'high' deciles 8 – 10 to provide clusters of sufficient size for class groups (refer to Table 4.3). The ratio of students at low: mid: high decile schools in this region was approximately 5:10:16. Schools were then selected to provide a correct ratio by decile group and school type to represent the region, the types being: full primary (year 1-8), intermediate (year 7 and 8), year 7 – 15 and year 1 – 15. As far as possible within this, attention was then paid to maintain correct ratios by:

- category (1 private, 4 integrated, 11 state),
- religion (3 Roman Catholic schools, 1 Anglican, 12 secular),
- gender (14 mixed sex, 1 boys only, 1 girls only),
- area (14 urban, 2 rural), and
- ethnicity (although individual data on this was not collected, the schools chosen had a representative range for the region) (Table 4.4)

Twenty one schools were asked whether they may be interested in taking part in the survey. Eighteen said they may be and asked for extra information to be sent. Sixteen of these took part. Twelve of them contributed a mixed year 7 and 8 class,[35] 1 contributed a year 7 class, and 2 contributed a year 8. One rural school had a combined year 6, 7 and 8 class; only data from those year 6 students who fell within the age range of all other participants were included. The regional distribution can be seen at Figure 4.1.

[35] It is common in New Zealand for Year 7 and 8 classes to be combined

Figure 4.1 The southern part of New Zealand's north island, indicating approximate locations of participating schools.

To maintain anonymity, those that would enable identification have been left off. There was one each in Porirua City area, Masterton District and South Wairarapa District.

Table 4.2 Year 7 and 8 students in the Wellington Region in the year prior to the study

Students in Year Level 7 and 8 by Decile and School Type in Wellington Region in 2008							
Decile	Composite (Year 1-15)	Primary (Year 1-6)	Full Primary (Year 1-8)	Intermediate (Year 7 & 8)	Secondary (Year 7-15)	Special School	Grand Total
1		16	272	235			523
2	24	15	457	744	127		1,367
3	58	40	117				215
4		56	244	333	158	10	801
5		21	351	412	207		991
6		48	363	307			718
7	18	3	311	1,316			1,648
8	6	15	1,027	1,129	22	2	2,201
9		39	810	307	64		1,220
10	631	89	1,667	544	375		3,306
n/a					12		12
Total	737	342	5,619	5,327	965	12	13,002

Note: Primary schools are officially referred to as Contributing schools.

There were 342 year 7 or 8 students at Primary schools (see Table 4.2). None were invited to participate since Primary schools have only Year 1 to 6 classes and therefore did not meet the study protocol. There were insufficient numbers at special schools to include them.

Once participating schools were confirmed, each was asked to select a year 8 class, or a combined year 7 and 8 class, as it suited them and with no guidelines given. This was to provide a random element. (Year 7 and 8 students are frequently in a combined class.)

A high response was expected because of the age group's interest in cellphones, the chance to use them in class, and the activity taking place during school time. For these reasons, the number finally invited to take part was not much larger than that required.

Table 4.3 Participant grid.

	Participant numbers needed* (Counts ≤12 excluded as less than class size) Decile groups				Number invited to take part Decile groups				Number who took part Total
	1-3	4-7	8-10	Total	1-3	4-7	8-10	Total	
Year 1-15	2.5	0.5	19	22	0	0	16	16	16
Year 7-15	4	11	14	14	0	0	24	24	23
Full primary	25	38	105	168	27	82	113	222	188
Intermediate	29	71	60	160	24	92	61	177	146
Primary schools	2	4	4	10					
Special schools	0	0.4	0	0.4					
Totals				374.4				439	373

*Numbers in this column represent 3% of the regional total of 13,002 Year 7 and 8 school students (for each decile group and school type).

Table 4.4 Comparison of ethnic balance for Year 7 and 8 students in the Wellington Region and that of the participating schools.

			Ethnicities in participating schools (most up to date ERO report 2007-2010)
European descent	45,975	58%	54%
Maori	15,201	19%	15.5%
Pacific Islander	8,529	11%	11%
Asian	6,965	9%	9.5%
Other	2,162	3%	10%
FFP*	603	0.01%	
Total	79,435	100%	100%

* Foreign Fee Paying international students
The slight discrepancy may be due to some schools merging Pacific Islands and/or Asian and/or Other in their ERO report Wellington region ethnicities Year 7 and 8 as at 1 July 2009

4.4.4 Parental participation in survey

Eighty seven percent of parents returned the parental questionnaire. The data for age and sex of all children participating was collected (see below). All respondents answered questions on whether they had a corded landline at home, and on ownership of a cordless phone and the number of years of such ownership. The students' own responses (rather than their parents') about the number of years of cordless phone-use was used for analysis in this thesis. Responses regarding perception of risk were received from almost all those who were asked, although many chose the "don't know" category. The question about WiFi at home received only 64% responses. The question about the distance to the nearest base station had only a 14% response, so this information was not used.

4.4.5 Non-return of parental surveys

Parental questionnaires were sent home with the consent form, to be returned together. When consent was given but the survey not returned, some factual information asked for in it was gleaned from the teacher or child when it was known by either one. This comprised the participant's date of birth, sex, the number of older siblings, and whether there was a cordless phone and/or wired landline at home. When the parental questionnaire was not returned, the questions on perceived health risk and WiFi at home were marked as unanswered.

4.4.6 Non-participation

Those who were invited but did not participate were categorized as 'absent', 'consent denied', 'consent not provided', or 'ineligible'. There were 6 in the last category: 2 were year 6 and younger than the youngest year 7 participant. The other 4 included 1 student who declined to participate, 1 who did not hand in the questionnaire and could not find it when contacted later, 1 who had insufficient English and no support person to enable participation, and 1 whose questionnaire had strong internal inconsistencies. The distribution of these categories can be seen at Table 4.5

Table 4.5 Reasons for non-participation and cellphone ownership status where known. There were 66 non-participants.

	Yes#	No*	Not known‡	Total
Absent on day of survey	4	1	21	26
Consent denied	3	5	5	13
No consent received	5	4	12	21
Year 6, too young: ineligible	2	0	0	2
Ineligible	0	1	3	4
Totals	14	11	41	66

Number who owned a cellphone
* Number who did not own a cellphone
‡ Cellphone ownership unknown

4.4.7 Administering the survey

I delivered parent packs to each school at least one week before the date set for their participation. It included brief instructions for the class teacher specifying what was in each pack and what to tell the class when handing packs out. I included this in case I was unable to personally talk to the class at the time I visited.

On the survey day, the survey was administered in the context of a science lesson about wireless phones and non-ionising radiation. The content included:

- Introduce myself and what would be happening during the session
- Deliver a two-slide background of cellphone 'history': when and by whom cellphones were invented, and countries in which they are now used (see lesson power point on CD in back pocket)
- Show a slide illustrating the phone types about which they would be answering questions in the questionnaire
- Conduct the questionnaire and collect when finished
- Ask students to do explorative activities using cellphones and AM radios after handing in their questionnaire
- Discuss what they discovered
- Run the remainder of the lesson

I maintained a high degree of uniformity in survey administration by running all survey sessions myself. This ensured the requisite standardisation of data collection and classification procedures and curtailed the need for training and eliminated, or minimized, errors resulting from lack of uniformity when using extra administrators (Szklo and Nieto, 2007).

All sessions were run during the morning to provide as similar research conditions as possible between schools. At the beginning of the session, I introduced myself and explained that first they would complete a survey about their cellphone and cordless phone use finishing with a few questions about their general well-being and lifestyle habits; this would be followed by a science lesson about these phones. Students were asked not to compare answers or discuss them during the survey; they were assured that their answers would be treated confidentially and no-one would be identified in any outcomes; and they were encouraged to ask me if they did not understand the question or wanted help.

I intended for the questionnaire to be self-administered, allowing participants to go through the survey at their own speed and ask questions as needed. This went smoothly for the first two schools, both of which were in the top decile (SES ranking). At the third, lower decile school, it was quickly apparent that some students were very slow and having difficulty with comprehension so I led the class through the questionnaire, reading each question aloud. I continued with this approach for the remainder of the schools. I considered this would help ensure a more uniform understanding of the questions by side-stepping poor or slow reading among some participants. It should thereby have helped reduce the cognitive burden common in self-administration (Bowling, 2005). There are indications that recall bias is lower in questionnaires administered by interview and telephone interview (orally) than when self-administered, so (as questions were read aloud) my approach may also have helped reduce recall bias (Bowling, 2005). A review of best practice on designing and administering questionnaires recommends minimising the effort required by participants to interpret and answer questions (McColl et al., 2001).

After the science lesson about wireless telephones which followed completion of the questionnaires, the questionnaires were briefly examined for inconsistencies and omissions. These were dealt with in the first place while still on site by drawing aside individual participants (Litwin, 1995). Unfortunately, I did not start doing this until a few schools had already taken part having realised it was necessary after encountering a few problems with early data entry. This method helped to clarify illegible writing and provide more appropriate information such as a number rather than words.

Each school was sent a letter of thanks for their participation and interest, and, later, a brief outline of the descriptive results. Parents were sent a letter thanking them for their and their child's participation and a brochure providing some of the information covered in the lesson.

4.5 The science lesson

Most parts of the science lesson did not form part of my research, although recordings were taken of the ways students demonstrated using their phones. This aspect was not very informative and I have not used that data. The main rationale for the lesson was that it provided a way for me to give something relevant back to the community that was helping me. As such, it does not form an official part of this thesis, but is outlined here because I regard it as an important part of the interaction with the student community who agreed to participate.

I am a registered teacher with several years' day-relief teaching experience. I prepared the science lesson to meet requirements set in the New Zealand Science Curriculum document. This included all information necessary for it to form part of the teacher's record of curriculum content covered in class: the subject, level, achievement objectives and learning objectives; a lesson summary and full list of lesson activities and procedures; details of inquiry-based explorative activities; and a quiz about the electromagnetic spectrum, with answers. Each question could be used to prompt further student-centred research and learning.

Each teacher also received master copies of two follow-up activity worksheets (for photocopying) along with answer sheets, and suggested web pages for further follow-up. These were suitable materials towards a further lesson. One of them was offered as a parallel activity during the survey for students who did not have parental consent to participate in the study. The powerpoint presentation used in the lesson is included on the disc accompanying the hard copy of the dissertation.

4.6 Data editing and data entry

Codes for participants' missing data were categorized as: 'missing', 'don't know', and 'not applicable', as appropriate. These approaches are reported in the results where relevant since no answer or inability to give an answer carries information in itself (Warwick and Lininger, 1975)

During data entry, if two responses were given I took the lesser one when it related to numbers, or the first when it related to words unless the other was clearly more relevant from the way the rest of the questionnaire was answered (Warwick and Lininger, 1975). Inconsistencies or omitted data not picked up while still on site were treated in the context of both the student and parent questionnaire together. Where these could be inferred or filled with certainty, this was done. If not, then the given data (or lack of it) was entered (Litwin, 1995).

4.7 Analysis

4.7.1 Software

SPSS 16 (SPSS Inc, Chicago IL 2008) was used to analyse the data from both the school policy survey and the parent questionnaires. SPSS versions 16 to 19 (SPSS Statistics 17.0.1, 2008) were used to analyse the student surveys.

Other software programmes used were Excel 2010 (Microsoft, Seattle WA), and MatLab (MATLAB®, 2005).

4.7.2 Calculating billed weekly text use

If the parent reported their child's monthly text total for an unnamed, recent month, a week's use was deemed to be (a / 30) x 7 where a equals the number of texts. There were very few of these. Students reported the number of texts remaining on their plan in the current month. The daily, weekly and monthly use was calculated from this.

Telecom plans ran from the 1st of the month. Since Vodafone accounts had individual billing dates, the weekly use was calculated as [(a – b) / c] x 7 (where a was the total texts available on the plan, b number remaining in the current month, c the days since the beginning of the billing

month). When the remaining texts for a Vodafone plan were given, but the billing date was not, the information could not be used and was entered as missing.
Five students had a plan that gave unlimited use. The extent of their use was also unknown and therefore could not be used.

4.7.3 Outliers on billed data variables

Outliers were checked for correct calculation from given data and cross-checked for correlation with data given by parents where applicable. Corrections were made if necessary, then participants whose answers remained as outliers were re-visited and asked to clarify their answer or asked to check their current use. This served to ensure that original data was likely to be correct. The billed data from one extreme outlier was excluded as the participant said that a sibling used his cellphone heavily for texting.

4.8 Shortcomings in the design

There were a few shortcomings in the questionnaire design that affected data entry or analysis. The categories in question B10 asked students to select the best description for how much they used each of their cellphone functions. These were: Never, Hardly ever, Sometimes, Often, Very Often, My phone can't do this. When qualitative answers for the texting function were compared with quantitative estimates of the number of text messages sent, it became apparent that non-time-specific subjective descriptions were interpreted very differently by different students. Extreme examples include a student who said s/he texted "Very often" then estimated sending "3 daily" (this person's billed rate was 2 daily). At the other end of the scale, was "Hardly ever" with a daily estimate of 20 (the billed rate was 134.6). I therefore created a dichotomous answer combining Never and Hardly Ever as one category and Sometimes, Often and Very Often as the other. As this solution was not entirely satisfactory, the responses to this question were only used for reporting the most popular cellphone functions (Chapter 5 text and table 5.1).

Neither the parents nor students were asked the location of the cordless phone base.

There were no questions about existing medical conditions and medications, nor about known reasons for experiencing the health symptoms included in the survey. This may have had some impact on the analyses.

I have tried to assess whether the odds ratios of headache for combined cellphone and cordless phone use was greater than for either one. This was not simple as the questionnaire had not been designed with this in mind and because of some missing data. The most likely variable to indicate a difference from use of both rather than just one phone seemed likely to be the variable which asked about the number of calls over 10 minutes weekly. I found rather little difference. However this may have been due to the pattern of student phone use; this is discussed at 9.5.2.8.

5 New Zealand adolescents' cellphone and cordless phone user-habits: are they at increased risk of brain tumours already?

> "Like a drug, the machine is useful, dangerous, and habit-forming. The oftener one surrenders to it the tighter its grip becomes. You have only to look about you at this moment to realize with what sinister speed the machine is getting us into its power." George Orwell (1937) from *The Road to Wigan Pier*

5.1 Introduction and overview

This chapter presents the wireless phone user-habits of those who participated in the New Zealand survey, as outlined in the methodology. This is the first study in New Zealand to explore adolescents' use of wireless phones, and some aspects have rarely, if ever, been studied elsewhere. For instance, students reported on the cellphone functions that they used the most; the people that they texted most frequently; and where the cellphone is usually carried and for how long each day. A thorough exploration of the extent of cordless phone use is provided. Appendix 1 provides an analysis of the extent of cellphone and cordless phone use in a similar age-group in Melbourne, Australia. I did the analysis and wrote that paper during my Master's year and it is published and in the disc that accompanies this thesis. The results in the current study supported those from Melbourne – heavy phone use of both wireless phone types was positively associated. In the currents study, participants also said whether they preferred a cellphone, cordless phone or wired landline for long calls, along with reasons for the preference.

After completing the descriptive analysis, it was apparent that a small proportion of young adolescents use one or both wireless phone types extensively, and a third had already used a cordless phone for 7 years or more. This may be of significance for risk of brain tumours if considered with relation to brain tumour studies of those with long-term wireless phone use.

One interesting feature that became apparent during analysis was that cordless phones and cellphones have different patterns of use. The cordless phone was by far the most popular for long calls at home, and approximately a third of those with cellphones did not use them for calls at all, and a few received but did not make calls. When I asked about this last point, the reason was usually that the student did not really want a cellphone but the parent wanted to be able to contact their child or wanted them to have one for emergencies. At the time of the study, texting was considerably more affordable than calling.

Citation details

Redmayne, M., Smith, E. & Abramson, M. 2012. New Zealand adolescents' cellphone and cordless phone user-habits: are they at increased risk of brain tumours already? A cross-sectional study. *Environmental Health,* 12**,** 5. http://www.ehjournal.net/content/12/1/5. It received four peer-reviews[36] and is highly accessed.

5.2 Abstract

5.2.1 Background

Cellphone and cordless phone use is very prevalent among early adolescents, but the extent and types of use is not well documented. This paper explores how, and to what extent, New Zealand adolescents are typically using and exposed to active cellphones and cordless phones, and considers implications of this in relation to brain tumour risk, with reference to current research findings.

5.2.2 Methods

This cross-sectional study recruited 373 Year 7 and 8 school students with a mean age of 12.3 years (range 10.3-13.7 years) from the Wellington region of New Zealand. Participants completed a questionnaire and measured their normal body-to-phone texting distances. Main exposure-metrics included self-reported time spent with an active cellphone close to the body, estimated time and number of calls on both phone-types, estimated and actual extent of SMS text-messaging, cellphone functions used and people texted. Statistical analyses used Pearson Chi^2 tests and Pearson's correlation coefficient (r). Analyses were undertaken using SPSS version 19.0.

[36] The thesis examiners asked for a few comments to be added. As this is a published paper, I have added them in the footnotes of this chapter.

5.2.3 Results

Both cellphones and cordless phones were used by approximately 90% of students. A third of participants had already use a cordless phone for ≥ 7 years'. In 4 years from the survey to mid-2013, the cordless phone use of 6% of participants would equal that of the highest Interphone decile (≥ 1640 hours), at the surveyed rate of use. High cellphone use was related to cellphone location at night, being woken regularly, and being tired at school. More than a third of parents thought cellphones carried a moderate-to-high health risk for their child.

5.2.4 Conclusions

While cellphones were very popular for entertainment and social interaction via texting, cordless phones were most popular for calls. If their use continued at the reported rate, many would be at increased risk of specific brain tumours by their mid-teens, based on findings of the Interphone and Hardell-group studies.[37]

5.3 Background

Today's young adolescents have grown up with cordless phones and cellphones in their homes, and commonly with old cellphones available to use as toys at home and in pre-schools. This equipment is therefore an integral part of their everyday lives. In the US, SMS (texting) now dominates young adolescents' communication choices and the use of cellphones, as a way to develop and maintain social interactions, is growing (Lenhart, 2012).

Studies to assess young people's telephone user-habits have generally focused on cellphones. A German study found 34.7% of mostly 9-10 year-olds owned a cellphone by late 2002 (Böhler and Schüz, 2004). The following year 45% of English students were found to own one (Davie et al., 2004b). By 2005, 76% of Hungarian 9-12 year-olds were reported owning a cellphone (Mezei et al., 2007). That year, 77% of Australian 11-13 year-olds had their own (Inyang et al., 2009a) and a Swedish group reported that ownership among students aged 7-14 grew from 7.3% in 7 year-olds, 57.8% aged 10 and 95% aged 14 (Söderqvist et al., 2007). In early 2007, 96.5% of Spanish students aged 13-20 years owned their own cellphone (Sanchez-Martinez and Otero,

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[37] Comment requested by thesis examiners: A direct comparison with the Interphone and Hardell-group studies is not possible as the study parameters were different. This statement therefore should read "many participants may be at increased risk of specific brain tumours by their mid-teens, if this extent of use in the current study is in accord with findings of the Interphone and Hardell-group studies."

2009). These studies demonstrate both increasing uptake over those years as well as increasing ownership with age. Extensive use was commonly associated with being female (Söderqvist et al., 2007; Sanchez-Martinez and Otero, 2009; Mezei et al., 2007).

Internationally, concerns have been voiced at governmental level and by scientists regarding possible adverse health outcomes from frequent wireless phone use by young people (Sagi and Sadetzki, 2011). Cellphones are equipped with Adaptive Power Control (APC), which reduces the power output to the minimum necessary to establish a good connection. Cordless phones are a type of cellphone but very few, and none in New Zealand, have APC; they function on full power at all times providing the base is plugged in and turned on at the wall.

Potential vulnerability to neurological and other health effects from exposure to radiofrequencies and extremely low frequencies is commonly regarded as higher in young people than adults (Leitgeb, 2008). Discussions among the scientific community now seek the best methods for risk management and prevention of harm (Kandel, 2011). Recommendations for a precautionary approach or for children to minimise their use of cellphones are common (Sagi and Sadetzki, 2011; Council of Europe, 2011). New Zealand, however, does not recommend reduced use of wireless phone by children, but states that "use of cellphones by children should be a matter for informed choice by parents" (National Radiation Laboratory, 2012).

Studies have examined the relationships between duration and intensity of wireless phone use and several types of brain tumour. The most consistently found risks appear to be from intensive use over a few years, extensive use over ten or more years, use predominantly on the side on which the tumour appears (adult studies), and living rurally. There have been only two publications involving people younger than 20 years. One of these (Hardell et al., 2009) found a consistently greater risk for those whose first use of wireless phones was before the age of 20. The other found an exposure-response association between brain tumours and the side of the head next to which the cellphone ; these were statistically significant for subscriptions >4 years (operator recorded data) (Table 5) (Aydin et al., 2011c). It was unexpected to find an increased risk for opposite side use, but we note the study did not control for wearing metal-framed eyeglasses. Davias and Griffin explain that the basic resonant frequency for the whole frame of metallic glasses is approximately 900 MHz (Davias and Griffin, 1989), the same as that on which many cellphones and cordless phones operate. Could this impact on opposite-side RF absorption?

Aydin et al. also reported a statistically significantly increased risk of tumours in brain locations other than temporal, frontal lobes and cerebellum in regular cellphone users, locations where exposure is highest when the phone is held at a normal angle to the head. They argued against a causal relationship.

A few case-control studies have evaluated tumour risk from cordless phone exposure. These have found a statistically significant increase in risk of malignant tumours and benign tumours related to extended hours and years of use (Hardell et al., 2006b; Hardell et al., 2006a).

Findings have not been consistent across all studies. The most notable problem, common to all, is the large variance of residuals for recalled to billed cellphone use. This is likely due to being asked to recall use from many years ago, further confounded by answers from participants with brain tumours being affected by reduced cognitive acuity. Despite the problems faced in doing case-control studies, they provide the most robust evidence (Baan, 2011).

No studies in the peer-reviewed literature have explored the extent of wireless phone use among New Zealand's school-age population.

Our aim was to find out how, and to what extent, New Zealand adolescents are typically using and exposed to active cell phones and cordless landline phones (active denotes switched on, transmitting or not, including stand-by), and to consider implications of this in relation to brain tumour risk, with reference to current research findings.

Our focus was on self-reported user-habits. Actual SMS (text) records provided a baseline by which to assess the reliability of self-reporting.

5.4 Methods

5.4.1 Participants and setting

This cross-sectional survey explored adolescents' wireless phone user-habits. Sixteen of the 142 schools in the Wellington region of New Zealand each nominated one year 7 and/or 8 class to take part. This amounted to 3% of the region's year 7/8 population, and provided a representative sample based on school type (years 1-8, year 7-8, years 1-13, and years 7-15) and socio-economic school ratings (decile 1-3, decile 4-7, decile 8-10). Schools are allocated a decile number by the Ministry of Education indicating the proportion of students drawn from low socio-economic communities; the indicator is based on Census data for households with school-aged children in each catchment area (Ministry of Education, 2010). Decile groups are equated here with socio-economic status (SES). The ratio of students at low: mid: high decile schools in this region was approximately 5:10:16. There were 373 participants aged 10.3 - 13.7 years (mean age 12.3), representing an 85% response rate. There were 207 male (55.5%), 165 female (44.2%) and 1 transgender (0.3%) participants. Most were aged 11 or 12 (87.4%) with 83% of the remainder being 13 years old.

The study population was drawn from across New Zealand's Wellington Region. This includes the capital city, several smaller urban centres, small towns and rural areas.

Participants completed a questionnaire based on that of the MoRPhEUS study (Abramson et al. 2009) and took measurements of phone-to-body distance during use. Working in pairs, participants measured their normal texting distances when sitting and when lying in bed (if used that way). One sat holding the phone as usual and the partner measured the distance to the phone from the abdomen, then (for those who used their phone in bed) the phone holder lay down and held the phone as used in bed while the partner measured the distance from the phone to the bridge of the nose.

5.4.2 Exposure-metrics

Main exposure-metrics included estimated time spent with an active cell phone close or adjacent to the body, estimated time and number of calls on either phone type, estimated and actual extent of SMS text-messaging (texting), functions used, category of people texted, and use at school. The last of these has been reported elsewhere (Redmayne et al., 2011).

5.4.3 Statistical analysis

Relationships were assessed using Pearson Chi^2 tests and Pearson's correlation coefficient (r). A *p* value of 0.05 was considered statistically significant. We applied a method of reducing estimation bias (Redmayne et al., 2012b) to one recalled phone use variable for comparison. Analyses were undertaken using SPSS version 19.0.

5.4.4 Ethics

Ethical approval was given by the Victoria University of Wellington human ethics committee. Informed consent was obtained from principals of participating schools and parents of participating students.

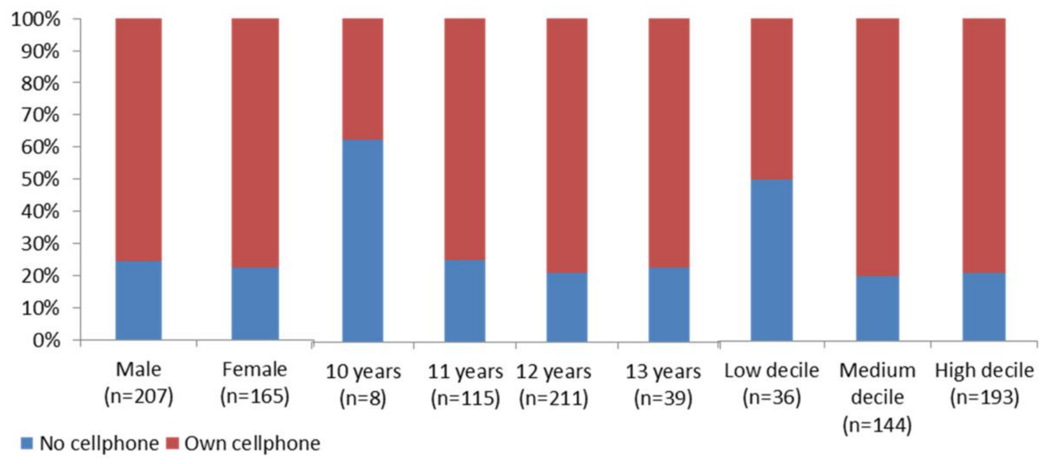
5.5 Results

5.5.1 Cellphone user habits

Age of first cellphone use peaked at 10 years, but 37% of participants first used one at ages 7 to 9, and 5.5% reported first using one before the age of 7. Years of cellphone use was slightly positively skewed; the median was 2.77 years (interquartile range 2.47). Cellphone ownership at the time of the survey is shown by age, gender and deciles group at Figure 5.1.

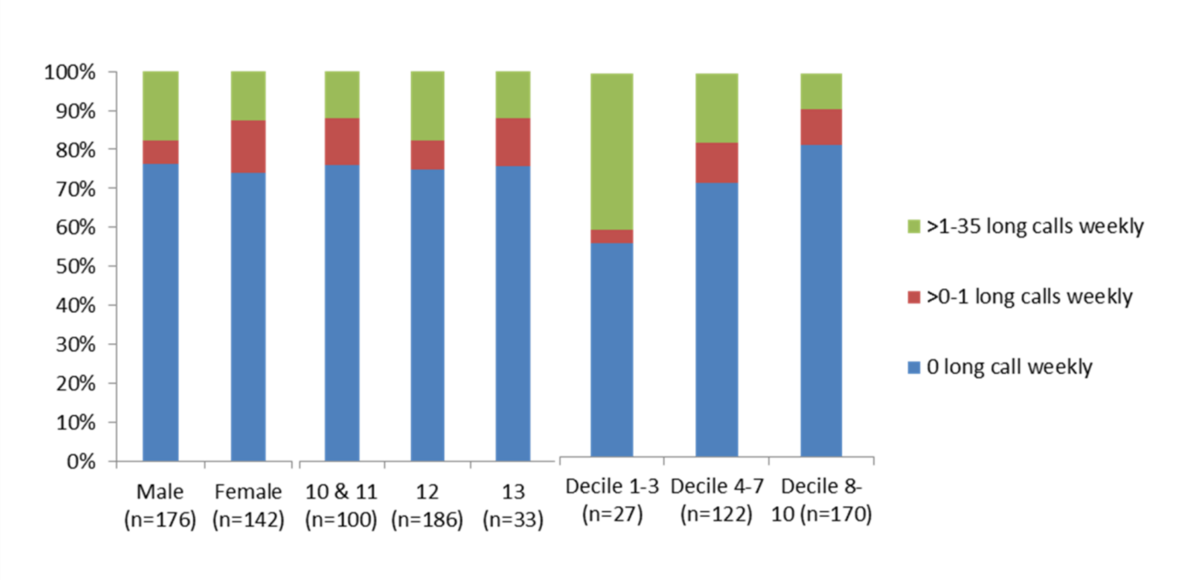
Most students regularly used a cell phone (70% owned one, 6% owned two, 12.5% regularly borrowed). There was no clear association between age and long cellphone calls weekly (N=319, χ^2 3.34, df4, p=0.503). Boys made more long cellphone calls, although this was not statistically significant (N=318, χ^2 5.53, df2, p=0.063). Percentage distributions of long cellphone calls made and received according to gender, age and school decile group are shown in Figure 5.2.

Figure 5.1 Comparative percentage distributions of cellphone ownership by gender, age and school decile (SES)



Three quarters of students owned a cellphone (70% owned one, 6% owned 2). Cellphone ownership was similar for girls and boys, and there was not a statistically significant difference in ownership by age, although ownership was proportionally lower among 10 year olds. Those in low decile schools (poorer SES) were less likely to own one.

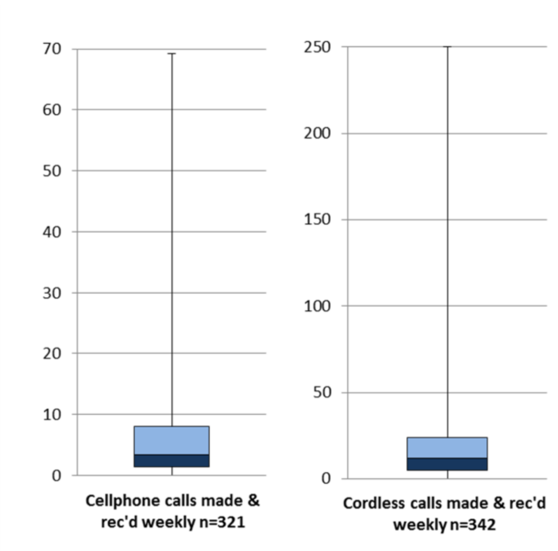
Figure 5.2 Comparative percentage distribution of long cellphone calls (>10 minutes) made and received weekly



Use of cellphones for long calls was light. There was no statistical difference according to age or gender, although girls were comparatively less likely than boys to make more than 1 long call weekly. Of those low decile students who made long cellphone calls, they were proportionally more likely to spend extended periods on the cellphone than the high decile students.

Cellphone ownership was influenced by socio-economic factors (N=373, χ^2 7.493, df2, p=0.0004), with those in low-decile schools less likely to own one. However, many students borrowed cellphones, and SES and cellphone calls were negatively associated (N=319, χ^2 19.380, (df4), p=0.001), with >1 long call weekly associated with *low* SES (p=0.00014).

Figure 5.3 Box and whisker plots of total wireless phone calls weekly



Cellphone and cordless phone use had similar distributions, but cordless phone use was much greater. The blue boxes indicate the 75th and 25th percentiles and the median.

Reported cell phone use had a positive skew (Figure 5.3). The median number of weekly voice calls was 3.2 (interquartile range 6.9, full range 0-69). The median number of billed weekly texts was 103 (interquartile range 217, full range 0-1187). Texting, receiving calls and taking photographs were the most popular functions (Table 5.1) with at least 70% of cell phone owners having a texting plan. Participants could also nominate other functions they used. The most popular self-nominated uses were as an alarm and as a calculator. More than half (58% of cellphone users) reported that they sent most texts to friends. Almost 5% of cellphone users said their most texted person was not a parent, friend or relative (Table 5.2).

The two most common places that cell phones were carried were a side pocket in trousers or skirt (66%) and a hoodie side pocket (18%). There was a wide variety of locations for carrying a cell phone, a more unusual one being under the bra strap or in the bra which three girls, each from different schools, reported. Cellphones were routinely kept turned on when being carried (90%). Approximately 20% of cell phone owners kept their phone active and in a pocket more than 10 hours daily. The duration of carrying a cell phone by day and having it turned on at night were positively related (χ^2 35.96, 3df, p <0.00001).

Table 5.1 Cellphone functions used by participants.

Survey categories	**% of all participants (N)**	**% of those who used a cellphone (N=331)**
SMS texting	80.7 (301)	90.9
Receiving calls	60.1 (224)	67.7
Camera	59.0 (220)	66.6
Online games/music/internet	46.4 (173)	52.3
Making calls	39.1 (146)	44.1
Self-nominated categories		
Alarm	13.7 (51)	15.4
Calculator	8.8 (33)	10.0
Play stored games	4.6 (17)	5.1
Calendar	4.6 (17)	5.1
Bluetooth	4.0 (15)	4.5
Listen to stored material	3.2 (12)	3.6
Watch	2.7 (10)	3.0
Voice/video recorder	2.4 (9)	2.7
Timer/stopwatch	1.9 (7)	3.1
Send photos	1.9 (7)	2.1
Screen saver/tones etc	1.9 (7)	2.1
Social networking	< 1% (1)	< 1% (1)
Check account	< 1% (1)	< 1% (1)

Not all functions were available on all phones. It is possible that some participants allocated social networking to 'internet' use

Table 5.2 People most-to-least texted.

	Most texted	2nd most texted	3rd most texted	Least texted
Friend	**193**	61	24	18
Parent/caregiver	79	**127**	51	24
Other relative	16	55	**129**	71
Someone else	16	37	64	**153**

Not all participants answered all rankings. Equal rankings (n=31) encompassed all combinations and are not shown. Bold print indicates the most prevalent response for each textee's popularity

Many sent texts daily from inside the pocket (n=136, 36.6%), and 64.9% (n=242) sent texts with the phone resting in the lap. The median measured distance from the face for normal texting while standing was 30 cm, with 20cm to the abdomen when lap texting and 23 cm to the eyes when texting in bed. Six students reported usually sending texts with the phone against the abdomen; eighteen usually texted from within 10 cm of the eyes when in bed.

5.5.2 Cellphones at night

Two-thirds of cellphone owners kept their cellphone beside the bed at night, 12.4% kept it under the pillow. Location of the phone during the day was related to that at night ($\chi^2$14.5, 4df, p = 0.006) with a positive association between keeping it in a pocket by day and under the pillow at night. Having the phone in or beside the bed was positively associated with it being switched on overnight (χ^2 11.46, 2df, $p < 0.003$). More than a third (37%) of those who kept a cellphone beside or in their bed at night reported being woken by it at least weekly; having an active phone nearby overnight was related to being woken at least once a week (χ^2 53.4, 1df, p = <0.00001). One third reported being woken regularly by their phone (13% 1-2 times weekly, 10% 3-4 times weekly, 7% 5-10 times weekly; 3% 11—100 times weekly). Being woken at night was reflected in being chronically tired at school (χ^2 16.8, 1df, p = 0.00004).[38]

5.5.3 Cordless landline user-habits

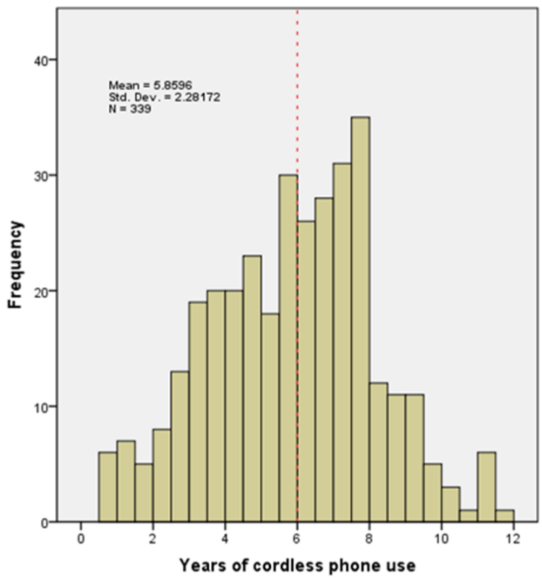
Most (N=341, 91.4%) participants reported using a cordless phone at home. The mean reported period of cordless phone use was 5.9 years (student data) (Figure 5.4), and the mean period of cordless phone ownership 8.3 years (parent data). Almost one third (n=117) had used a cordless phone for ≥ 7 years.

[38] The examiners considered that this was an important finding and deserved comment on its significance in both the discussion and abstract. I agree and have included some comment on the likely impact on young people's ability to learn in the final chapter.

Socioeconomic influence was apparent regarding the type of cordless phone at home (N=127, χ^2 12.727, df2, p=0.002), with those in the highest SES group being more likely to own a newer model Digital Spread Spectrum Frequency Hopping (DSS FH) cordless phone, while low SES group was associated with not having one at all.

The number of calls made and received weekly on a cordless phone was positively skewed and had a median of 11.8 (interquartile range 19.0, full range 0-250) (Figure 5.3).

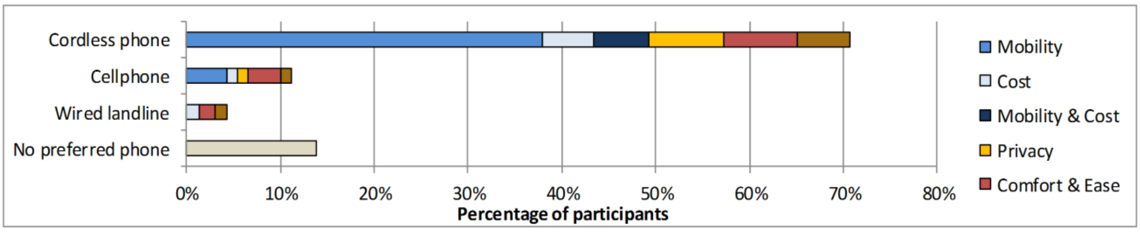
Figure 5.4 Years of cordless phone use at the time of the survey (mid 2009)



The mean age participants reported starting cordless phone use was 6 ½ years. All bars to the right of the broken line indicate students who will have had ≥ 10 years' use by mid-2013.

The cordless landline was by far the most popular phone for long calls from home (70%), while 11% preferred a cellphone and fewer than 5% a wired landline (Figure 5.5). The price structure for landline calls in New Zealand means that local calls are essentially free, being included in a fixed monthly line rental. There was no association between SES and the time spent daily on a cordless phone (N=324, χ^2 4.23, df6, p=0.645).

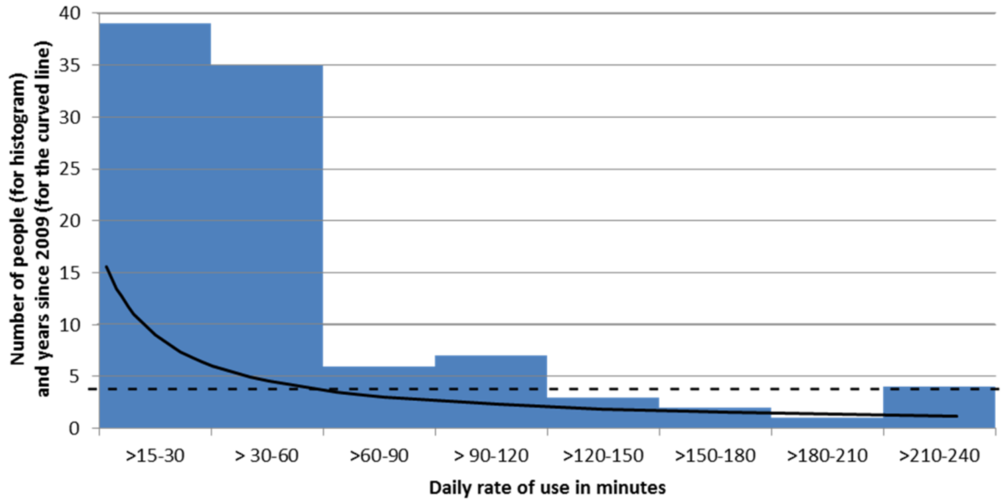
Figure 5.5 Preferred phone for long calls made at home, with reasons



Cordless phones were by far the most popular for long calls from home. Participants provided reasons for their choice of favourite phone from which the categories shown in the legend were compiled. Mobility was the most important reason. For many, this was to allow them to do something else at the same time. N=369.

Recalled time per evening on a cordless phone also had a strong positive skew (histogram component of Figure 5.6). Students were asked how long they spent daily, on average, on the cordless phone between the end of school and when they went to sleep. Some reported in minutes and some in fractions of hours. The median time was 5 minutes. However, a third of cordless phone users (32.8%) reported spending ≥ 15 minutes per day on one and 23.8% spent 30 minutes per day on one. Applying a method (Redmayne et al., 2012b) to reduce estimation bias of daily minutes on a cordless phone reduced original estimates that were > 60 and increased those that were < 60. The resulting forecast values suggested almost half those with a cordless phone (47.6%) spent ≥ 15 minutes on a cordless phone daily and 25.3% spent ≥ 30 minutes. Girls were statistically significantly more likely than boys to spend a longer time on a cordless phone daily (N=323, χ^2 26.54 (df3) p<0.00001). There was no clear association between age and cordless phone minutes daily (N=324, χ^2 2.66 (df6) p=0.850) (Figure 5.7).

Figure 5.6 Time since survey to reach 1640 hours' cordless phone use at the reported daily rate



This figure has a dual purpose. It shows both the reported time spent daily on a cordless phone (as a histogram) and the years since 2009 that it will take for participants to reach 1640 hours on a cordless phone at the reported rate of use (the black curved line). The curved line charts the critical rate of use over x years to reach 1640 hours' use since the survey. The broken line indicates mid-2013 (4 years since the survey). All those to the right of where the lines cross (i.e. more than 60 mins/day) will have had ≥ 1640 hours' exposure by mid-2013. This extent of use is equivalent to the top decile Interphone use.[39] Previous use and cellphone use are not included. Only those who reported >15 minutes/day are shown in the histogram.

Cellphone and cordless phone use were correlated (Pearson r 0.255, 2-tailed, $p<0.0001$). Parents' perception of possible health risks from wireless phones was greater for cellphones than cordless phones (Table 5.3).

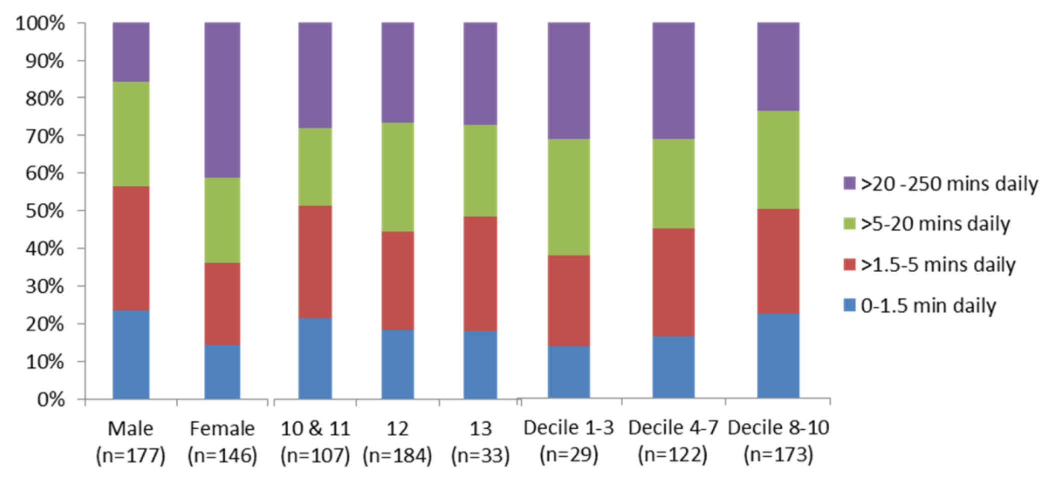
Table 5.3 Parents' perception of health risk from wireless phones

Risk concern	Cellphone % (N=325)	Cordless phone % (N=324)
None	7.4	23.5
Low	37.2	34.9
Moderate	29.8	11.1
High	7.1	4.0
Don't know	18.5	26.6

Parents' perception of health risk was greater for cellphones than cordless phones.

[39] Comment asked for by thesis examiners: The highest category of use in the Interphone study does not represent an unusually high level of use currently. Further, the 1640 hours cut-point is arbitrary and does not indicate a definite level of use at which risk begins.

Figure 5.7 Comparative percentage distributions of daily minutes spent on a cordless phone



Cordless phone use did not differ by age or school decile (SES), but girls were more likely to spend extended periods on the cordless phone. There were too few 10 year olds to include them as a separate category in the analysis.

5.6 Discussion

The use of both cellphones and cordless phones was a normal activity for the large majority of participants and each was used very differently although the amount of cordless phone use was positively and systematically related to the amount of cellphone use, as reported elsewhere (Redmayne et al., 2010; Söderqvist et al., 2007). The cellphone was more popular for texting, for internet, games and music, as a camera, and for receiving phone calls than for making calls. The cordless phone was clearly the most popular choice for long phone calls.

We now discuss some long-term health considerations. In the years since the study, the popularity of these most popular functions has grown, with social networking being increasing in popularity among adolescents since 2009 (Lenhart, 2012) . In our study, many students used the phone in their lap, sometimes with the lower edge resting against the abdomen with the phone at right-angles to the body. Peak-penetration of the energy is focused more deeply when the phone's antenna is at right angles to the body (Ismail and Mohd Jenu, 2007). A majority carried it in a pocket, with many texting from that location. Smartphones, which have rapidly gained popularity with adolescents (Lenhart, 2012, March 19; Channel 4, 2011, 04 August) present new challenges as they are continually transmitting data, especially when connected to Twitter or Facebook, and continue to do so while in the pocket (personal communication, C Zombolas, Managing Director, EMC Technologies, 5

December 2012). Use of a cellphone in these locations could be of concern for future fertility (Redmayne et al., 2011).

Another consideration is the growth plate of the femur, located in the metaphyseal region, which would lie directly under the side pocket in many cases. The femur and growth plate are in a highly proliferative state during the adolescent years.

Exposure of T-lymphoblastoid leukaemia cells to unmodulated 900 MHz frequencies has been demonstrated to increase apoptosis (natural cell death), but continued exposure resulted in pro-survival signals preventing death of damaged cells (Marinelli et al., 2004). Other research observed increased inhibition of DNA repair foci in stem cells after exposure to typical GSM and UMTS signals; the effect was thought to be caused by the extremely low frequencies resulting from modulation (Markova et al., 2009). Fibroblasts mostly adapted when exposure was chronic, but stem cells did not.

Increased protein synthesis has been observed when proliferating human fibroblasts were exposed to low intensity 1800 MHz radiofrequency (Gerner et al., 2010), commonly used by cellphones as a carrier frequency.
There has so far been no research examining bone cancer and cellphone radiofrequency exposure, although there are a few leukaemia studies. In vivo research of radiofrequency impacts on fertility parameters has been restricted to human adults and animals.

5.6.1 Implications for brain tumour risk

Cardis and Sadetzki, lead researchers in the Interphone study, remark that, "Indications of an increased risk in high- and long-term users from Interphone and other studies are of concern" (p.170) as, "Even a small risk at the individual level could eventually result in a considerable number of tumours and become an important public-health issue (Cardis and Sadetzki, 2011). It is, then, appropriate to compare our young generation's extent of phone use with that which has been found in various studies to be related to increased risk of brain tumour.[40]

In our study, 274 participants (74%) had used both a cordless and cellphone for more than a year, ranging up to 11.45 and 10.85 years, respectively. The distribution of calls made and received on these phones was very similar, but the extent of cordless phone use was much

[40] Comment asked for by thesis examiners: It should be noted that the brain tumours discussed in this paper are very rare conditions (approximately 4/100,000 person years).

the greater and their years of use were longer. This means that overall radiofrequency exposure in the brain of the participants was likely to be greater from their cordless phone use than cellphone use. By mid-2013, 46% of all participants will have used a cordless phone for ≥ 10 years.

In 2010, the International Agency for Research on Cancer met to assess the carcinogenicity of RF. After evaluating the available research, the committee rated "radiofrequency electromagnetic fields, such as, but not limited to, those associated with wireless phones" as a 2B carcinogen. This decision largely hung on the evidence presented in two large case-control studies: a pooled analysis of 2 case-control studies of wireless phone use and the risk of malignant brain tumours by the Hardell group (Hardell et al., 2011a) and the 13-country Interphone study (Interphone Study Group, 2010b).

Most of the Interphone results were statistically insignificant or even suggested either a protective effect or methodological problems, but there were a few statistically significant results in categories of heaviest or longest use (Interphone Study Group, 2010b). An association of intensive and extended wireless phone use with some brain tumours is common to most studies in this area.

One studied tumour-type has been gliomas, which are generally malignant. Interphone participants had an odds ratio (OR) 1.40, 95% confidence interval (CI) 1.03-1.89, between ≥ 1640 hours cellphone use and glioma, while that extent of use over only 1-4 years before the reference date had an OR 3.77, 95% CI 1.25-11.4 (Interphone Study Group, 2010b). Intensity of use appears important as, when only those with ≥ 10 years use were considered, the result was not statistically significant (OR 1.34, 95% CI 0.90-2.01). Odds ratios were higher when proxy interviewers were excluded and only data collected by experienced interviewers used.

In the Hardell-group pooled analysis, the highest OR was in those who began wireless phone use before the age of 20 years and had >1 year's use (Hardell et al., 2006b). The odds ratio of malignant tumour for this age group from cordless phone use was OR 2.1, 95% CI 0.97-4.6 while for digital cellphones it was OR 3.7, 95% CI 1.5-9.1. When data for those with >1 year's wireless phone use (all age groups) were analysed, neither cellphone nor cordless phone use were independently related to increased malignant tumour incidence (Hardell et al., 2006b). But all *combinations* of phone use were. For instance, use of both a digital cellphone and a cordless phone had OR 1.4, 95% CI 1.1-1.8 while analogue cellphone and a cordless phone had OR 1.6, 95% CI 1.2-2.2.

In many respects, the Interphone findings were not consistent with those found in other studies, particularly those of Hardell's group. These differences have been analysed (Levis et al., 2012; Levis et al., 2011), and the authors point out that Hardell's studies generally include a higher number of participants with ≥ 10 years' use. The methodology of the two groups also differed. When Hardell's group re-analysed their case-control glioma study (Hardell et al., 2006b) using the same criteria as that in the Interphone study Appendix 2 (Interphone Study Group, 2010a) the results for ≥ 10 years and cumulative use ≥ 1640 hours were similar (Hardell et al., 2011b). For instance, the ORs and 95% CI for those with glioma and ≥ 1640 hours use were 1.89 (1.08-3.30) compared to 1.82 (1.15-2.89), respectively. This represented those aged 30-59. Further analysis by the Hardell group study, including ages 20-59, increased the OR to 2.23 (1.30-3.82).
If the reported rate among those in our study using a cordless phone stayed the same since participating in the survey, and if cordless phone and cellphone use carry a similar risk, the total hours of intensive cordless phone use alone will place 22 students in our study (6%) in the category of at least 1640 hours' use over the 4 years from the survey to mid-2013, suggesting a 3.77-fold increased risk of glioma.[41] At that time, their average age will be 16¼ years.

The present study used participants' self-reported data. Four factors suggest 1640 hours of use would be reached sooner rather than later by the heavy users. Firstly, prior cordless and all cellphone use are not included in calculations of the time it will take to reach 1640 hours' use. Secondly, the extent of cordless phone use is positively related to that of cellphone use for calls, both in this study and elsewhere (Söderqvist et al., 2007; Redmayne et al., 2010), so heavy use of one phone type is compounded by heavy use of the other. Thirdly, several studies have shown that adolescent wireless phone use tends to increase rather than decrease or remain static from pre-adolescence through the high school years (Söderqvist et al., 2007), not beginning to decrease until the age of 18 (NielsenWire, 2010). Finally, the heaviest users' underestimated their extent of texting (Redmayne et al., 2012a) so this may well also have applied to their estimates of phone use.

[41] See footnote 39

5.7 Conclusions

By 2009, New Zealand's adolescents were using both cellphones and cordless phones extensively and in many ways. The extent and duration of cordless phone use by some students raises concerns that by the age of 16 many were already in a category of increased risk of brain tumours; in the adolescent years leading up to this, their brains are undergoing dramatic transformation (Blakemore and Choudhury, 2006b). Rodier suggests that because the central nervous system and its myelinisation developmental processes are vulnerable to interference by agents that adult physiology can cope with, it is reasonable to expect that the later stages of brain development present particular risks (Rodier, 2004).

The common habit of carrying and using a cellphone in a pocket or the lap suggests a possible avenue for research considering whether radiofrequency exposure from wireless technology is related to tumours found in the proximal femur or pelvis. Important examples are Ewing's sarcoma, osteosarcoma, and fibrosarcoma of bone, all of which occur most often in young people (Wheeless, 2012).

New Zealand's wireless billing system varies from that of some countries making local cordless calls free while cellphone calls are relatively costly. So, while the balance of cordless to cellphone use may vary between countries there are common threads. Texting has become popular internationally among young people, and extensive calls on one phone type or another are common among a proportion of that population. Advice to reduce exposure is not likely to be very effective with adolescents who feel impervious to risk. An alternative approach which would enable informed choice is educating children and parents about radiofrequency technology and the circumstances under which cellphones increase and decrease their energy output. Teens can then be encouraged to formulate ways they can continue using phones while reducing their radiofrequency exposure. Education is a step supported elsewhere (Sagi and Sadetzki, 2011; Kandel, 2011).

6 Adolescent in-school cellphone habits: a census of rules, survey of their effectiveness, and fertility implications

> "I never let schooling get in the way of my cellphone use"
> With apologies to Mark Twain

6.1 Background

A large part of young people's lives is spent at school. This chapter concerns cellphone use during this part of their day. Specifically, it examines the approach that schools in the Wellington Region take to their students bringing cellphones to school and using them while there. This is achieved by combining results from the census of the region's school cellphone rules and data related to cellphone behaviour at school, as reported by participants in the cross-sectional survey.

There are other sources of radiofrequency exposure commonly encountered in schools that are not included in the paper but warrant mention. These are principally nearby cellphone base stations, and wireless broadband (WiFi), common in many schools. Both these exposure-types have become targets of protest by concerned parents in New Zealand and, more so, overseas. Both are sources of on-going, very low-level radiofrequency exposure.

Exposure from laptops that use the WiFi is less controversial, but provides a higher level of radiofrequency exposure – especially when used on the lap. Such use is very relevant to this chapter and to New Zealand Standard 2772.1:1999 as it can rapidly cause an unsafe increase in temperature in male genitals (Sheynkin et al., 2011).

WiFi exposure is usually reported as time-averaged, as for DECT cordless transmission. This is pertinent for assessing overall exposure with relation to compliance with thermally-based Standards, but gives no information about peak exposures and does not consider other mechanisms of interaction. Khalid et al. (Khalid et al., 2011) calculated that the peak SAR in the torso of a 10 year old child model at a distance of 34 cm from the antenna would be 80 μW/kg. The locations of the antennae vary according to the laptop model; they can be either side of the lid or in the base. The example used by Khalid et al. had a single antenna in the lid. Exposures from body-mounted antennae or with the equipment sitting on the lap are not given but would be considerably greater.

When a laptop is used on the lap, exposure to radiofrequencies is likely to be above the limit permitted in the Standards. The industry is aware of this and is addressing it by introducing a feature called dynamic power control (DPC) in some laptops and tablets with built-in Universal Mobile Telecommunications System (UMTS) antennae. In equipment using DPC, "proximity sensors will detect when the device is being used close to the body and automatically reduce the output power to ensure compliance with SAR limits in Standards" (Interagency Committee on the Health Effects of Non-Ionising Fields, 2012). This feature is not in use at the time of writing; laptops without it will presumably continue to be non-compliant when used on the lap.

The chapter has been published as a paper in *Reproductive Toxicology* (Redmayne et al., 2011).

Unpublished supplementary tables are available at Appendix 5.

Citation details
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http://www.sciencedirect.com/science/article/pii/S0890623811003546
Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.reprotox,2011.08.006.

The paper had 1 citation in a peer-reviewed journal as of 4 November 2012 (Starkey, 2011), excluding self-citations.

6.2 Abstract

We explored school cellphone rules and adolescent exposure to cellphone microwave emissions during school with a census and survey respectively. The data were used to assess health and policy implications through a review of papers assessing reproductive bio-effects after exposure to cellphone emissions, this being most relevant to students' exposure.

All schools banned private use of cellphones in class. However, 43% of student participants admitted breaking this rule. A high-exposure group of risk-takers was identified for whom prohibited in-school use was positively associated with high texting rates, carrying the phone switched-on >10 hours/day, and in-pocket use.

The fertility literature is inconclusive, but increasingly points towards significant time- and dose-dependent deleterious effects from cellphone exposure on sperm. Genotoxic effects have been demonstrated from 'non-thermal' exposures, but not consistently.

There is sufficient evidence and expert opinion to warrant an enforced school policy removing cellphones from students during the day.

6.3 Introduction

Adolescent cell (mobile) phone ownership has become ubiquitous over the last few years. There are several reasons that young people are more vulnerable than adults to environmental stressors (Tamburlini, 2002), so concern has grown internationally over their increasing levels of exposure to this radiation due to possible adverse health effects. Using the Short Message Service (texting) is adolescents' preferred form of use (Hanman, 2005). Inevitably this has meant that a majority of students take a cellphone to school, often into class, and use it there.

However, there is very little research on what regulatory approaches schools take towards cellphones being kept or used by students during school, students' responses to those rules, or health implications of typical student use.

Microwave exposure Standards are designed to prevent thermal injury by keeping power output within set parameters (ICNIRP, 1998; Institute of Electrical and Electronics Engineers, 2005). Usual testing procedures allow a gap of up to 2.5 cms from the source, but independent testing (Zombolas, 2008) has shown that transmission from against the body can exceed maximum safety levels set by these Standards. There is research indicating possible microthermal 'hot-spot' effects (Ruediger, 2009), but these have not been confirmed. Much research is being focused on effects from very low microwave intensities typical of cellphones, often referred to as 'non-thermal'. No mechanism causing such effects is yet fully understood, however Stewart (Stewart, 2008) emphasizes that observations with no proven mechanism should not be disregarded.

Health concerns from cellphone microwave exposure have led to several recommendations that cellphone use by young people should be restricted or kept to emergencies (*A6-0089/2009* European Parliament B Series). The French Senate has legislated a ban on cellphone use by under 15-year-olds in locations specified in school rules (Assemblée Nationale de France, 2010). Furthermore, the United Kingdom Department for Education (Department for Education, 2010) discourages routine or prolonged use of cellphones by young people, and suggests schools consider this when setting cellphone policies. Evidence given to the President's Cancer Panel hearing on risks from radiation cautioned that children should not carry cellphones in pockets while switched on (President's Cancer Panel, 2009). This is supported by at least two fertility research groups (Agarwal et al., 2009; De Iuliis et al., 2009).

Despite these precautions, research has not previously examined whether health risks exist from adolescents' typical cellphone behaviour in school. After ascertaining school rules and their effectiveness, we reviewed the relevant literature on bio-effects and adolescents' particular susceptibilities, and asked whether policies to eliminate or control cellphone access at school were advisable.

6.4 Methods

In 2009, a telephone census was taken of all 139 schools with year 7 and 8 classes in the Wellington Region, New Zealand. This sought to ascertain the rules regarding cellphones at school. Students in these classes were mostly aged from 10 to 12 at the start of the school year in February. Data were obtained via a telephone questionnaire directed to the Principal or Deputy. If neither was available, it was emailed.

The design was limited to six questions to encourage participation. They focused on whether the school had cellphone rules and if so, what they were and consequences of breaking them. Answer categories were formulated using thematic analysis of responses to open questions asked in a pilot study of eight principals conducted by phone.

The effectiveness of the rules was assessed within a larger cross-sectional cluster survey (n=373). Briefly, 16 schools from throughout the Wellington Region each nominated one year 7 and/or 8 class to take part. This amounted to 3% of the region's year 7/8 population, and provided a representative sample based on socio-economic school ratings (decile 1-3, decile 4-7, decile 8-10) and by school type (year 1-8, year 7-8, year 1-13 and year 7-15). New Zealand schools are allocated a decile number by the Ministry of Education indicating the proportion of students drawn from low socio-economic communities; the indicator is based on Census data for households with school-aged children in each catchment area (Ministry of Education, 2010). The ratio of students at low: mid: high decile schools in this region was approximately 5:10:16. The region includes the capital city, urban and surrounding rural areas.

All participants were allocated numbered questionnaires which were completed during school, with the teacher present. Data were analysed with SPSS version 17.0 (SPSS Statistics 17.0.1, 2008), using Pearson Chi-square tests.

The survey was carried out between mid-June and October 2009. The teacher was asked not to look at students' answers just prior to the school-related questions. The students were assured of confidentiality, with an explanation.

A review of literature on cellphone bio-effects related to reproductive health was made using Science Direct, EMF Portal, and International EMF Project search engines, with a few papers accessed through Google Scholar or papers' references. The literature review was initially limited to peer-reviewed research involving human subjects or cells published in English since 2000. Search words included one of: reprod*, fertil*, sperm*, endomet*, genotox*, trophoblast*, acrosome and one of: mobile phone, cell* phone. EMF Portal limits were 'fertility' and 'gene expression, mutation', plus 'mobile phone related frequencies'. International EMF Project limits were: frequency range: 100kHz to 300 GHz; frequency sub-range: mobile phone and wi-fi communication.

Ethical approval was given by the Victoria University of Wellington human ethics committee. Consent was obtained from principals of participating schools and parents of participating students after receiving written information about the study and having the opportunity to ask questions about it.

6.5 Results

6.5.1 Census

The census of school cellphone rules had a participation rate of 98.5%; only one school declined to participate and one did not respond. Table 6.1 presents census results, outlining the rules regarding the presence and use of cellphones in school and consequences of disobeying them. All schools with reasonable cellphone reception (96%) and year 7/ 8 students had either formal or informal rules regarding cellphones at school.

Most schools disallowed cellphone use during school (110 or 87%), while 14 (11%) allowed their use during breaks. Two (1.6%) high decile schools allowed some cellphone use in class as a learning tool.

There were various consequences for breaking cellphone rules. A quarter of those with no specific second consequence (for repeat offending) said they had little or no trouble with abuse of the rules and therefore did not need a further consequence, and 15% reported that they had never needed a second consequence.

Table 6.1 Results of census of 'cellphones in schools' (to the nearest 1%)

Question 1 Do you have a policy or rules about cell phones in school?

Yes, policy or formal, written rules	60%
Yes, informal rules	35%
No	5%

Question 2 Are students allowed to bring cell phones to school?

Yes, as a right	87%
Yes, if a note is brought at start of year	4%
No	4%
Only in an emergency, with a note	2%
Not applicable	3%

Question 3 What happens to cell phones that are brought to school?

Hand in to office or teacher for the day	52%
Student to choose location	24%
Keep out of classroom (can't hand in)	15%
Keep out of classroom (can hand in)	2%
Not applicable	7%

Question 4 Are students allowed to use cell phones in school hours, and if so when?

No use during school hours	80%
May use during school breaks	10%
Yes, for specified learning purposes	2%
Not applicable	8%

Question 5 What is the first consequence of using ignoring the rules?

Confiscate for the day	30%
Confiscate until parent collects it	30%
Other (specific)	15%
No specific consequence	14%
Confiscate for the week	7%
Not applicable	4%

Question 6 What is the consequence of further ignoring the rules?

No specific consequence	42%
Other, usually behaviour management plan	19%
Confiscate until parent collects it	17%
Confiscate for the week	7%
Confiscate for a month or rest of term	6%
Phone banned at school in future	5%
Not applicable	4%

Figure 6.1 School policy and cellphone handing-in behaviour

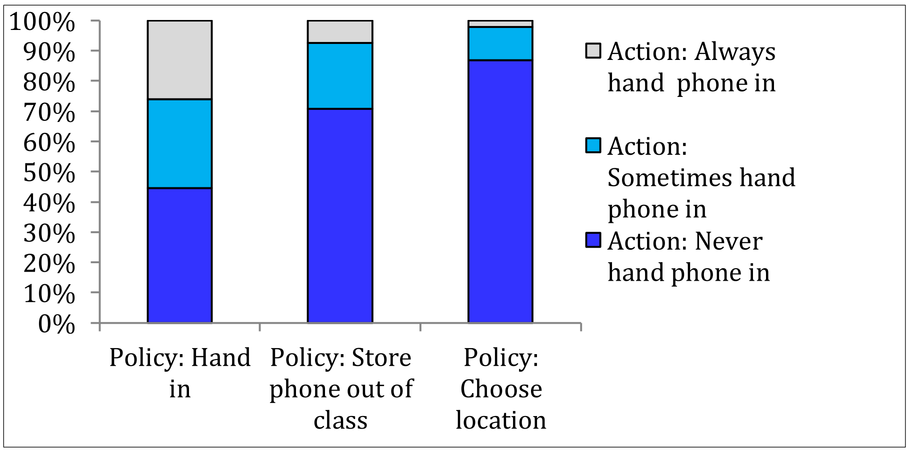

Fig. 6.1 compares survey participants' cellphone handing-in behaviour with their school's policy approach regarding phone location. The comparative proportion who handed in their phone was greatest when that was required. Totals in each column are: 146, 41, 92. When the policy was to keep the phone out of class, 73% had no handing-in facility, while for those choosing a location, 26% had no handing-in facility. Refer to Supplementary Table 1 in Appendix 5.

6.5.2 Survey

The survey involved 373 (207 male, 165 female, 1 transgender) students. The age range was 10.3 to 13.7 years, mean age 12.3 (SD 0.6) yrs. Several questions from the survey permitted evaluation of the effectiveness of school policies.

At least one cellphone was owned by 285 (76%) participants, but 330 (88.5%) reported using one at least weekly. All surveyed schools allowed cellphones to be brought to school, one of these following provision of a parental note.

More than 90% of those who owned a cellphone and 23% who did not brought one to school at least sometimes. Almost half of those who could or should hand in their phone for the day, reported 'never' doing so; only 21% claimed they 'always' did. Of those students who could *choose* whether or not to hand them in, < 2% 'always' did so (Figure 6.1).

Rules on phone location during the day did not appear to significantly affect the extent of phone use in class (χ^2=2.89, p=0.24). Of all cellphone users, 43% admitted to having used one during lessons in the current year.

Forty two percent reported texting from inside a pocket up to 120 times daily. The median estimate was 5 [Interquartile range 2-10] per day for both boys and girls (48.5% sent <5/day, 11.2% sent 5/day, 40.3% sent >5/day). This translated to 20% of all participants, including those who did not use a cellphone, sending ≥ 5 texts daily from inside a pocket. Within this group, reported daily pocket-texts numbered 5-29 by 85%, and 30-120 by 15%. Total texting rates were considerably higher.

The side-pocket was the favoured location for cellphones, placing the phone near the inguinal region. Almost 30% of cellphone owners reported carrying a switched-on (active) phone in a side-pocket for more than ten hours every day of the week, with a further 24% doing so for 6-10 hours. There was a strong positive relationship between the number of hours a day an active phone was carried and the frequency of pocket texting (χ^2 =36.6, p<0.0005).

Some consequences for breaking the school rules were found to be more effective than others. Using the phone in class was related to the first consequence for doing so (χ^2=14.1, p=0.007);

specifically, 'confiscation for a week' and an unknown consequence determined by the circumstances appeared effective (see Supplementary Table 4, Appendix 5). Handing-in behaviour was also related to first consequence (χ^2=22.1, p=0.001), positively when 'confiscation until parental collection' applied (Figure 6.2). There was an unexpected finding that significantly *more* students 'never' handed in their cellphones at schools where the first consequence was confiscation for either a day or week.

Figure 6.2 First consequence for not handing phone in and handing-in behaviour

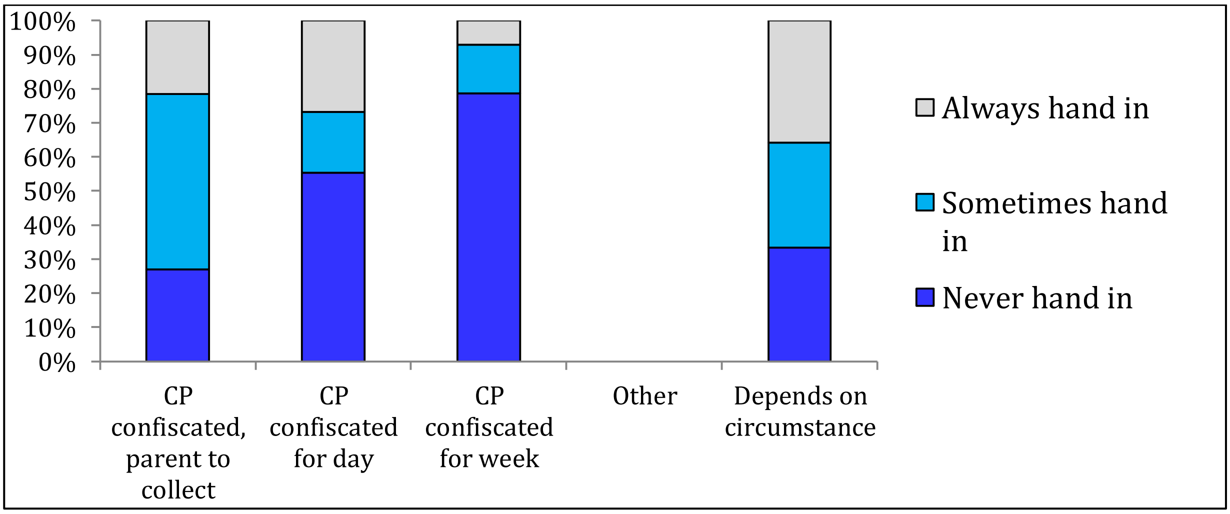

Figure 6.2 compares handing-in behaviour (of those required to hand their phones in) with the first consequence for not complying. Total participants in each column total: 37, 56, 14, 0, 39. Refer to Supplementary Table 2 in Appendix 5.

Second consequences (repeat offending) and student handing-in-behaviour were strongly associated, (χ^2= 53.8, p <0.0001), but not always helpfully so (Figure 6.3). In particular, confiscation for the rest of the term and confiscation until parental collection resulted in significantly *fewer* handed-in phones. However, an unspecified consequence, or other specific consequences increased compliance. No significant relationship was found between repeated use in class use and consequences (χ^2=7.2, p=0.203).

Figure 6.3 Second consequence for not handing phone in and handing-in behaviour

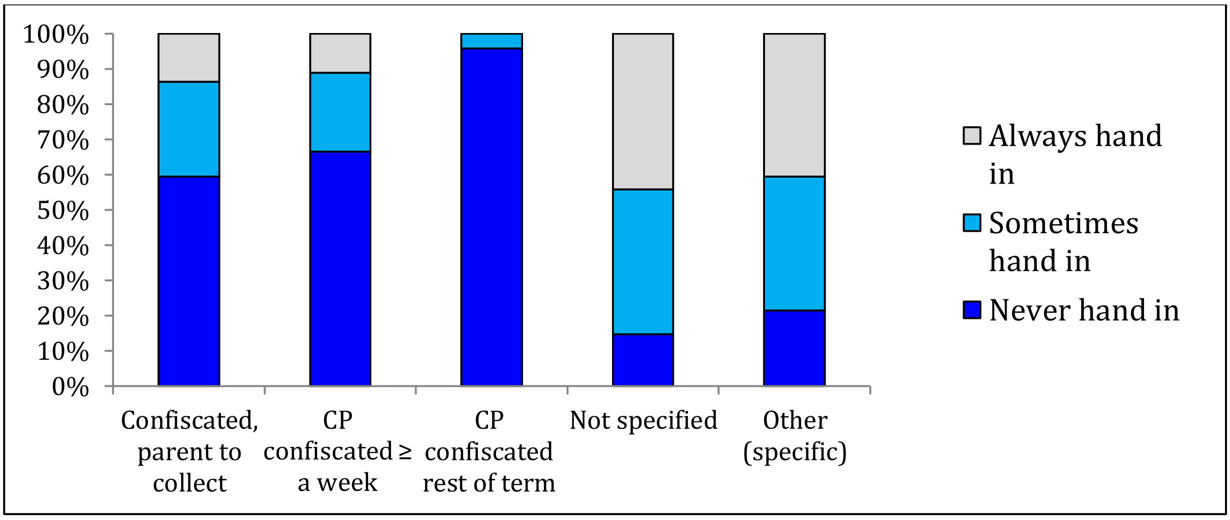

Figure 6.3 compares handing-in behaviour (of those required to hand their phones in) with the second consequence for not complying. Total participants in each column total: 37, 9, 24, 34, and 42. The 'other' category included: ringing a parent only after a pattern of behaviour was noticed - the school preferred to give students the opportunity to correct their own behaviour; confiscation for the day; and risk of theft. Of those schools which confiscated for the parent to collect, one said it would be banned in future, but hadn't needed this yet, and another would include a 'parent conference'. Refer to Supplementary Table 3 in Appendix 5.

6.6 Discussion

6.6.1 Survey and census

Our combined survey and census found that approximately 20% of adolescents fell into a 'high exposure' category. They carried and used their cellphones during lessons irrespective of school rules and the active phone was in a side-pocket or hand > 10 hours/day. This pattern was positively associated with highest overall texting rates and keeping an active phone close-by at night. Research shows that the highest use of cellphones among adolescents is associated with health-risk behaviours (Sanchez-Martinez and Otero, 2009).

There have been very few surveys of school cellphone policies and this appears to be the first census. By comparing school expectations with students' reports of in-school cellphone habits, we have been able to assess the effectiveness of school rules, and the duration and proximity of student cellphone exposure during the day.

We found that when reception was satisfactory, all regional schools had either formal or informal rules banning private use during lessons. This is similar to the findings of some surveys, which found that rules on private cellphone use by students are usually punitive (Obringer and Coffey, 2007; Fielden and Malcolm, 2007). Health reasons were not mentioned, but the current study indicates these are unlikely to have been considered. For other reasons, about 70% of the region's schools expected students to hand them in each day or keep them out of class. If these rules were strictly enforced then their current policy would provide a precautionary approach, regardless of the intention.

While most schools prohibited any cellphone use by students during school, some allowed private use during breaks and almost half allowed students to choose where their phones were kept. Allowing students to carry a cellphone but prohibiting its use, seems unrealistic and would be hard to enforce. Accordingly, we found considerable disparity between cellphone policy requirements and students' compliance. So while a requirement to hand cellphones in was somewhat effective, it did not appear to reduce the texting frequency during lessons; many students covertly texted close to their abdomen or inguinal area. This may indicate that while the low risk-takers tended to conform to the requirements, the rules had little impact on higher risk-takers. This was particularly evident in harsher consequences for re-offending which appeared to be counter-productive.

If the phone was retained, it was likely to be kept in a pocket. In turn, a longer daily period of carrying the phone was associated with an increase in covert texting from that position and therefore increased microwave exposure.

Many principals stated that they had no, or few, incidents of private cellphone use during lessons, whereas by students' own admission, 43% regular cellphone users had used one in class in the current year and a further 12% (who denied using one at school) reported sending texts regularly from within a pocket.

6.6.2 Experimental research

In vitro and in vivo research findings from experiments involving cellphone-like exposure have not been completely consistent due to inherent difficulties of research involving electromagnetic fields. Firstly, studies using real cellphones provide a genuine exposure scenario, but are unable to be accurately replicated due to random frequency and output power changes, while cellphone-like apparatus typically emits pure-tone signals. One solution is available in a programmable exposure system developed to reproduce typical cellphone-like exposures (Schuderer et al., 2004).

Secondly, many studies considering effects on sperm morphology and motility use rodents, but their outcome cannot be assumed to apply to humans (Cairnie and Harding, 1981). Despite this, results such as those of Aitken et al. (Aitken et al., 2005), who found significant genotoxic damage to the nuclear and mitochondrial germline DNA in mice exposed to cellphone microwave output, need to be taken into account. Unless specified, research discussed below focuses on humans or human cells exposed to cellphone-like frequencies.

6.6.3 Fertility review

Most research related to the effects of cellphone-like exposures on human fertility date from 2005 onwards. There have been no epidemiological studies of female fertility following exposure to cellphone microwaves. An Italian group has carried out several in vitro studies using extravillous trophoblasts with results implying cellphone exposure could have an impact on successful pregnancy (Valbonesi et al., 2008; Franzellitti et al., 2008; Cervellati et al., 2009). Also DNA breaks were found in trophoblasts after 8 hours' intermittent exposure (Franzellitti et al., 2009).

Several epidemiological studies have observed associations between cellphones and sperm motility or morphology variously associated with increased duration and extent of cellphone ownership and use, or carrying the phone on a belt-carrier or in a trouser side-pocket (Agarwal et al., 2008; Fejes et al., 2005; Kilgallon and Simmons, 2005; Wdowiak et al., 2007). Despite their consistent findings, these studies had design and/or reporting limitations.

Many, but not all, in vitro studies have found increased reactive oxygen species (ROS) after exposure. Falzone et al. (Falzone et al., 2008) suggest that leukocytes could account for generation of excess ROS contained in whole sperm samples, affecting motility. They therefore used purified and anti-leukocyte-treated samples, although not assessing ROS in this study. Results showed no significant effect on motility after 1 hour exposure at 2 W/kg (the permitted maximum) or 5.7

W/kg. However, straight-line velocity of sperm was reduced both in a 'time-elapsed-after-exposure' and a dose-dependent manner.

In another study (Agarwal et al., 2009), 1 hour exposure (GSM phone; talk mode at 2.5 cms from the antenna) of unprocessed samples led to decreased motility and viability, excess ROS production and decreased total anti-oxidant capacity, but not DNA fragmentation. The authors suggested that this indicated oxidative stress and warned against carrying an active cellphone in a pocket.

De Iuliis et al. (De Iuliis et al., 2009) also expressed this concern for males of reproductive age. They identified a dose-dependent activation of ROS, and pointed out that spermatozoa are particularly vulnerable to oxidative stress. Their results, using Percoll purified (but not leukocyte treated) healthy sperm, indicated that electron leakage from the mitochondrial electron transport chain was one source. Significant oxidative stress was apparent after exposure at 2.8 W/kg, with a dose-dependent increase thereafter. Analysis revealed correlated dose-dependent DNA strand breaks after 16 hours' exposure to pure-tone of 1.8 GHz. Epididymal spermatozoa are unable to self-repair, leaving little time for the fertilized egg to make such repairs should fertilization take place. Without repair, DNA mutation may be inherited possibly disrupting healthy embryonic development (Aitken et al., 2005).

Most recently, Falzone et al. (Falzone et al., 2011) found that 1 hour exposure (simulated GSM 900 MHz for 1 hour) halved the sperm head area and reduced acrosome percentage by a third, although not significantly reducing the number of sperm with an intact acrosome. However zona-pellucida binding was reduced by about a third in vitro. This perhaps indicates that microwave exposure may impair fertilizing potential since such binding correlates with fertilization rate.

The most pertinent findings for adolescents are potential damage to health of future offspring (De Iuliis et al., 2009) and the indication of reducing sperm quality with duration of ownership and location of storage.

Genotoxicity has been investigated in many studies. A recent review of 101 publications found that 49 reported a genotoxic effect, while 42 did not; 8 found enhanced genotoxic action of known antagonists. The conclusion was that there was evidence that RF-EMF can change genetic material (Ruediger, 2009).

6.6.4 Technical points and implications specific to adolescents

Leading hypotheses suggest the highest susceptibility for environmental and lifestyle testicular damage occurs around birth or at puberty (Agarwal et al., 2008). We found that 17 % of male participants, all around pubertal age, were in the high-exposure group and almost 30% of participants carried an active phone in a side-pocket >10 hours daily. In this position, indentation in the inguinal region increased the current density in that area (Dimbylow, 1998).

Safety standards do not consider such close exposure. Compliance testing is carried out using a homogenous fluid-filled phantom head with non- microwave-conductive spacer of 7-12mm to allow for the pinna (Gandhi and Kang, 2004). In the near field, the exposure increases rapidly, so in a pocket next to the carrier's body safety limits may be exceeded each time the phone makes contact with the base station; penetration of the energy increases with proximity.

The possibility of exceeding safety limits is often reflected in the safety information of cellphone user-manuals. For instance, instructions for a model popular among participants in the current study advises on page 81 that the phone meets the exposure guidelines next to the ear or "when positioned at least 2.2 cms from the body" and should be carried no closer (Nokia, 2007).

The highest power output of a cellphone is adjacent to the antenna. Approximately 10% of cellphone antennae are now located inside the bottom of the casing (Baumann et al., 2006). This location reduces microwave exposure within the brain during voice calls, but will increase exposure in the abdominopelvic region during transmissions from the lap while sitting at a desk.

Fertility-related outcomes have not consistently been observed, but an explanation has been offered. Gerner et al. (Gerner et al., 2010) reproduced others' findings, both positive and negative, reconciling assorted conflicting studies. They depended upon the stage of cell cycle at exposure and duration of exposure. Metabolically active or proliferating cells were found to be more sensitive to cellphone-like microwaves, suggesting greater sensitivity in children and adolescents, as well as in spermatogenesis. There are indications that periods of 30 to 90 minutes without exposure may be needed to allow damaged cells to be repaired (Franzellitti et al., 2009).

6.6.5 Strengths and limitations

Strengths of this study lie in the high level of participation in the census providing highly representative results. This also applies to the survey that had an 85% participation rate. All data were collected and entered by the lead author avoiding inter-rater-error.

However the design introduced a couple of limitations. Asking students to report on their use of cellphones in class risked both under-reporting due to lack of trust, and over-reporting due to rebellious excitement or peer pressure. The occurrence of the latter, with relation to self-reported drug use, has been found to be < 0.5% (Wade and Brannigan, 1998).

6.6.6 Further research

Research is needed to evaluate increased Specific Absorption Rate around metal objects such as copper-containing intrauterine devices and body studs. Copper is highly conductive and we suggest emissions from 900 MHz or lower frequency bands may penetrate sufficiently to cause hot-spots. Navel studs are very popular among young women. Use of the cellphone resting against these could lead to an exceptionally high electric field between spherical holders if the diameter of each sphere were greater than the gap between them (Lekner, 2010).

6.6.7 Cellphone effects and school policy

The accumulating evidence for effects on reproductive health, and many students' habit of carrying and using an active phone in a pocket or close to the pelvic region, suggests the advisability of enforced policies requiring students to part with their phones during school. Many schools had, but did not enforce such a rule.

Quite apart from any biophysical effects, pocket-texting will affect their own and others' learning through lack of attention. To prevent or reduce this requires teachers to notice and be prepared to enforce school policy. Schools cannot be expected to eliminate cellphones from classes without the support of the community. Since parents commonly want their child to have a cellphone at school (Johnson and Kritsonis, 2007), public education is required (Schüz, 2005).

6.7 Conclusion

This study is the first to consider specific health implications for adolescents related to the way they use and carry their cellphones at school. Most principals were under the impression that their school had no or few problems with students breaking cellphone rules. However responses from participants indicated that a large proportion of those who were supposed to hand them in did not do so, but instead carried an active phone all day, with many using it regularly in a pocket.

Possible adverse effects from chronic cellphone exposure on reproductive integrity are still poorly understood, but early indications of a relationship between duration of cellphone ownership and sperm damage should be taken seriously until further explored. There is sufficient evidence, supported by recommendations from fertility researchers and governmental bodies, to make it advisable for schools to have and enforce policies that remove cellphones from students' pockets during school. Realistically, this means requiring cellphones to be handed in; this would not prevent occasional distribution for educational purposes.

To successfully implement policies that remove cellphones during the day, it may be necessary to provide factual, non-alarmist education for students, teachers and parents on the status of relevant research and methods to reduce personal exposure.

7 Patterns in wireless phone estimation data from a cross-sectional survey: what are the implications for epidemiology?

> "Research is creating new knowledge"
> Neil Armstrong

7.1 Background

There have now been many case-control studies to evaluate whether use of a cellphone increases the risk of developing a brain tumour, an acoustic neuroma or a parotid tumour, located in the salivary gland. These studies often begin with a validation study which evaluates the level of agreement between self-estimated use and operator records, drawing on a sample of the whole study group. Neither self-estimation nor operator records are ideal. Recall has a very large estimation error, and operator records are not always available and do not account for use across all phones used. Shared phone use, common among young people, further complicates this approach.

Problems with the reliability of recall due to random and systematic recall errors have led some to discount this data type as not sufficiently accurate to provide useful results. However, it is still often all that is available as some countries, such as Switzerland, delete stored user-data after a few months (Aydin et al., 2011a). Further, accessing network operator data requires the participants to remember their subscription type and phone numbers over the studied years (Aydin et al., 2011a). For studies relying on recall it is necessary to minimise the amount of error and introduced bias in recall data. This and the next chapter address these problems.

The results reported in this chapter came about after I noticed a tendency for participants to consistently and illogically underestimate their extent of texting over a week and a month compared to the amount they estimated for a day. I would not have had all three estimates had the pilot study participants not suggested I should include all three options, and had participants not mostly provided all three estimates despite the question asking them to estimate their use over one of these periods. Additionally, for some participants, I had the billed number of texts sent for the current month with which to compare the estimates. Exploration of their actual and comparative recall revealed information about the mental process involved in recalling a number of events which mirrored that used by people who are estimating a number of objects they see.

This process is not linear, but logarithmic; that is, we estimate numbers in ratios. This carries implications for how recall data should be treated when participants estimate a range, or when the researcher wishes to impute a central quantity. This paper addresses how to handle these situations in order to avoid introducing bias. One such concern arises from assigning the arithmetic mean rather than the geometric mean when an estimated range of use is provided by participants. I examined the impact this had when the data was then categorised by forming two variables: one where I assigned the arithmetic mean of data given as a range, and one where I assigned the geometric mean of such data. A range was provided by 13.8% of those who used the cordless phone (N=319); using the arithmetic mean resulted in 4.7% of these being assigned to the wrong category.

This chapter has been published as a research article in *BMJ Open* (Redmayne et al., 2012a).

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7.2 Abstract

7.2.1 Objective

Self-reported recall data are often used in wireless phone epidemiological studies, which in turn are used to indicate relative risk of health outcomes from extended radiofrequency exposure. We sought to explain features commonly observed in wireless phone recall data and to improve analytical procedures.

7.2.2 Setting and participants

The study took place in the Wellington Region of New Zealand. Each of sixteen schools selected a year 7 and/or 8 class to participate, providing a representative regional sample based on socio-

economic school ratings, school type, and urban/rural balance. There was an 85% participation rate (N=373).

7.2.3 Main outcome measures

Planned: Distribution of participants' estimated extent of SMS-texting and cordless phone calls, and the extent of rounding to a final zero or five within the full set of recall data and within each order of magnitude. Unplanned: The distribution of the leading digits of these raw data, compared to that of billed data in each order of magnitude.

7.2.4 Results

The nature and extent of number-rounding, and the distribution of data across *each* order in recall-data indicated a logarithmic (ratio-based) mental-process for assigning values. Responses became less specific as the leading-digit increased from 1 to 9, and 69% of responses for weekly texts-sent were rounded by participants to a single non-zero digit (e.g. 2, 20, 200).

7.2.5 Conclusions

Adolescents' estimation of their cellphone use indicated it was performed on a mental logarithmic scale. This is the first time this phenomenon has been observed in estimation of recalled, as opposed to observed, numerical quantities. Our findings provide empirical justification for log-transforming data for analysis. We recommend the use of the geometric rather than arithmetic mean when a recalled numerical range is provided. A point of calibration may improve recall.

7.3 Introduction

Using recalled cellphone data is problematic for case-control studies which are exploring a possible relationship between wireless phone radiation and health effects. This is because studies that have used this approach (Vrijheid et al., 2006b; Vrijheid et al., 2009a; Parslow et al., 2003; Inyang et al., 2009b; Aydin et al., 2011c) have routinely reported recall data as skewed and having a large estimation error. Rather than trying to explain this, there have been calls for caution in interpretation (Inyang et al., 2009b) and doubt expressed about the usefulness of recall data (Aydin et al., 2011c).

In 2009, we ran a survey of New Zealand adolescents' wireless phone use. We also found recalled use was positively skewed, with the distribution of recalled texts-sent being log normal. We had asked participants to estimate various aspects of their cordless phone and cellphone use, including the number of SMS-texts they sent daily, or weekly or monthly. They could estimate a range, if preferred. Many students chose to estimate the extent of their texting for all three periods. This led, serendipitously, to the findings presented in this paper.

During data entry we noticed a common tendency for individuals' weekly and monthly estimates to be absurdly low in comparison to their daily texting estimates. For instance, one participant estimated10 daily, 35 weekly, and 150 monthly, and another recalled 20 daily, 50 weekly and 150 monthly. At first, we thought this may reflect poor arithmetic skills, but one teacher had informed us that the class they had selected for participation was a top-stream one: students' science grades all exceeded 85%. Despite this, they showed the same estimation tendency. Consequently we explored the literature on magnitude estimation.

Magnitude estimation is a foundational area of research, currently considered in the field of neuroscience. In 1834, Weber observed what change in weight was needed for the person lifting it to notice. He realised that "the extent to which two stimuli can be discriminated is determined by their ratio" (Izard and Dehaene, 2008). Fechner developed this theory, "postulating that the external stimulus is scaled into a logarithmic internal representation of sensation" (Dehaene, 2003). These concepts came to be called the Weber-Fechner law whereby linear change in sensation (S) is proportional to the logarithm of the stimulus' magnitude (m): $S = k . \log (m)$, where k is a constant. It has been shown to apply generally to the way our senses perceive environmental stimuli (e.g. light intensity, volume, length). Over the last few decades, research has suggested that a logarithmic mental number line is also consistent with the estimation of observed numerical quantity (referred to as the numerosity) (Dehaene et al., 2008; Hollingsworth et al., 1991).

Here, we explore our data for indicators of the mental process behind estimating a number of past events – specifically, the extent of cellphone texting and cordless calls made weekly. We checked whether the consistent, but unexpected, tendencies we had observed in participants' texting estimates were explained by the Weber-Fechner law. We sought to find explanations for commonly observed features of recall and use these to inform correct analytical procedure in epidemiological risk analyses which use numerical recall data. Results based on such data provide indications of public health risk from environmental exposures or medical interventions, therefore it is important to minimise bias in the analytical methods and resulting inferences.

7.4 Methods

The methodology evolved during examination of the data. The analysis was undertaken using data from our cross-sectional survey of New Zealand adolescents' wireless phone habits. The study population has been described previously (Redmayne et al., 2011). Briefly, it was representative of the region for school type and decile (socioeconomic ranking of schools by their area), and included the capital city through to rural areas. Year 7 and 8 students (N=373; 207 male, 165 female, 1 transgender) from around the region participated. The median age was 12.3 years. There was an 85% participation rate. Ethical approval was given by the Victoria University of Wellington human ethics committee. Informed consent was obtained from principals of participating schools and parents of participating students. Students could choose to opt out.

7.4.1 Primary independent variables

We examined the following variables: recalled and billed weekly texts sent, pairs of recalled and billed weekly texts sent from those on 500 and 2000/month plans, and the estimated number of cordless phone calls made weekly.

Participants retrieved their remaining text balance on their prepaid monthly plan from their provider. This allowed us to calculate their daily actual use ('billed') pro rata by dividing the used portion by the number of days since billing, and multiplying this by 7 for the weekly rate.

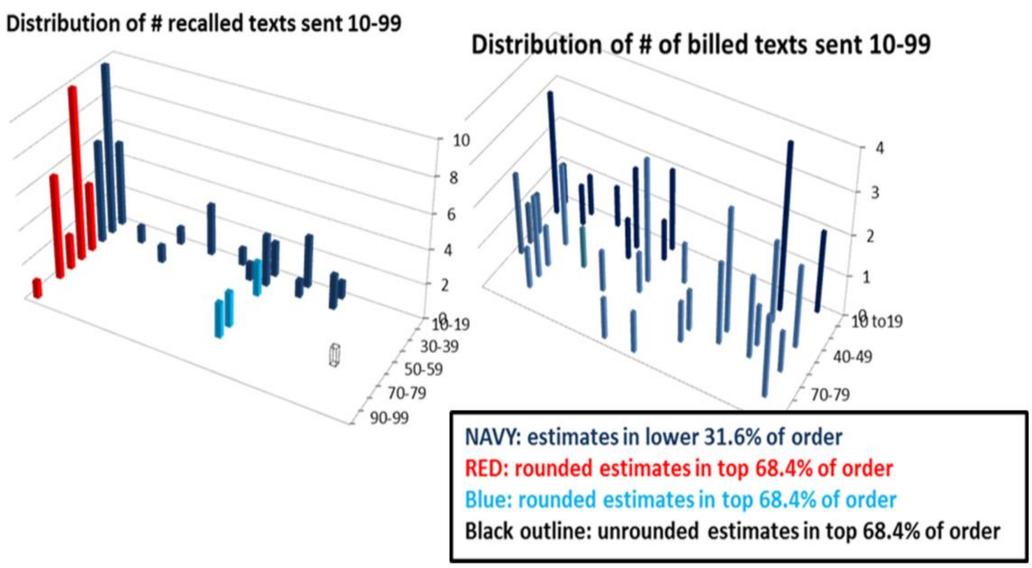
7.4.2 Statistical analyses

7.4.2.1 Distribution of the estimation data

We considered two aspects of the distribution of the estimation data. Firstly, that of the estimates themselves, both overall and within each order of magnitude, which could reasonably be expected to reflect the distribution of actual use. Secondly, that of the leading digits, which we would expect to be randomly and uniformly distributed if the mental processes involved in recollection were linear. Analyses were undertaken using the statistical programmes SPSS 17.0.1, Chicago, Illinois, 2008, and Microsoft Excel, 2010.

The distribution of estimated and billed weekly texts-sent was examined with cumulative distribution plots using raw and log transformed data. These raw text data were plotted on 3-dimensional column graphs (for the orders 1-9, 10-99, and 100-999) (2nd order of each at Figure 7.1). This was to enable us to examine the nature and extent of rounding within each order of magnitude, and the distribution of data across each order. We calculated the extent of rounding to fives/tens and fifties/hundreds in the 2nd and 3rd orders of magnitude, respectively. The percentage of datapoints in the lower 31.6% of each order of magnitude was calculated, 31.6% being the half-way point on a logarithmic scale for 10 (base 10; geometric mean (1,10) = √10 = 3.16). Regression plots were used to assess 'daily' versus 'weekly' and 'billed' versus 'estimated' texts sent. We checked whether there was a tendency toward over- or under-estimation with increasing numerosity (in the texting data) by regressing the difference of the log-recalled and log-billed against the log-billed. The explanation for this variation to the Bland and Altman approach (Bland and Altman, 1999) is given elsewhere (Redmayne et al., 2012b) .

Figure 7.1 Distribution of estimated and billed weekly texting data



(Figure on left) Distribution of weekly texting estimation data (second order): 61% of estimates fell in the lower 35% of the order, and there was a strong rounding effect. There were only three unrounded estimates in the upper 65% of all orders (1 in the second order). (Figure on right) Distribution of weekly billed texts (second order) shows a homogeneous distribution despite the overall data being log normally distributed; 36% of estimates fell in the lower 35% of the order All specific (i.e. non-range) estimates are shown, with columns representing the number of participants who gave each estimate. Read from the back-left across each row, working forward in rows.

We assigned the geometric mean to responses given as a range (explanation below); these were included in overall distribution reporting but excluded from digit analysis in this paper as we focused on specific estimates when exploring the mental process of estimation.
Valid zeros were included in reporting the overall distributions, but not in the calculations of mean and standard deviation of the log transformed data.

7.4.2.2 Distribution of the first digits in estimation data

We assessed first digit distribution in estimates of weekly texts-sent and cordless phone calls-made. For comparison, we did the same for a set of random numbers drawn from the same distribution. We began by removing all data given as a range, and all estimates of zero. We sorted those remaining into nine groups, one for each digit from 1 to 9. Each was then allocated into two groups: those with only a single non-zero leading digit (e.g. 2, 20, 200), and the remaining estimates starting with that digit (in the example case 2). These were displayed as stacked columns, with each 2-part column representing the percentage of estimates starting with that digit (Figure 7.2).

7.5 Results

7.5.1 Descriptive statistics

At least one cellphone was owned by 285 (76%) of participants, while 331 (89%) currently used one. Most participants had a cordless phone at home which they used (341, 91%). We retrieved paired estimated and billed texting data from 108 participants (38% of cellphone owners). Other relevant descriptive statistics can be seen in Table 7.1.

Table 7.1 Texting rates and percentage of texting estimations in the lower 31.6%* of each order

Estimated number of texts sent over different periods#				
	Daily	Weekly	Monthly	
Total N	248	240	247	
n (%) who provided a range	66 (27)	51 (21)	55 (22)	
Mean of estimated texts sent	37.04	146.90	643.44†	
Percentage of estimated and billed weekly texts in lower 31.6%* of each order of magnitude				
	n	Estimated	n	Billed
1st order (0-9)	40	50%	18	72%
2nd order (10-99)	71	48%	55	33%
3rd order (100-999)	74	58%	75	64%

Includes data given as a range with the geometric mean applied
†617.60 with top outlier excluded
* This represents the half-way point on a logarithmic scale
N.B. The 2nd order of magnitude is most relevant as there are no outside influences on the distribution. It is not clear whether first order values are estimated on a mental linear or logarithmic scale, and the third order is influenced by the group who had only 500 texts available monthly: their weekly estimates will fall in the lower half of the order, and are more likely to be less than about 150.

Figure 7.2 Distribution of leading digits in estimates of texting and cordless calls

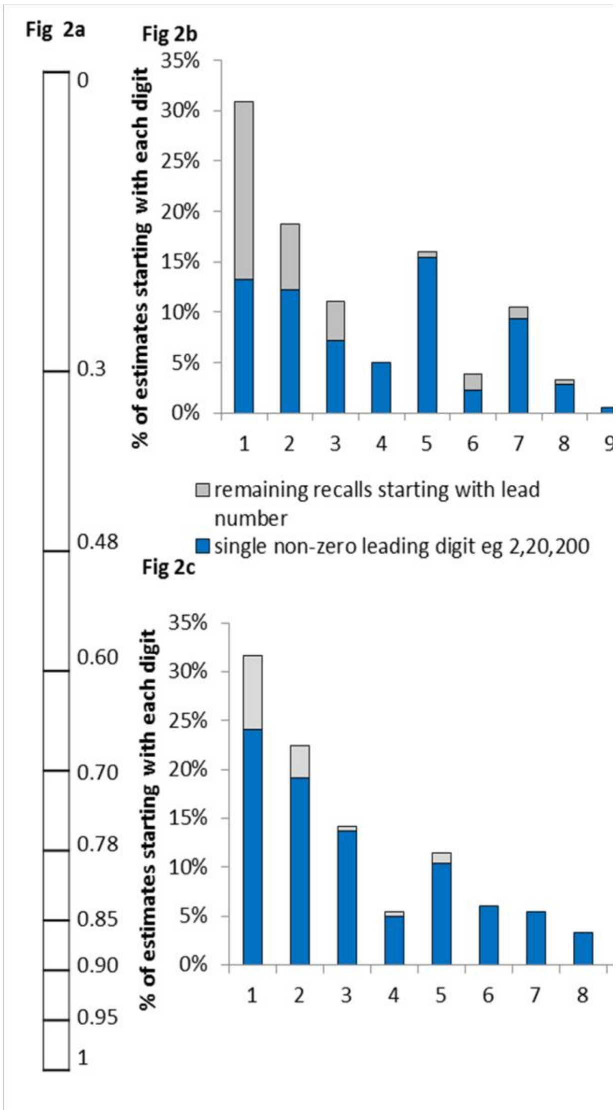


Figure 7.2a marks the distribution of 'tenths' from 0 to1 on a log scale (equivalent of 1-10 on a linear scale. 7.2b shows the distribution of leading digits of participants' estimated number of texts sent weekly, n = 181, range 1-1800, and 7.2c records estimates of cordless calls made weekly, n = 183, range 1-150. The columns add up to 100% of specific estimates made. All columns are split into participants' estimates with single non-zero digits (e.g. 2, 20, and 200) and the remaining ones for each leading digit (e.g. 23, 25, and 270)

7.5.2 Overall distribution of estimation data

Recalled estimates of recent texts sent were right skewed. The variance of estimates increased by a fixed ratio with increasing estimated numerosity. Once the data were log transformed, the regression of estimated daily-to-weekly texts became linear (Pearson's r 0.91 p <0.01) (Figure 7.3), showing a systematic tendency to underestimate use over a week compared to that estimated for a day. The log estimated to billed texts (Pearson's r 0.78 p<0.01) revealed a large, but homogeneous, variance of the residuals of log to log regression (random error).

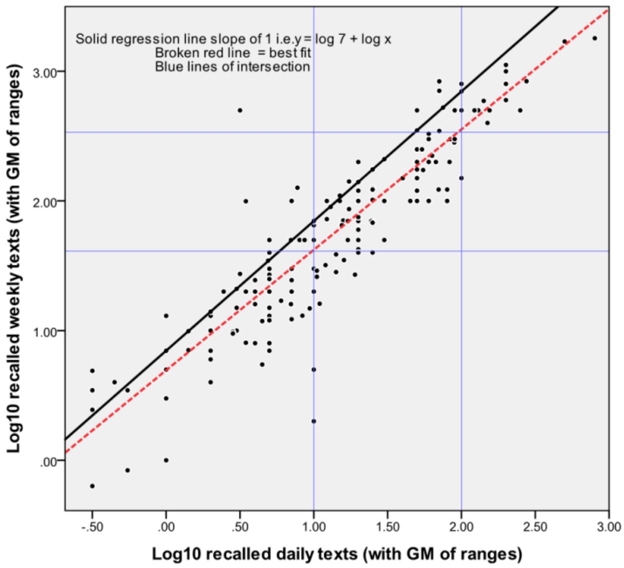


Figure 7.3 Regression of participants' weekly-to-daily texts estimates (log-transformed data).

The best-fit line indicates that on average weekly use is underestimated compared to estimates of daily use. For instance, on average, estimates of 10 or 100 daily were allotted 40 or 340 weekly, respectively (blue gridlines).

Log transformed data from all those who sent texts followed a normal distribution (not shown), while the influence of a plan with a known pre-paid quantity of texts monthly (500 or 2000) appeared to have a calibrating effect on daily and weekly estimates. This was evident in each plan's data, which had a distribution closer to exponential i.e. $f(b) \cong (1/\mu)\exp(-b/\mu)$ where μ was the population mean use, estimated by the sample mean. The mean of estimated texts sent weekly for the 2000/month plan fell within the 95% confidence interval of four times that of those with the 500/month plan.

Two types of systematic error existed in recall. The first resulted in a trend significantly different from zero, moving from overestimation by those who sent few texts towards underestimation by those who sent many (Figure 7.4). The second systematic error was apparent when comparing recalled texts sent over different periods (Figure 7.3). The ratios of individual recall (daily:weekly and daily:monthly) were both only a little over half that expected (0.58 and 0.54), while that of weekly:monthly was 0.90. This applied, both between and within participants, in data which ranged from 0 to > 1000.

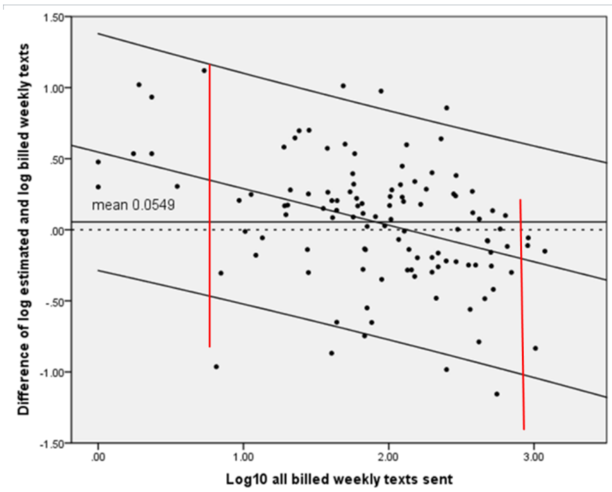


Figure 7.4 Bland and Altman plot displaying the difference of the logged estimation and billed weekly texting data against the log-billed.

Accurate estimates would all fall on the dotted line. There is a clear and significant trend from overestimation of little use to underestimation of extensive use. All lowest and highest estimates to the left and right of the red lines were too high/too low, respectively.

7.5.3 Distribution of estimated and billed texts within each order

About half or more of participants' estimates fell in the lower 31.6% of each order of magnitude (Table 7.1). This represents the half-way point on a logarithmic scale. The billed data was homogeneously spread (illustrated for the 2nd order of each at Figure 7.1). The 2nd order of magnitude is most relevant for comparison as there were no outside influences on its distribution.

7.5.4 Distribution of digits and rounding effect

The leading digits of texting and cordless phone-call estimation data were distributed very unevenly, with proportions of each digit from 1 to 9 resembling those of the intervals on a log scale (Figure 7.2a).

There were several rounding effects. Responses became less specific as numerosity increased within *each order* of magnitude, and as the leading digit increased from 1 to 9 (Figure 7.2b and 7.2c). Distribution of leading digits showed that 123 (68%) of weekly texting responses were rounded by participants to a single non-zero digit, as were 158 (86%) of cordless call responses.

There was an additional rounding-effect to final digits of 5 and 50 in the upper 68.5% of the 2nd and 3rd orders, respectively; these are visible as bright blue columns in Figure 7.1. Only three texting responses (5%) greater than 35 or 350 in the 2nd and 3rd orders, respectively, were not rounded thus, being 68, 525, and 839; for cordless phone calls, only 2 (15%) were not rounded (being 53 and 59).

We can only hypothesise about the spike in estimates starting with 5 and 7 (Figure 7.2b). An excess of leading fives is probably related to the rounding effect and is shown in fewer leading fours. (The same applies to almost no nines in preference for rounding to a final zero). However, the excess of leading sevens, may reflect a more linear approach from a quarter of those estimating 1, 10 or 100 texts daily, whose weekly estimates were 7 times greater. This explanation is supported by there being no excess of leading sevens for the estimated number of cordless phone calls weekly (Figure 7.2c).

Although 50% of first order texting estimates fell in the lower 31.6% (Table 7.1), we could not resolve whether the mental process for estimating very low numerosity is better described as linear or logarithmic, but speculate that the 1st order of magnitude is transitional towards the latter.

7.6 Discussion

We report for the first time that the way numerosity of recent events (specifically cellphone use) is recalled conforms to the Weber-Fechner law. In other words, there appears to be a mental logarithmic scale consistent with that found in estimation of observed numerosity. This provides a new direction for understanding human magnitude estimation, as, rather than a mental representation of an environmental stimulus, it is the outcome of an internally generated (i.e. recalled) stimulus.

Let us examine the evidence for this. Texting estimation data were very unevenly distributed, but with strong similarities in each order. Firstly, the majority of estimates fell in the lower 31.6% of each order, possibly related to a mental logarithmic scale, but also consistent with the estimations accurately representing the log normal or exponential distribution of the billed data. Secondly, there was a strong rounding effect; data were almost exclusively rounded in the upper 68.5% of each order, reflecting a logarithmic mental estimation scale. This is clearly visible in Figures 7.1 and 7.2. Further, the pattern of leading digits in the estimation data did not match that of leading digits of random numbers drawn from this distribution. This only occurred (in the first digit after the decimal) after log transformation.

If estimation were carried out linearly for data which, overall, formed a log normal distribution, then we might expect more than half of all estimates to be *evenly distributed* through the lower 31.6% of the full range 1 to 1000, with the balance being *evenly distributed* through the remainder. This is what we saw in the billed data (Figure 7.1).

The neuroscience literature describes a numerical magnitude effect: "discrimination of two numerosities of a given numerical distance becomes more difficult as the absolute values of the two sets get higher" p.4 (Nieder, 2005). Our data shows that this applies *within each order*. There needed to be an appreciable imagined difference (stimulus) in numerosity on a log scale for it to be acknowledged in the resulting estimate. This is evidenced in the rounding effect within orders. Testing of visual estimation of numerosity has generally been limited to the first two orders of magnitude (1-9, 10-99) so rounding appears only to be have been commented upon by Krueger (Krueger, 1982) who reported 89% of estimates being rounded to a last digit of 5 or 0 when participants were shown arrays of Xs numbering 25 to 300.

If the mental estimation process were linear we would expect all leading digits to be equally represented, but their distribution closely resembled the intervals of a logarithmic scale. This also applied to the distribution of leading digits in recalled cordless call data. Integers with single non-zero digits were vastly over-represented (Figure 7.2). Looking to the remaining digits in estimations, these were also far from evenly distributed. The rounding effect was so strong that estimates in the top 65% of the 2nd order were almost exclusively rounded to tens or fives (Figure 7.1), and in the 3rd order to hundreds or fifties. These effects are all consistent with estimation on a logarithmic mental scale.

Most of the phenomena we have reported are consistent with the estimation of *observed* numerosity, but estimation of *recalled* numbers of events over recent months has not previously been reported in the psychology literature. Estimation of observed numerosity is one of several foci of magnitude estimation. When these ratio-based estimations are log-transformed they become linear (Krueger, 1982). This mental process reflects logarithmically compressed number-neurons operating like a slide-rule by ensuring accuracy proportional to the size of the numbers being processed (Dehaene, 2003), thus maximising neuronal efficiency. In humans, this neuronal activity has been traced to the horizontal segment of the intraparietal sulcus (Piazza et al., 2004). It has been suggested that this logarithmic method of weighing the comparative value to ascribe to a large numerosity may be 'deeply embedded' as the default method in humans (Dehaene et al., 2008), a pre-linguistic in-born approach to number (Nieder and Miller, 2003).

The logarithmic mental process has been shown to result in increasing numerosity progressively being assigned proportionally lower comparative values, with high numbers commonly under-estimated (Izard and Dehaene, 2008). This applied to our data, that of Inyang et al. (Inyang et al., 2009b) and to the CEFALO study (Aydin et al., 2011b).

Hollingsworth et al. (Hollingsworth et al., 1991) reported the same tendency in a psychological test resulting in mean over-estimation of an array of <130 dots and under-estimation of large arrays up to 650 dots. Several cellphone studies have found the opposite tendency, with high values overestimated. Since much of the literature on magnitude estimation has adult participants, we doubt this 'reverse' trend is a feature of age, but suggest it may result from the elapsed period since that being recalled, as cellphone studies often ask participants to recall their phone use over periods up to ten years. The Interphone study reported greater over-reporting in this situation (Vrijheid et al., 2009a).

Psychological studies of observed numerosity-estimation have resulted in the hypothesis of a consistent variance of the residuals once the data are log transformed (Izard and Dehaene, 2008) thus providing a common probabilistic range at any given point on the line. We found this applied to recalled numerosity, as has been reported in other cellphone studies (Tokola et al., 2008; Vrijheid et al., 2006b). However, recalled estimation has an important difference from the visual estimation process as the variance of the residuals in recall estimation reported in this and other cellphone studies is routinely much wider than when numerosity is observed. It appears that this is a function of recall, introducing greater random error.

7.6.1 Implications for epidemiology

Our findings have implications for other cellphone studies and other epidemiological studies involving recalled numbers of events. A high proportion of rounded estimates could affect categorization. Specifically, if quantile-cuts occur at round-numbers (particularly those starting with 1 and 5), there may be many same-value digits. Forming cut-points before or after these would form irregularly sized quantiles. Arbitrarily allotting same values to different quantiles is not viable as it would return different results when analysed against other variables depending upon how the dataset was ordered prior to categorization. This would be true independent of sample size.

The mental process of estimation affects how given ranges of data should be averaged. The geometric rather than arithmetic mean is likely to align better with single value estimates as this is equivalent to averaging the logarithms of the values and back transforming.[42] It would thus avoid introducing bias which would occur by mixing specific estimates made on a logarithmic scale with the arithmetic mean of a range, which is appropriate for a linear process. The geometric mean would also be better when imputing missing central data between two provided estimates. Typically in cellphone research, these situations have been allocated the arithmetic mean or median (Cardis et al., 2007; Abramson et al., 2009; Aydin et al., 2011a). An example from our study of the possible outcome being strongly affected is when the range is wide and starts at a low number, for instance, 1-70. Here the arithmetic mean is 35.5, while the geometric mean is 8.37. A quarter of all weekly-text estimates were provided as a range. Recording their geometric means instead of arithmetic means resulted in the mean of all the data being 10% lower.

There is some evidence from the cognitive neuroscience literature that it may be possible to reduce recall inaccuracy by providing a calibration point (Izard and Dehaene, 2008). Variability in our study was smaller where participants knew the monthly maximum available on their account compared to those with no account. This also applied to two Interphone studies (Vrijheid et al., 2006b; Vrijheid et al., 2006c) where location questions may have acted as contextual prompts (Tokola et al., 2008). Variability was considerably broader in the MoRPhEUS study (Inyang et al., 2009b) where no prompts were given, and in the UK Interphone validation study (Parslow et al., 2003) which was conducted by postal questionnaire. The possible beneficial influence of a calibration point suggests that supplying participants in case-control studies with an accurate

[42] As an example of the better suitability of the geometric mean to the way people estimate, one student proffered a range of 1 to 6 hours cordless phone use daily. The arithmetic mean (AM) of the range is 3.5 hrs/day compared to the geometric mean (GM) of 2.45 hrs/day. When asked to provide daily estimates for a typical week, this student specified 1, 2, 1, 4, 0.5, 5 and 1 hours per day. The AM of this is 2.07. Clearly the GM of the given range is nearer the AM of the more closely specified averages.

record of their recent cellphone use may allow them to better judge their earlier levels of use. This could be tested in further research.

In summary, *recalled* numerosity of recent events appears to be processed in the brain in a very similar way as is *observed* numerosity. This finding extends the psychology literature on estimation of numerical quantity, and lends some predictability to epidemiological studies involving recalled numerosity: Numerical recall estimated on a logarithmic mental scale means that as numerosity increases, estimations reduce comparatively. This trend from over- to better- or underestimation in recall of the extent of recent events is of great importance for epidemiology, as is the large variance in the residuals of recalled data. If these aspects are not allowed for during analysis, it may introduce error or bias, leading to over- or under-estimation of relative risk for those with extremes of cellphone use. Bias or error may also be introduced as the high incidence of rounding could affect categorisation.

We offer some solutions. Firstly, the rounding effect and a logarithmic mental process imply that recalled numbers should be log-transformed prior to analysis. This is usual, but our study provides empirical justification. Secondly, recalled number-ranges and imputed missed data between given estimates are better represented by the geometric rather than arithmetic mean. And thirdly, informing study participants of their correct current level of use over a short period may improve estimation of use over somewhat longer periods. These steps should help reduce random and systematic bias in cellphone studies, but we anticipate will also be applicable to other research which relies on recalled estimations of recent numbers of events.

8 A forecasting method to reduce estimation bias in self-reported cellphone data

> "An AP reporter on the presidential campaign trail told me once [that] to get an accurate crowd estimate ask the organizer, divide that number by 2 and subtract a third."
> James Lynch, Fox News reporter

8.1 Background

The last chapter explained the mental process in recalling a number of events, and provided a few ways of reducing the introduction of bias into recall data at the data entry and analysis stages. However, it did not address the main problem that has led some to question the value of recall data: its inherent large estimation bias. Having both billed and estimated texting data meant it was possible to develop a model which would reduce this.

Basing the forecast model on a regression approach was untenable: the very large scatter in the data meant that high recall values produced seriously exaggerated forecast values. To overcome this, we took a Bayesian approach, incorporating genuine prior information about the billed data distribution along with the estimation data. Applying Bayes' theorem provides a "weighted compromise between the prior information and the sample data" (Stevens, 2009). This approach moderated the values forecast at the upper end.

This method is described below and should be applicable to recall data in other qualifying studies. The results are calculated numerically using a computer programme such as MatLab.

This chapter has been published as a research article in the *Journal of Exposure Science and Environmental Epidemiology* (Redmayne et al., 2013).

Citation details

Redmayne M, Smith E, Abramson M: **A forecasting method to reduce estimation bias in self-reported cell phone data**. *Journal of Exposure Science and Environmental Epidemiology* 2012(advance online publication 18 July 2012; doi: 10.1038/jes.2012.70).

The paper (as presented at the ICNIRP WHO conference in Ljubljana, 2011) had 1 citation in peer-reviewed journals as of 18 September 2012 (Aydin et al., 2011b) excluding self-citations.

8.2 Abstract

There is ongoing concern that extended exposure to cellphone electromagnetic radiation could be related to increased risk of negative health effects. Epidemiological studies seek to assess this risk, usually relying on participants' recalled use, but recall is notoriously poor. Our objectives were primarily to produce a forecast method, for use by such studies, to reduce estimation bias in the recalled extent of cellphone use. The method we developed, using Bayes' rule, is modelled with data we collected in a cross-sectional cluster survey exploring cellphone user-habits among New Zealand adolescents. Participants recalled their recent extent of SMS-texting and retrieved from their provider the current month's actual use-to-date. Actual use was taken as the gold-standard in the analyses. Estimation bias arose from a large random error, as observed in all cellphone validation studies. We demonstrate that this seriously exaggerates upper-end forecasts of use when used in regression models. This means that calculations using a regression model will lead to under-estimation of heavy-users' relative risk. Our Bayesian method substantially reduces estimation bias. In cases where other studies' data conforms to our method's requirements, application should reduce estimation bias, leading to a more accurate relative risk calculation for mid-to-heavy users.

8.3 Introduction

As time passes, cellphone use continues to increase and the age of first ownership continues to decrease (Mediamark Research & Intelligence, 2010). Concurrently, there is an ongoing debate about possible biological and health effects from exposure to cellphone microwave radiation which has led to calls for further research, especially regarding effects on children (World Health Organisation, 2010). Studies include those exploring whether cellphone use is associated with a variety of brain and neck tumours (Interphone Study Group, 2010b; Christensen et al., 2005; Hardell et al., 2005; Hardell et al., 2007; Hepworth et al., 2006; Lahkola et al., 2008). Such case-control studies evaluate participants' relative risk according to their extent of cellphone use, but these evaluations usually rely on participants' recall for extent of use.

Validation studies comparing recalled and billed data have shown that recall is notoriously inaccurate, introducing estimation bias. Both adult (Parslow et al., 2003; Vrijheid et al., 2009a; Vrijheid et al., 2006b) and adolescent data (Aydin et al., 2011a; Inyang et al., 2009b) have shown strongly right-skewed billed and recalled distributions. In each case, log transformation of recalled data has produced a Normal, or nearly Normal, distribution. However, there always remains a broad scatter of residuals indicating a large random error in recall. This random error has been shown to have a high impact on risk estimates towards a null effect (Vrijheid et al., 2006c). Another study has reported that random recall errors can lead to a large under-estimation in the risk of brain cancer associated with mobile phone use if the true odds ratio is greater than 1 (p. 380) (Vrijheid et al., 2009a).

This paper presents a forecasting method to reduce estimation bias using recalled data. It has been based on recall of the extent of adolescents' recent weekly SMS-texting.

8.4 Method

8.4.1 Setting and population

The method was developed using data collected in a cross-sectional cluster survey exploring wireless phone user-habits among adolescents (age 10.3 to 13.7, median 12.3 years) of the Wellington Region, New Zealand, carried out during 2009 (N=373). One randomly selected year-7 and/or -8 class from each of 16 schools across the region took part. Participation was 85% of those invited, comprising 55.5% male, 44.2% female and 0.3% transgender students. The sample was proportionately representative of the region's socioeconomic school ratings and school type: full primary, intermediate, year 1-13 and year 7-13; state/private; mixed/single sex; and secular/religious. Ethical approval was obtained from the Victoria University of Wellington human ethics committee, and informed consent was given by principals of participating schools and parents of participating students. All participants were asked to bring their cellphone to school on the survey day if they owned one.

8.4.2 Data collection

All survey sessions were completed during morning classes for uniformity. Participants who owned or regularly used a cellphone were asked to nominate their recent average daily, weekly, or monthly number of SMS-texts (texts) sent, or to provide a range if preferred. They were also asked to name their provider; their payment type; their texting plan, if any; and the billing date where relevant. Those with a fixed-price plan allowing up to 500 or 2000 texts-per-month (500 and 2000 plan) and who had their phone at school retrieved their remaining text allowance for the current month.. This service was available free-of-charge by calling or texting their provider. An automated response reported either, "As of (date) you have (number) texts remaining on (plan type)" or, "Your text balance is (number) and recurs on (date)", depending on the provider to which the participant subscribed. The data were used to deduce actual weekly use by dividing the number of texts sent in the current month by the number of elapsed days, then multiplying by 7. We assumed that errors in the actual (billed) rate of use were negligible i.e. actual use was taken as the gold-standard. Data of those with no text plan (n=36) and those on family plans (n=2) were excluded from development of the model. Note that data of those with no plan, where available, indicated negligible texting use.

8.4.3 Analysis of relationship between recalled and billed data

The primary exposure-metrics used were weekly $\log_{10}$ actual texts sent (billed) and weekly $\log_{10}$ estimated texts sent (recalled).

We measured the agreement between recalled and billed data by regressing the difference of the log-recalled and log-billed against the log-billed data. This adaptation of Bland and Altman's method (Bland and Altman, 1999) was preferred as one variable (billed) was known to be more accurate than the other (recalled), unlike the medical situations for which the method was developed. In this case, using the mean of the logs on the horizontal axis, as in the Bland and Altman approach, would introduce an unnecessary random error in the abscissa.

The regressed residuals were tested for homogeneity by applying F-tests to compare the variances of the outer quartiles and central 50% of the billed data.

We regressed the log-recalled against the log-billed data and obtained regression coefficients β_0 and β_1 for use in the Bayesian method.

Variability of use during the month since billing was checked by ordering billed data by days elapsed since billing, and examining the distribution of each tertile.

Analyses were undertaken using statistical programmes SPSS 17.0.1, Chicago, Illinois, 2008, and MatLab®, 7.1, Natick, Massachusetts, 2005.

8.4.4 Background explanation for our approach

Psychological literature on how people estimate a number of observed objects (known as the numerosity) suggests that this occurs on a logarithmic mental scale (Izard and Dehaene, 2008). Distribution of numbers and digits, and the extent of rounding, in our data indicated this also applies to recalled numerosity; the detail and psychological implications of this have been explored elsewhere (Redmayne, Smith and Abramson, under review)[43]. The evidence of a mental logarithmic scale guided the way we handled the data. Firstly, the geometric mean was assigned when a participant provided a recalled range of use; if the range began with zero, 1 was added to enable the calculation. The data thus treated was used for all analyses, the regression model and the Bayesian method. Secondly, we log-transformed the data to obtain the regression for the Bayesian method. Log transformation is commonly employed prior to analysis, but the evidence that number recollection takes place on a mental logarithmic scale provides an empirical justification for doing so.

8.4.5 Development of a regression model and Bayesian method

A regression model and Bayesian method were developed using the weekly data of those with the 500 and 2000 texts-per-month plans, and with these data pooled. Billed zero use was entered as 1 (2 participants) to allow viable log-transformation.

An inverse linear regression forecast model was first tested with log-transformed data, using

$$\log(b) = (1/\beta_1)(\log(r) - \beta_0) \tag{1}$$

where (*b*) is billed texting rate and (*r*) is recalled, and β_1 and β_0 are the regression coefficients after regression of log(recalled) against log(billed). This approach, also known as statistical calibration, uses the estimated relationship between responses *r* and a reliable covariate *b* to infer the values of unknown *r* from recorded *b* (Jones, 2008) (Jones, 2008). The inverse approach [equation (1)] was

[43] Subsequently published: REDMAYNE, M., SMITH, A. & ABRAMSON, M. 2012. Patterns in wireless phone estimation data from a cross-sectional survey: what are the implications for epidemiology? *BMJ Open,* 2.

used because regression of billed against recalled use violates the assumptions of linear regression as recalled use had considerable error.

We then adopted a Bayesian approach, which has been successfully used elsewhere in epidemiology (Thomas et al., 2007). This method incorporates problem-specific contextual information; in this case, it is the prior distribution of the billed data. We used Bayes' rule:

$$f(b \mid r) = \frac{f(b,r)}{f(r)} = \frac{f(r \mid b) f(b)}{f(r)} \qquad (2)$$

to calculate the distribution of billed use (*b*) conditional on recalled use (*r*), where the functions *f* are probability density functions (pdfs), conditional ($f(r \mid b)$ *r* given *b*, $f(b \mid r)$ *b* given *r*) and unconditional, single ($f(r)$, $f(b)$) and joint $f(b,r)$, of recalled and billed data. $f(b)$ is the prior, $f(r \mid b)$ is the likelihood function, and $f(b \mid r)$ is the posterior.

$f(r \mid b)$ is provided by the regression of log *r* on log *b* assuming Normal errors in the log *r* residuals with mean zero and variance σ^2 estimated from the regression residuals. Forecasts of *b* are taken as the medians of $f(b \mid r)$, and 95% credible intervals for the forecast values are provided by the 2.5 and 97.5 percentiles of $f(b \mid r)$, all determined by numerical integration of $f(b \mid r)$ (equation 2) to get the percentiles. It is required that the distribution of the billed values $f(b)$ be known (or approximated) but not the distribution of the recalled, because $f(b \mid r) f(b)$ is normalised to integrate to unity (numerically integrated). Because we had analytical expressions for the priors (exponential, lognormal), simulations were unnecessary.

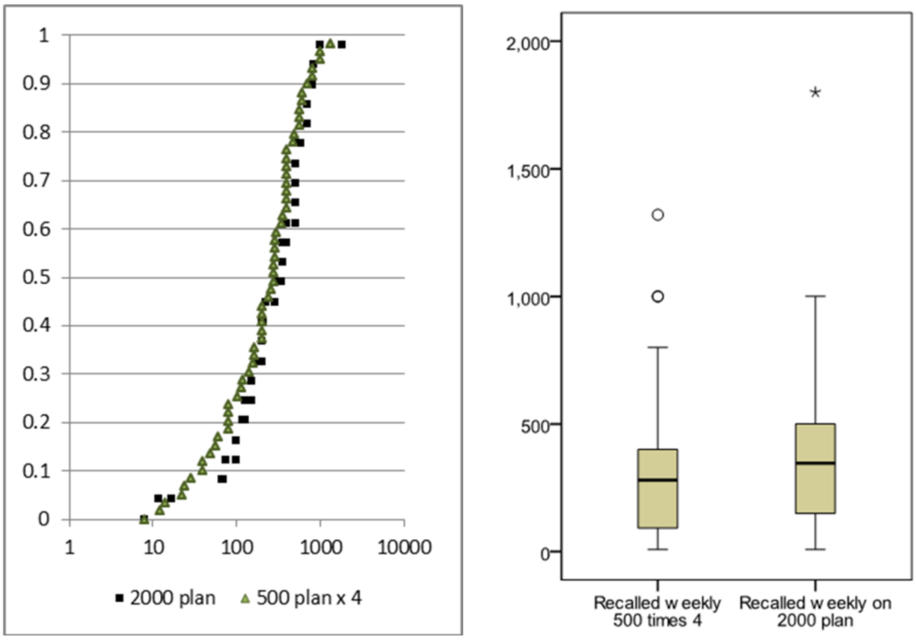
This forecasting method was based on the following requirements: 1. log transformed recalled data were linearly related to log transformed billed data; 2. residuals were Normal and had a common variance i.e. the scatter was independent of billed use; and, 3. the number of days since billing did not significantly ($p<0.05$) affect levels of use. 4. The distribution of billed use $f(b)$ is known or can be approximated. Forecast modelling was undertaken with MatLab®.

8.5 Results

8.5.1 Participation

At least one cellphone was owned by 285 (76%) participants; 201 (70.5%) cellphone owners had a texting plan, 189 (94%) of these with a 500 or 2000 texts/month plan. Paired 'recall' and 'billed' data for weekly use by these plan-holders were available from 108 participants: 59 on the 500 plan, and 49 on the 2000 plan. The two groups shared the same distribution of data (Figure 8.1a); the mean of the 2000 plan fell within the 95% confidence interval of four times the 500 plan (Table 8.1, Figure 8.1b). A range of recalled use was provided by 24 participants (22%) in the pooled groups, while the remainder were specific. We chose three datasets to illustrate our method: the weekly data from the 500 and 2000 plan datasets, and the combined set of 500 and 2000 plan weekly data.

Figure 8.1 (a) Cumulative distribution, and (b) box and whisker plots, of $\log_{10}$ transformed recalled SMS texting data for 4x500 plan and 2000 plan.



N.B. No-one subscribed to both plans.

Table 8.1 Descriptive and weekly texting statistics from paired 'recall' and 'billed' data for those on 500 and 2000 texts/month plans.

N[1]	*SMS Texting Plan*	*Age range (median)*	*Mean billed texts sent (95% CI)*	*Mean recalled texts sent (95% CI)*	*Bland & Altman Slope*[a,b] *(Regression-based 95% CL)*
32/27	500/month x 4	11-13.2 (12.3)	79.97 (57, 103) 319.88 (228, 412)	78.42 (60, 97) 313.68 (241, 386)	-0.387 (-0.543, -0.230)
18/31	2000/month	10.9-13.1 (12.5)	344.24 (265.7, 422.8)	388.91 (293.7, 484.2)	-0.412 (-0.630, -0.194)

[1] Participants providing paired billed and recalled data, by gender (male/female) [a] Log_{10} data. [b] Billed use on horizontal axis (see figure 8.2) .

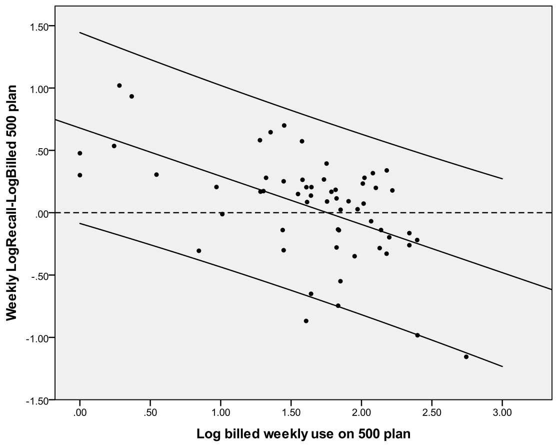
8.5.2 Accuracy, variability and trend of recall

Data were right skewed, consistent with having an exponential distribution (see 8.5.3) Log_{10} transformation resulted in a slight left skew. It also linearised the relationship between recalled and billed data (2-tailed $r = 0.721$, p 0.01).

Residuals of recalled weekly data used for the Bayesian method had a homogeneous variance of scatter with respect to billed value (variance ratios Q2+3:Q1 F=1.23, p=0.28; Q2+Q3:Q4 F=1.41, p=0.165; Q1:Q4 F=1.15, p=0.36). We assumed the residuals to be normally distributed (J-B 2.12, p=0.34) (Jarque and Bera, 1987).

Mean recalled use fell within the 95% confidence interval of mean billed use (Table 8.1). However, this was less important than a trend from over-estimation to under-estimation, apparent as the billed use increased. As this trend was significantly different from 1, it indicated that regression-based 95% limits of agreement should be adopted (Bland and Altman, 1999) (Figure 8.2). Variability was large with a 95% multiplicative error factor of 5. This means, for example, that for a billed use of 100, 95% of recalls would range from 20 to 500.

Figure 8.2 Difference between the $\log_{10}$ recalled and billed weekly SMS texting data versus $\log_{10}$ billed use for (a) 500/month and (b) 2000/month plan holders



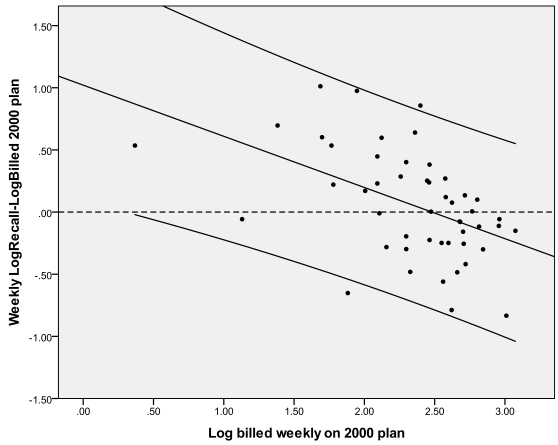


Figure 8.2a Figure 8.2b

Tables include regression lines and 95% confidence intervals (following from Bland and Altman, 1999). For significance, see text.

All participants who provided billing data had had 3 or more days since billing. Variation in the extent of use according to days that had passed since billing was not statistically significant (p<0.05).

8.5.3 Distribution of the data

It is common to treat cellphone data as having a log-Normal distribution, which was approximated in our pooled data (Figure 8.3a). However, both billed and recalled single plan data more closely fitted an exponential model (Figure 8.3b). (i.e. $f(b) \cong (1/\mu)\exp(-b/\mu)$ where μ is the billed use population mean, estimated by the sample mean). The similarity of the recalled and billed distributions suggests that if only the recalled distribution is available, it could be substituted for the billed distribution in the Bayesian method.

Figure 8.3 Cumulative probability distribution for billed and recalled data (stairs), and best-fitting log-normal and exponential models for the billed (curves).

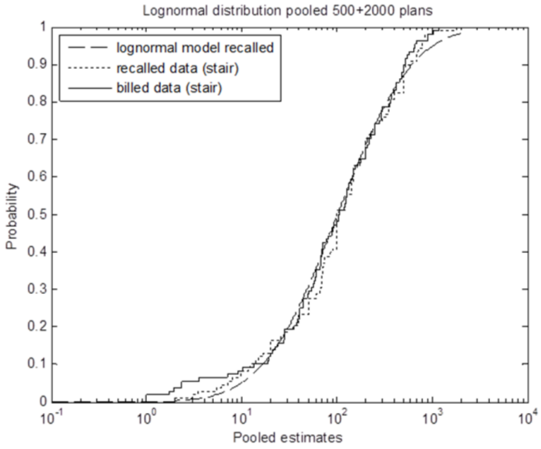


Figure 8.3a

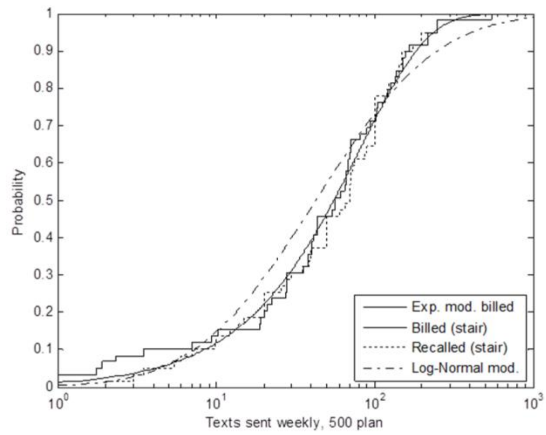


Figure 8.3b

(8.3a) Shows the pooled 500 and 2000 texting plan data and (8.3b) the 500 plan alone. In both cases, an exponential model for recalled use is indistinguishable from the billed model.

8.5.4 Mental process behind recall

Recall data revealed a pattern of reporting digits and an extent of rounding which indicated that recall of numbers was logarithmic in nature, rather than linear. In addition, as the number (of texts/minutes/calls) being recalled increased, assigned values were lower proportionally than those expected. This is apparent in the trend seen in figure 8.2a &b.

8.5.5 Forecasting method

The inverse linear regression model resulted in upwardly biasing the top ~50% of forecast values by up to a factor of 6. For example, the highest recalled weekly texting value of 1800, with corresponding billed value of 250, yielded an inverse linear forecast billed value of 4800 for the pooled dataset (Figure 8.4b, c).

Figure 8.4 a, b and c compare the inverse regression forecast model and Bayesian forecast method for both 500 and 2000 plan (exponential data distribution), and the pooled data (log Normal distribution)

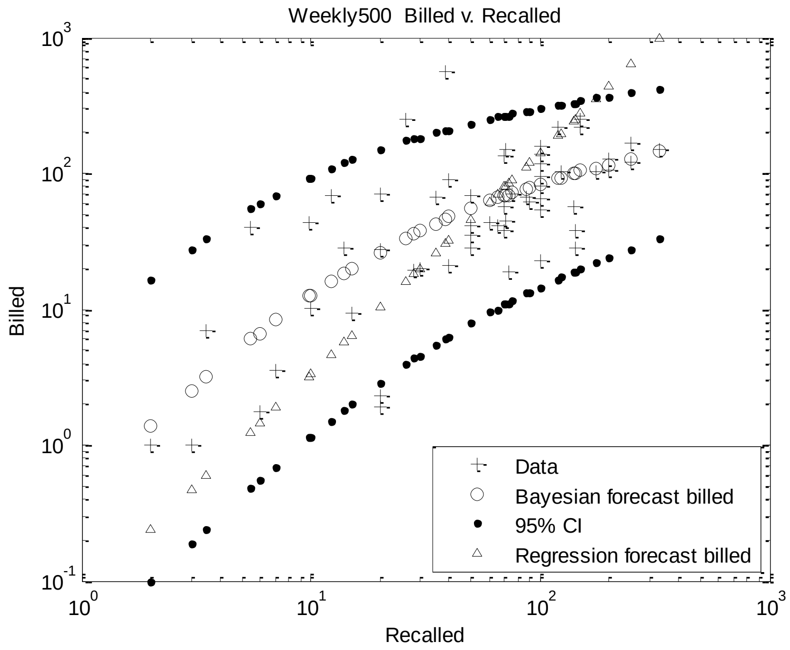


Figure 8.4a

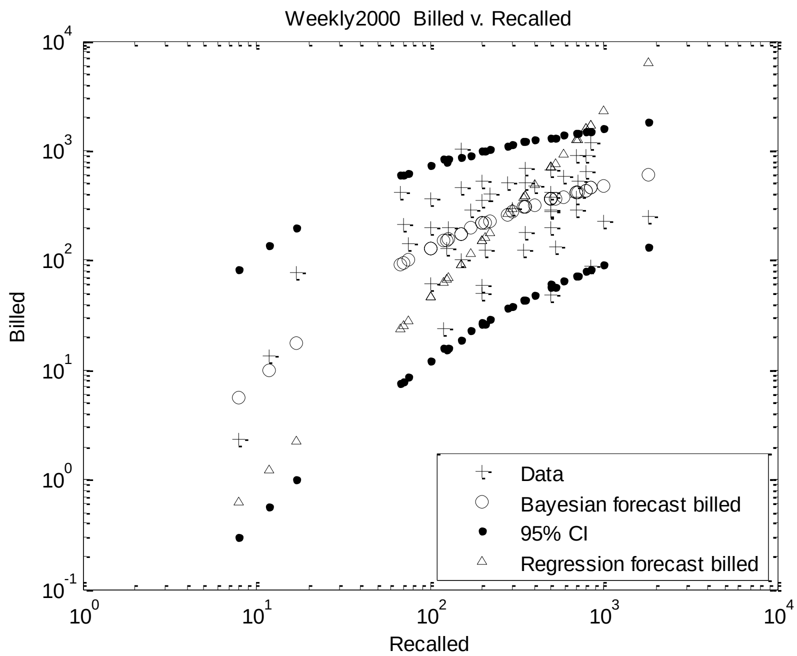


Figure 8.4b

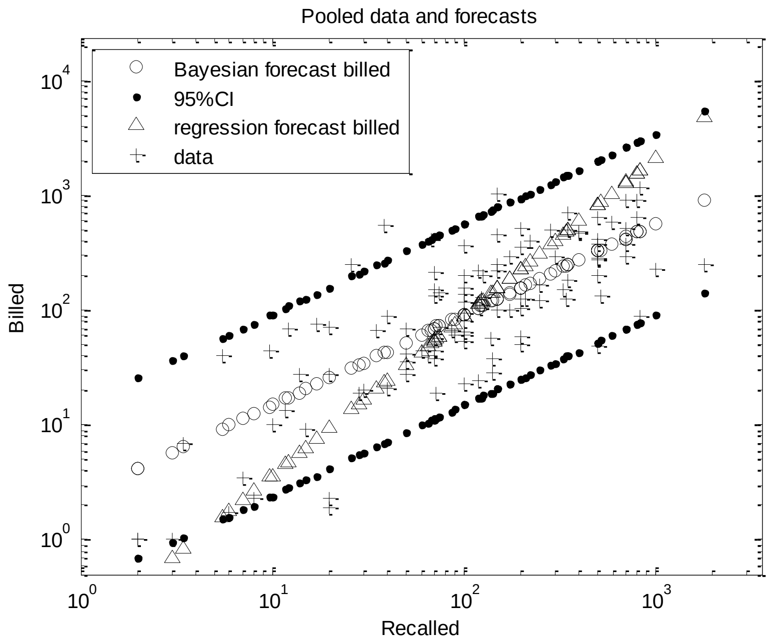


Figure 8.4c

Data points are shown for comparison. Note the high regression forecast values from heavy recalled use. Bayesian forecast uncertainties are represented by 95% credible intervals.

The forecast was therefore calculated using the Bayesian method. Figures 8.4a, b and c compare the Bayesian forecasts with inverse regression forecasts and the data for the 500 plan 2000 plan and pooled data respectively. Bayesian forecast uncertainties are represented by 95% credible intervals. The previous example with a recalled value of 1800, returns a much improved forecast value of 912 using the Bayesian method on the pooled dataset.

8.5.6 Applying the method

Providing the prior distribution of the billed (actual) data is known or can be approximated, other cellphone studies may apply this method. The similarity of the billed and recalled distributions for each of the 500, 2000 and pooled datasets, suggest that it may often be possible to use the distribution of recalled for the prior distribution of the billed.

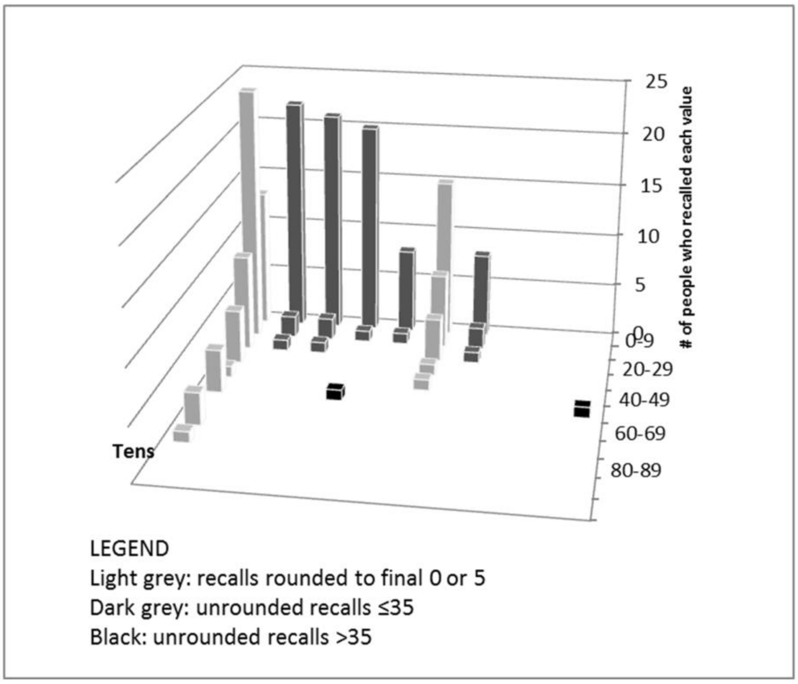
8.6 Discussion

This paper is the first to present a Bayesian method for reducing estimation bias in recalled cellphone text data. In cellphone studies, the broad scatter of recall data poses a real problem, potentially seriously affecting risk calculations. Our method offers a possible solution.

This method has been developed to reduce estimation bias which arises from the large random error inherent in recalling numerosity; this error has been observed in the recall of cellphone use in all studies that have gathered data this way. We developed the method using texting data, but the use of a logarithmic mental scale for recalling numerosity was equally apparent in the recalled weekly number of cordless phone calls made (Figure 8.5). There is a considerable body of literature on the mental process of estimation numerosity not naturally being linear (reviewed in part by Brannon (Brannon, 2006), and in more recent research, much of it involving Izard and Dehaene, e.g. 2008 (Izard and Dehaene, 2008)).

There are other factors that are worth consideration. The first is the influence of a known pre-paid number of texts, and the second is the short period over which average use was recalled.

Figure 8.5 Recalled number of cordless calls made weekly.



The location of each bar represents a specific quantity of calls made; the height represents the number of people who recalled that quantity. Numbering starts at the back left, and works across rows with ten to each row (see scale 0-89), to the highest recall on the chart of 80 (there were also 2 of 100 and 1 of 150, not shown). If recall were on a linear mental scale, we would expect columns in each row to be randomly and uniformly distributed.

Knowing the pre-paid number of texts available monthly (500 or 2000) might be expected to influence the accuracy of recall by providing a point of calibration, even though extra texts could be sent at extra cost. This appears to have been borne out: despite the two groups in our study comprising different participants, the estimates of those with the 2000 limit were, on average, very close to 4 times that of those on the 500 limit. There is also evidence in the psychology literature to support this suggestion (Krueger, 1984). Many participants in other studies may also have had a calibration point, provided by the number of monthly calls they made being itemised in their monthly bill. Indeed, this may be one reason why recall of the number of calls generally has less variability of recall than their duration (Inyang et al., 2009b; Parslow et al., 2003; Vrijheid et al., 2009a; Vrijheid et al., 2006b). This concern is one reason that we based the method on weekly rather than monthly recall. There is little restraint on upper-end use over the course of a week, as demonstrated by 26 (24%) plan-holders using more than a quarter of the plan allowance in that time. One of these used the whole allowance of 500 in a week, while recalled use was 30-50. Overall, despite knowing their monthly pre-paid plan allowance, the random recall error for weekly use was still high.

Our study asked participants to recall their most recent month's use; even recall this recent displayed a large variability. We would expect the variability to be even larger where recalled used is from a period of several years. The important point is that the wider the scatter in recall, the more necessary it becomes to use an approach other than regression. This is because a large error in recall increasingly biases forecast values positively as the recalled quantity increases. The essence of this is demonstrated in figure 8.4. The larger the variability, the greater this introduced error. It is inevitable that the upper end of such a regression model will be greatly overstated where the variance is large. If these predictions are then used to calculate relative risk, it will be under-estimated.

The magnitude of scatter is consistent with other cellphone studies so is not a result of our particular dataset. Since heavy use is of most interest in terms of assessing a possible relationship with brain tumours or other health problems, it is vital that a forecast method should not exaggerate this, particularly since doing so could lead to under-estimation of relative risk for heavy users.

A Bayesian approach overcame this problem, and is applicable whether or not a systematic error (causing increasing over- or under-estimation) is present. The method transformed recall data into a distribution of 'actual' data that matched well the billed data within the 95% Credible Interval. These forecast values can then be used to evaluate relative risk.

Our independent study has several strengths. Paired billed and recalled data were available for a reasonably large proportion of the main study's cellphone owners. Missing recalled values were not imputed. Data collection and data entry were carried out by the first author thereby eliminating inter-rater-error. Further, the sample group was representative on several fronts (see *2.1)*.

There were some limitations in the survey. One consideration is the accuracy of the gold-standard, which was dependent upon participants correctly reporting the information they retrieved from their provider. However, risk of error was low. Another consideration is the possibility of others' use of the phone. This was not asked about. The analysis assumes everyone interpreted the questions similarly, although this may not be the case (Dillman, 2000).

Two international case control studies currently underway will examine risk factors for brain tumours in young people. One is MOBI-KIDS, following and modelled on the Interphone study published in 2010 (Interphone Study Group, 2010b), considering those aged between 10 and 24 years. Validation of recall accuracy will be needed for this age group. The other is CEFALO which is considering children aged 7-19 in 4 European countries (Feychting, 2006). Results giving brain tumour risk have recently been published (Aydin et al., 2011c); these were calculated using data collected in categories and conditional logistic regression models. Although we have presented reasons why our method could successfully be used by studies asking participants to recall numerosity of phone calls, the current study was undertaken with texting data. This remains a limitation. We recommend that studies such as those named above seek to validate our method for use with recalled phone call duration or number of calls made and received.

In conclusion, a regression model using log-transformed data greatly exaggerated inferred upper-end use due to a wide variability of recalled cellphone use. The wider the variability, the greater this effect is. If this model were relied on to calculate tumour-risk from cellphone use, it would lead to under-estimation of relative risk for heavy users. A Bayesian approach resolved this. If cellphone exposure increases the risk of negative health impacts, it is heavier use that seems likely to provide evidence of this, but only if the methodology used is not itself introducing bias towards the null. We anticipate that other studies could apply our method in this and possibly other epidemiological circumstances (such as medical studies) where participants' recalled data involving numbers are available and the method's requirements are met.

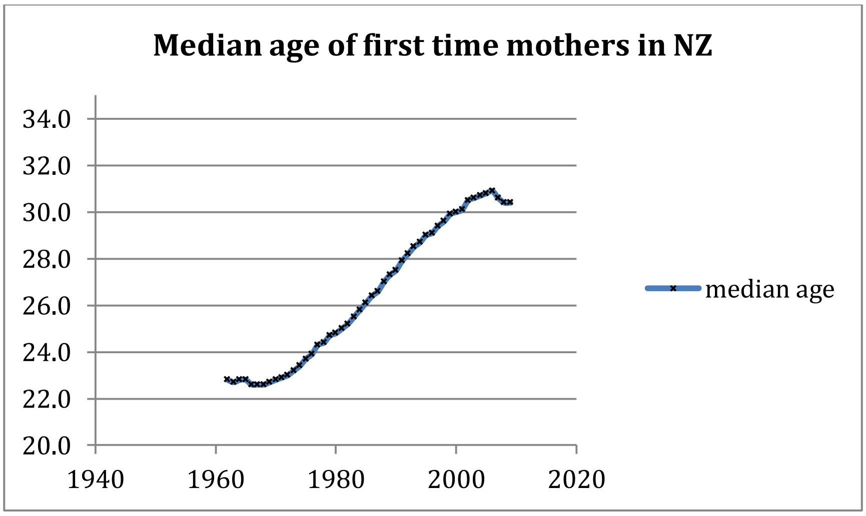
9 Well-being with relation to adolescent wireless phone use

"When one is concerned with the mysterious and wonderful functioning of the human body, cause and effect are seldom simple and easily demonstrated relationships."
p.170 (Carson, 1965)

9.1 Background

As we saw in the chapters 5 and 6, students' use of cellphones in the lap or pocket may prove to be risky behaviour for their long-term health, but effects on future fertility can only be conjecture at this stage. Due to the common practice of delaying motherhood until the early thirties (Figure 9.1) (Statistics New Zealand, 2009), and fatherhood until the age of 32, on average (Welch, 2010), it is too early to embark on research with those who are trying to conceive and who have used cellphones since they were in early adolescence.

Figure 9.1 Median age of first time mothers (current relationship) in New Zealand.



Data source, Statistics New Zealand (Statistics New Zealand, 2009)

This chapter asks whether recent and current wireless phone use is related to everyday well-being. Aspects considered were headaches, tinnitus, feeling down or depressed, and various sleep parameters: trouble falling asleep, waking in the night, and feeling tired at school.

The chapter has been submitted as a paper: Redmayne, M., Smith, E., & Abramson, M. The relationship between adolescents' well-being and their wireless phone use.

This chapter provides a fuller version, apart from section 9.4.1 which has been shortened to reduce repetition within the thesis.

9.2 Abstract

Objective

To ascertain associations between New Zealand adolescents' subjective well-being and self-reported use of, or exposure to, wireless telephone and wireless internet technology.

Study design

In this cross-sectional survey, participants completed questionnaires in class time. Parental questionnaires provided data on WiFi and cordless phone model. Data were analysed with logistic regression adjusting for common confounders. Odds ratios were calculated per 10 minutes or 10 calls.

Results

The duration and number of cellphone and cordless phone calls were associated with increased risk of trouble falling asleep (ORs 1.08 to 2.58) and frequent headaches (ORs ranged from 1.08 to 3.08). The latter became significant at ≥15 minutes' cordless phone use daily (OR 3.27 (1.28, 8.32)). Being woken by the phone at least weekly was strongly related to chronic headaches (OR 5.89) and daily tiredness at school (OR 3.19 (1.90, 5.30).

Cordless but not cellphone use was associated with chronic tinnitus (ORs 1.13 to 1.27) and feeling chronically down/depressed (OR 1.13). Using any cellphone headset was associated with frequent headaches (OR 3.40) and wireless headsets were associated with regularly feeling down/depressed (OR 3.22). All cordless phone frequencies and modulation types except 2.4GHz and frequency hopping modulation were related to sleepiness at school. Waking nightly was five-fold less likely for those with WiFi at home.

Conclusion

Cellphone and/or cordless phone use was associated with increased risks of many outcomes except daytime tiredness. Tiredness was related, however, to being woken by the phone, and to particular cordless phone operating frequencies or systems, possibly indicating frequency- or

modulation-dependent effects. To safeguard young people's well-being, I suggest limiting use of wireless phones, with or without headsets, to < 15 minutes daily.

9.3 Introduction

Radiofrequency (RF) communication devices are constantly offering new options, and young people are making the most of them. Several official bodies and researchers have expressed caution about possible health outcomes of young people's increasing exposure to RF and the accompanying extra low frequencies resulting from modulation. These concerns are due to the young usually having a higher susceptibility to environmental 'toxins' and stressors. Discussion among the research community on how best to convey this concern[44] has been affected by caution about how to raise risk awareness among parents without causing alarm when scientific uncertainties remain (Polzl, 2011). Polzl concluded that it is necessary to take particular consideration of children when communicating risk related to cellphone use. Although several countries have issued warnings suggesting reduced use of cellphones by children as a precautionary measure, New Zealand has not followed suit. There are still limited studies of general health and well-being outcomes of young people's exposure to cellphones, cordless phones, or WiFi.

Health is "a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity" (World Health Organisation, 1948). One basic requirement for general well-being is sufficient good quality sleep. For children aged 9 or 10 years, owning a mobile phone has been associated with settling to sleep after 9 pm, with a quarter of the age group getting <10 hours sleep regarded as necessary to maintain good health (Heins et al., 2007). Preliminary results of a 4-year longitudinal study of mobile communication use by children aged 7-12 years identified related trends including increased fatigue (Grigoriev, 2012). A European study found tiredness among teenagers associated with increasing cellphone use after lights out, with odds ratios of 1.8 for use less than once a month to 5.1 for more than once weekly (Van den Bulck, 2007). Fatigue was also reported by participants in a German study of 8-12 year olds which measured all daytime RF exposures. In this case no statistically significant positive correlation was

[44] Risk communication was discussed at a conference titled NIR & Children's Health co-organised by ICNIRP, WHO, COST Action BM0704, German Federal Office for Radiation Protection (BfS), and the European Society for Skin Cancer Prevention (EUOR*SKIN*), May 2011 in Ljubljana.

found between RF exposure and fatigue or other chronic symptoms (Heinrich et al., 2011). However they did report reduced sleeping problems, significant in the 3rd exposure quartile [2nd highest]. The study did not adjust for the location of wireless phones or cordless phone base in relation to the bed, or for having WiFi at home.

Subjective reporting of headaches related to cellphone use has received some attention, with several studies finding an increased risk of headache with increasing call duration or exposure (Söderqvist et al., 2008; Hillert et al., 2007; Chia et al., 2000). Headaches were included in 8 of the studies in a recent meta-analysis (n=737) and were found to be marginally associated with RF (Augner et al., 2012). The standardised mean group difference for headache after exposure compared to no exposure was 0.08 and 95% CI -0.02 to 0.18. This inconclusive pooled effect warrants further study.

Other symptoms that have been described with RF exposure include chronic tinnitus (Hutter et al., 2009) and depression (Johansson et al., 2010). High mobile phone use has been associated with depression one year later, although the authors do not refer to RF exposure (Thomée et al., 2011) and this case may reflect an inverse relationship.

Thus, we asked New Zealand adolescents about sleep problems, sleepiness, headaches, tinnitus, feeling down or depressed, or having a painful texting thumb. We examined whether there was any association between these disorders and young adolescents' self-reported use of or exposure to wireless technology. We refer to cellphones and cordless phones collectively as wireless phones.

9.4 Methods

9.4.1 Participants and setting

A cross-sectional survey exploring wireless phone user-habits among adolescents of the Wellington Region, New Zealand, was carried out between mid-June and October 2009. Subjective well-being and lifestyle questions were asked towards the end of the questionnaire. There was the option to provide written comments.

Parental and participant questionnaires for this study were adapted from those used in the MoRPhEUS study (Abramson et al., 2009). Some symptoms measuring well-being were drawn from the WHO *Health Behaviour In School-aged Children* (HBSC) checklist (headache, feeling low, sleeping difficulties) (Haugland et al., 2001). I ran both parents' and student pilot sessions to identify and resolve wording that needed clarification.

Parental questionnaires asked for their participating child's date of birth and sex, ownership of a wired landline phone and cordless phone, cordless phone make and model, and whether they had WiFi at home. The cordless phone's make and model data were used to ascertain the frequency range and system of each phone, e.g. 2.4 GHz and DECT, respectively. Students' socio-economic status (SES) was taken as being that of the school decile rating.

Exposure variables were self-reported cordless and cellphone use, the use and type of cellphone headset, cordless phone frequency and modulation, and having a WiFi transmitting device near the bed (including through the wall). The number and/or duration of phone use for calls were collected as self-reported continuous data.

Outcome variables provided data on whether over the previous month, participants had had trouble falling asleep, been waking up in the night, been tired during school, and whether they had had headaches, been feeling down or depressed, experienced tinnitus, or had a painful texting thumb. Possible confounding influences we considered were age, sex, the socioeconomic rating of the school (SES), having recently had a cold or flu, usual bedtime, exercise levels, weekend viewing/gaming hours, TV in the bedroom, the number of times woken weekly by the cellphone, and cellphone storage and carrying habits. Age, the number of times woken by the phone, and the time of settling to sleep were continuous variables. Socioeconomic rating was grouped into decile 1-3, decile 4-7 and decile 8-10.

9.4.2 Statistical methods

Associations between outcome variables and possible confounders were assessed with Pearson Chi square tests. Those with $p<0.1$ were included in logistic regression models used to assess RF associations; this level was selected at the preliminary stage to ensure including those of marginal significance. Continuous exposure variables were split into tertiles to assess the influence of age, sex and SES using Pearson Chi square tests.

Outcome variables were dichotomised at each breakpoint, the three variables made thus represented yes : no weekly; ≥ 3times : fewer times or never weekly; and most days/nights : fewer times or never weekly. Unconditional logistic regression models were fitted for cellphone and cordless phone use, use of wired or wireless cellphone headset, wireless broadband at home, and the frequency and system of the cordless phone. Confounding variables were included as described above. Other outcome variables were not included as possible confounders to avoid colinearity.

Two approaches to logistic regression were tried.

The first tested for multicollinearity among all RF-related (independent) variables. Lack of collinearity was assumed if tolerance values were >0.2 (Menard, 1995), Variance Inflation Factor (VIF) values were <10 (Myers, 1990) and variance proportions of Eigenvalues < 0.25 were < 0.50 (Pedhazur, 1997). If there was more than one variable with variance proportions >0.50 and Eigen value < 0.25, only one from any row was included in the logistic regression model, being that with the largest variance proportion when clearly larger than the others, or the most appropriate for the outcome being tested where they were similar. Linearity of the logit was tested. Binary stepwise logistic regression was undertaken using statistical programme SPSS 19.0.1 (SPSS Inc., Chicago, Illinois, 2008). Models for each dependent variable were built including all RF-related variables (except those excluded through the multicollinearity testing), and all plausible confounders and those with a Pearson Chi-square p <0.1. This value was chosen to ensure not excluding those with apparently borderline significance. Dependant variables were not included as possible confounders. Where the model returned significance values >0.5, I removed the variable and re-ran the analysis. This method was abandoned due to complexity from allowing for collinearity. Resulting odds ratios for those completed using both approaches did not differ much.

The second method, which was the one adopted, used unconditional logistic regression. Confounders were included as indicated by the first method. Each best model was selected as that with the smallest Akaike information criterion (AIC). When there were models with the same AICs (and, necessarily, the same number of participants (n) in each), that with the best positive predictive value (PPV) or the highest Nagelkirke R-square value was selected.
Results were regarded as significant at the 95% level (p<0.05). Those symptoms experienced at least weekly over the preceding month I refer to as regular, three or more days weekly as frequent, and five or more days weekly as chronic.

All logistic regression models were tested with sex, age and decile; strongest models often did not include them.

9.5 Results

9.5.1 Descriptive

There were 373 participants: 207 male (55.5%), 165 female (44.2%) and 1 transgender (0.3%). One invited student chose not to participate. The mean age was 12.3 years, ranging from 10.4 years to 13.7 years. The participation rate was 85%. We collected data for age, SES, and gender from all participants. Between 0.3% and 6.4% of data were missing from questions related to phone use. Only 139 (37%) WiFi responses were returned by parents. Parental responses specific enough to obtain cordless phone frequency and modulation system were received from 41% and 39%, respectively, although 75% provided some information.

More than three-quarters (n=285, 76.4%) of participants owned a cell phone (23 of these owned two). A further 12.8% reported regularly using someone else's. Most (91%) participants reported using a cordless phone at home, and 47.5% had a wired landline (10% did not respond). There were analogue and digital cordless phones, the latter utilising DECT, DECT6, WDECT, WDSS, DSS, and FHSS modulation, each determining the way the signal is delivered in terms of radiofrequency and time. I categorised these in two groups: analogue , DECT and DECT6, and the remainder. The frequency ranges were 30-40 MHz and 900 MHz, 1.8 and 1.9 GHz, 2.4 GHz, and 5.8 GHz. I grouped the first two pairs for analysis to provide sufficiently large categories. Particular frequencies are not exclusive to each type of modulation system.

In New Zealand, Universal Mobile Telecommunication System (UMTS), also called 3G (2.1 GHz), was launched in August 2005 by Vodafone. Telecom launched theirs in May 2009, using the 850 MHz bandwidth for urban areas, and 2.1 GHz for rural. A third provider, 2 degrees, was launched in August 2009 in New Zealand. This was after the collection of data from 10 of the 16 schools. Their 3G bandwidth is 2.1 GHZ (urban) and 900 MHz (rural).

9.5.2 Relationships between symptoms and wireless phone use

A selection of statistically significant logistic regression results of self-reported wireless phone use and well-being outcomes are presented in Tables 9.1 and 9.2, in which odds ratios (OR) for wireless calls or minutes refer to each 10 calls or 10 minutes, respectively. Statistically significant associations were detected in 31 of 190 models (16.3%). The full results enabling comparison of ORs for differing prevalence of symptoms is at Appendix 6. Two to four participants chose not to answer the well-being questions.

Applying the Redmayne et al. forecast method (Redmayne et al., 2013) had the effect of slightly reducing ORs that were previously greater than 1 and narrowing the 95% confidence interval (CI) (Table 9.3). An OR of 1 remained the same, but the confidence interval narrowed. The extent of the effect in each case can be seen by comparing this with relevant rows in the supplement to Tables 9.1 in Appendix 6. Key findings are described below.

9.5.2.1 Headaches

Headaches were related to calls on both cordless phones and cellphones. For the former, this was statistically significant with ≥15 minutes' use (OR 3.27 (1.28, 8.32)) after allowing for confounding factors. The number of times woken in the night had a significant impact on headache prevalence.

9.5.2.2 Tinnitus

Chronic tinnitus was associated with the number and duration of cordless phone calls, as were cordless phones which operated on 1.8-1.9 GHz and 5.8 GHz. There was no significant association with cellphone use. Socio-economic status, as represented by low, medium or high decile ranking of the school, was significantly inversely related to chronic tinnitus (table 9.4).

9.5.2.3 Feeling down or depressed

There was no association between use of either phone type and feeling down or depressed occasionally, but the extent of daily cordless phone use carried an increased risk of chronically feeling down or depressed. Age, the use of a wireless earpiece and the number of times students were woken in the night by their cellphone were important confounders.

Table 9.1: Self-reported well-being symptoms and the use of wireless phone equipment estimated by unconditional logistic regression.

	Numbers in categories where applicable	Numbers with symptom /Total	Unadjusted OR (95% CI)	Adjusted [d] OR (95%CI)	Confounders in model [e]
Frequent Headaches (≥3 days weekly)					
Cordless minutes [a]	n/a	43/338	**1.09 (1.03, 1.16)**	**1.08 (1.01, 1.15)**	Cold/flu; sex; **times woken**
Cordless minutes in tertiles	<3 minutes daily N=100 3-14 minutes daily N=107 ≥15 minutes daily N=102	39/309	**Sig 0.005** **1.37 (0.50, 3.75)** **3.65 (1.48, 9.00)**	1 1.29 (0.47, 3.50) **3.27 (1.28, 8.32)**	Cold/flu; sex; **times woken**
# long cellphone calls [b]	n/a	45/347	**2.38 (1.02, 5.57)**	**2.51 (1.03, 6.14)**	Cold/flu; sex; **times woken**; cellphone location at night
Any cellphone headset	326 no headset 29 use headset	44/355	**3.74 (1.58, 8.85)**	**3.40 (1.27, 9.15)**	Cold/flu
Wireless cellphone headset 342 without: 13 with (3+ days)	342 no/wired headset 13 use headset	44/355	**4.86 (1.5, 15.6)**	**7.13 (2.07, 24.51)**	Cold/flu; sex
Chronic Headaches (most days) Cordless minutes [a]	n/a	16/338	**1.09 (1.00, 1.18)**	1.08 (0.99, 1.18)	Cold/flu; sex
# long cellphone calls [b]	n/a	16/347	2.38 (0.93, 6.07)	**3.08 (1.09, 8.69)**	Cold/flu; sex
Regular tinnitus (at least weekly) Cordless frequency	29 No cordless use 19 with ≤ 900 MHz 27 with 1.8-1.9 GHz 52 with 2.4 GHz 18 with 5.8 GHz	57/145		1 **3.41 (1.03, 11.28)** Not sig Not sig 2.4 (0.64, 9.04)	**Cold/flu**; times woken
Frequent tinnitus (≥3 days weekly) Cordless frequency	29 No cordless use 19 with ≤ 900 MHz 27 with 1.8-1.9 GHz 52 with 2.4 GHz 18 with 5.8 GHz	20/145		1 Not sig 3.74 (0.63, 22.11) Not sig **6.56 (1.06, 40.44)**	Cold/flu; times woken

Chronic Tinnitus (most days) # long cordless calls [b]	n/a	29/348	**1.24 (1.01, 1.51)**	**1.27 (1.03, 1.57)**	Cold/flu; times woken; **decile**
Cordless calls made & received [b]	n/a	30/353	**1.13 (1.02, 1.26)**	**1.13 (1.02, 1.26)**	Cold/flu; times woken; **decile**
Regularly Feeling Down/Depressed (at least weekly) Wireless cellphone headset	343 no/wired headset 13 wired headset	231/356	3.09 (0.99, 9.66)	**3.22 (1.01, 10.25)**	Cold/flu; age; use of wireless earpiece
Cordless frequency	27 No cordless use 20 with ≤ 900 MHz 27 with 1.8-1.9 GHz 53 with 2.4 GHz 18 with 5.8 GHz	97/145	**3.5 (0.99, 12.36)**	**1** **4.14 (1.13, 15.14)** Not sig Not sig Not sig	Cold/flu; times woken; age; use of wireless earpiece
Chronically Down/Depressed (most days) Cordless minutes [a]	n/a	6/355	**1.15 (1.05, 1.28)**	**1.13 (1.00, 1.29)**	**Times woken; age**
Any cellphone headset	326 no headset 29 use headset	6/355	**12.42 (2.39, 64.65)**	**7.31 (1.01, 52.87)**	**Times woken**
Wireless cellphone headset	342 no/wired headset 13 use wireless headset	6/355	**3.22 (1.01, 10.25)**	**23.45 (3.03, 181.07)**	**Times woken**
Regularly sore texting thumb (at least weekly) Billed texts [c]	n/a	35/148	1.01 (1.00, 1.03)	**1.02 (1.001, 1.04)**	**Cold/flu**
Cordless minutes [a]	n/a	57/337	**1.06 (1.00, 1.13)**	1.04 (0.97, 1.11)	**Time in pocket**; cold/flu; location at night; sex
# long cordless calls [b]	n/a	62/348	**1.34 (1.10, 1.62)**	**1.26 (1.02, 1.54)**	Time in pocket; **cold/flu**; **location at night**
Cordless calls made & received [b]	n/a	63/353	**1.15 (1.04, 1.26)**	**1.14 (1.03, 1.26)**	Time in pocket; **cold/flu; location at night (OR 4.1 under pillow)**
Cellphone calls made & received [b]	n/a	63/349	**1.39 (1.06, 1.82)**	**1.38 (1.02, 1.87)**	Time in pocket; **cold/flu; location at night OR 4.2 under pillow)**

[a] Per 10 daily; [b] Per 10 weekly; [c] Per 10 texts sent (subscriber data); Statistically significant results in **boldface**. [d] All models were tested with sex, age and decile; strongest models sometimes did not include them; [e] confounders with significant OR are in **bold font**

Table 9.2: Self-reported sleep-related symptoms, wireless phone use and WiFi exposure estimated by unconditional logistic regression.

	Numbers in categories where applicable	Numbers with symptom /Total	Unadjusted OR (95% CI)	Adjusted [c] OR (95%CI)	Confounders in model [d]
Trouble falling asleep ≥3 times weekly					
Cordless minutes [a]	n/a	259/331	**1.08 (1.02, 1.25)**	**1.08 (1.01, 1.15)**	**Time of light out**, sex, **decile**
# long cordless calls [b]	n/a	264/341	**1.26 (1.05, 1.51)**	**1.21 (1.01, 1.45)**	**Time of light out**
# long cellphone calls [b]	n/a	265/342	**2.33 (1.00, 5.50)**	**2.58 (1.00, 6.67)**	**Time of light out**, sex, decile
Trouble falling asleep ≥3 times weekly (reduced dataset)**					
# long cordless calls**	n/a	255/331	**1.25 (1.04, 1.50)**	1.19 (0.99, 1.43)	**Time of light out,** sex, decile
# long cellphone calls**	n/a	255/331	2.35 (0.99, 5.59)	1.81 (0.81, 4.06)	**Time of light out**
# combined long cellphone and cordless calls**	n/a	255/331	**1.26 (1.06, 1.49)**	**1.21 (1.01, 1.44)**	**Time of light out**
Wake in the night at least weekly					
Cellphone calls made & received [b]	n/a	170/344	**1.40 (1.02, 1.81)**	**1.36 (1.002, 1.85)**	**Woken by phone, sex,** cold/flu, time of light out
Wake in the night most nights					
WiFi at home	69 no wifi 66 have wifi	15/135	**0.22 (0.06, 0.83)**	**0.19 (0.05, 0.74)**	Age, cold/flu, TV in bedroom
Tired during school at least weekly					
Cordless frequency	28 don't use cordless 20 have ≤ 900 MHz 25 have 1.8-1.9 MHz 52 have 2.4 GHz 18 have 5.8 GHz	109/143	1 **4.25 (1.01, 17.90)** **3.94 (1.07, 14.52)** 2.25 (0.85, 5.98) **6.00 (1.15, 31.23)**	1 **5.38 (1.16, 25.01)** **4.98 (1.22, 20.23)** 2.13 (0.75, 6.04) **7.88 (1.37, 45.50)**	**Time of light out; cold/flu;** times woken by phone; age
Cordless system	29 don't use cordless 39 DECT 42 WDECT, DSS 27 Analogue	103/137	1 **3.89 (1.24, 12.16)** 1 .77 (0.65, 4.78) **4.06 (1.11, 14.80)**	1 **4.69 (1.42, 15.42)** 1.75 (0.63, 4.89) **4.69 (1.23, 17.93)**	Time of light out; cold/flu

[a] Per 10 daily; [b] Per 10 weekly; Statistically significant results in **boldface;** [c] All models were run with sex, age and decile; strongest models sometimes did not include them; [d] Confounders with significant OR are in **bold font,** those in regular font improved the model but were not in themselves statistically significant; ** This category was reanalysed to examine combined use; the numbers in the model had to be reduced to remove those with missing data (see text)

Table 9.3 Logistic regression results resulting after applying the forecast method to reduce estimation bias.

FORECAST METHOD APPLIED	N†	OR (95%CI) At least weekly	OR (95%CI) ≥3 weekly	OR (95%CI) Most days
Headache				
# long cellphone calls¶	347			**2.82 (1.24, 6.38)**
Feeling Down/Depressed				
Cordless calls made & received	353		1.00 (0.99, 1.02)	
Sore texting thumb				
Cellphone calls made & received	349	**1.35 (1.12, 1.78)**		

Same models used as in table 9.1 and Appendix 6, but with RF values resulting from applying the forecast method (Redmayne et al., 2012b) to the participants' estimates

9.5.2.4 Sleep and tiredness

Tiredness at school was the only well-being variable that had no statistically significant relationship with cellphone or cordless phone use, having WiFi at home, or with using cellphone headsets. However, having a cordless phone with any frequency except 2.4GHz and modulation type except Frequency Hopping ones was associated with an increased risk of daytime tiredness up to almost 8-fold. Fifty seven families had a 2.4 GHz cordless phone, 41 had one that used Frequency Hopping protocol, and 26 of these had both. As well as age, sex, decile, and having had a cold or flu in the last month, other confounders that were controlled depending on the model were light out time for the 'trouble falling asleep' variable, having a television in the bedroom and being woken by the cellphone for the 'waking in the night' variable, and light-out time, television and times woken by the cellphone for the 'tired during school' variable.

An important finding was that being woken by the cellphone was strongly related to daily tiredness at school (OR 3.19 (1.90, 5.30)) (Table 9.4).

Almost a fifth of all participants had trouble falling asleep three or more times weekly, and the later they settled down to sleep, the higher the odds of this being a problem (Table 9.4).

9.5.2.5 Wired and wireless headsets and symptoms

The use of wired or wireless cellphone headsets was significantly associated with frequent headaches and chronically feeling down or depressed. They were not statistically significantly associated with the measured sleep-related parameters or tinnitus although there were some positively related ORs. There were some significant findings related to specific cordless phone radiofrequencies or modulation

9.5.2.6 WiFi and symptoms

Having WiFi at home did not statistically significantly increase risk for any of the measured outcomes. There was a 5-fold decreased risk of waking most nights for those with WiFi at home.

9.5.2.7 The effect of considering both cellphone and cordless phone use

I tried to examine the effect of including use of both phone types in an analysis. I chose to examine the number of long calls made and received as this question was asked for both phone types and one where I anticipated that an increased effect from combined use would be readily apparent. I chose the category of 'three or more headaches weekly' as this had significant results for both phones separately (see table 9.1). There was some difficulty due to missing data in one or other category. In order to compare like groups, the variables for 'long cellphone calls made and received weekly' and 'long cordless phone calls made and received weekly' were copied and a third one made which combined the other two. All participants that had data missing in any of these variables were excluded for this analysis; in this way all three variables had a full set of data, but the numbers were reduced to 331 from 342. The results are included in Table 9.2. Each was modelled including the time the light was turned out at night (which always had a significant impact), sex, decile group, age and the number of times woken in the night. The last one was included in case some participants interpreted the question as trouble falling asleep after being woken, although when tested without it made little difference. Only the first three remained in the strongest models.

In this new analysis with reduced numbers, the odds ratio for combined use was higher than for cordless phone use alone, but lower than for cellphone use. The likely reason is very low use of the cellphone for long calls. Specifically, only a quarter of the 345 students made ten or more long calls each week in total, and of these only 28 made more than 1 of them on a cellphone. One outcome of this was that the data were unsuitable for categorisation as in order to achieve different values in each category of the long cellphone calls variable, too many categories had to be made for the size of the database to support.

Note that the original analyses that included data from more people had more significant positive associations with having trouble falling asleep.

9.5.2.8 Relationship between symptoms and confounding variables

Several confounding variables were related to well-being outcomes (Table 9.4) and were therefore included in the logistic regression models. In particular having tinnitus most of the time was inversely related to SES, and boys were more likely than girls to be tired every school day.

Chronic trouble falling asleep was positively related to the lateness of settling to sleep (OR 1.12 (1.06-1.17) per 10 minutes after 7pm).

Many participants reported having headaches at least weekly (37.5%) over the last month. One or two headaches weekly were strongly associated with having a cold or flu in that period, but less so for those with more frequent headaches. The data collection took place in early- to mid-winter during an influenza pandemic, perhaps explaining 59% having had a cold or flu within the month before the survey.

Tinnitus and feeling down or depressed were also common (38% and 35%, respectively) at least weekly, as were tiredness at school (77%), trouble falling asleep (48%) and waking in the night (50%).

9.6 Discussion

This study found many significant associations between the reduction in young adolescents' self-reported general well-being and their extent of exposure to RF emitting technology, after taking several other factors into consideration. This 16% of the logistic regression analyses is more than could be expected by chance alone (5%). The well-being outcomes fell into two groups: one related to physical or emotional pain (headache, tinnitus, feeling down or depressed, or having a painful texting thumb), the other related to sleep and sleepiness (trouble falling asleep, waking in the night, and being tired at school). These symptoms are relatively common, even among the young, and have many causes, several of which we controlled for.

Table 9.4 Sample relationships of confounding variables and well-being symptoms.

Confounding variable	Symptom	N	OR (95%CI)
Cold/flu in last month	Headache+	370	2.50 (1.57, 3.99)
Cold/flu in last month	Down/depressed‡	369	2.38 (1.04, 5.45)
Cold/flu in last month	Tired at school‡	368	2.07 (1.29, 3.32)
Cold/flu in last month	Sore texting thumb+	368	2.49 (1.31, 4.75)
Woken by cellphone at least weekly	Headache‡	356	4.70 (2.38, 9.29)
Woken by cellphone at least weekly	Chronic Headaches	356	5.89 (1.89, 18.30)
Woken by cellphone at least weekly	Down/depressed‡	355	2.42 (1.14, 5.12)
Woken by cellphone at least weekly	Tinnitus‡	355	2.46 (1.33, 4.56)
Woken by cellphone at least weekly	Tired during school‡	354	3.19 (1.90, 5.30)
SES*	Tired during school+	368	
Low			0.40 (0.18, 0.87)
Mid			0.59 (0.34, 1.01)
High			1
SES	Tinnitus#	368	
Low			1
Medium			0.17 (0.05, 0.57)
High			0.41 (0.15, 1.08)
Sex	Trouble falling asleep+	369	
Boys			1
Girls			1.97 (1.29, 3.00)
Sex	Wake up in the night+	369	
Boys			1
Girls			1.57 (1.04, 2.38)
Sex	Tired during school#	368	
Boys			1
Girls			0.51 (0.30, 0.88)
Time of light out, per minute after 7pm	Trouble falling asleep‡	363	1.008 (1.003, 1.012)
Phone location at night	Headache+	361	
Another room			1
By bed			1.95 (1.20, 3.15)
Under pillow			0.98 (0.43, 2.22)
Distance from eyes for bed-texting	Headache+		0.96 (0.93, 0.99)

* Socioeconomic status; +Regular; ‡Frequent; #Chronic

Each model controls for sex, age, and SES, and is estimated by unconditional logistic regression

9.6.1 Cellphone and cordless call associations

Both cellphones and cordless phones were, in some cases, associated with an increased risk of compromised well-being, but in other cases the symptoms were only related to one or other phone type. In some cases, the association appeared to be related to a specific RF carrier frequency or possibly the related extra low frequencies.

The duration and number of both cordless and cellphone calls consistently indicated an increased risk of having frequent or chronic headaches, and frequently having trouble falling asleep. In the peer-reviewed literature, the most consistently reported well-being association with wireless phone use has been headache (Hillert et al., 2007; Chia et al., 2000; Söderqvist et al., 2008). Söderqvist et al. reported a similar increased headache incidence as I found (but among older teenage cellphone and cordless phone users), with a somewhat higher odds ratio for use >15 minutes daily compared with less than this (Söderqvist et al., 2008). A possible explanation of the apparent link between headache and cellphone use is the involvement of the blood-brain barrier and the dopamine-opioid systems of the brain in headaches, both of which have been linked to RF exposures similar to those from cellphones (Frey, 1998).

The GSM talk mode has been identified elsewhere as stimulating intracortical excitability (Ferreri et al., 2006). My finding of delayed sleep onset (trouble falling asleep) was also shown by Hung et al. (Hung et al., 2007), but not by Danker-Hopfe et al. (Danker-Hopfe et al., 2011).

There are other possible explanations for trouble falling asleep. It may be that the stimulation of conversation or its content might impact on sleep-readiness. This may then provoke headaches due to sleepiness.

The connection between headache prevalence, tiredness at school and being woken by the cellphone at night is an important one. Daytime tiredness and headache are both likely to impact negatively on students' ability to learn effectively at school. Storing cellphones (and other transmitting devices) away from bedrooms overnight would remove this source as a reason for broken sleep.

The extent of use of both phone types was related to having a sore thumb, with a higher risk related to lengthy cordless calls than the number of texts sent. This result was unexpected. If it had only been related to texting it would have suggested a simple mechanical effect such as repetition strain injury, but no such action is involved in lengthy calls. The cause could not be identified in this study, but may have been the angle or grip on the handset, or the RF exposure. The RF from the back of a handset where the thumb often lies is often higher than from the front (unpublished results, Redmayne, 2009).

The only well-being factor affected by cellphone use alone was waking at least once during the week (the number of calls made and received weekly). This finding needs to be considered in light of the number of *long* cellphone calls having an inverse, although not statistically significant relationship, with waking, suggesting it may be a statistical co-incidence.

Several well-being parameters had an increased risk only from cordless phone use. This may be partly due to the cordless phone being considerably more popular than either a cellphone or wired landline for making long calls (see chapter 5). For instance, the use of a cellphone or cellphone headsets (either wired or wireless) had no statistically significant association with tinnitus. However cordless phone use was associated with a significantly increased risk of chronic tinnitus.

Some studies have failed to find a link between cellphone or cordless phone exposure and tinnitus (Frei et al., 2012; Mortazavi et al., 2007), but one found an association with years of cellphone use on the side tinnitus was experienced (Hutter et al., 2009). The current results indicated increased risk from some, but not all, cordless phone carrier frequencies and modulation protocols. This is the first study to take these aspects of cordless phone exposure into account, suggesting previous negative findings may have been biased towards the null by not doing so. Frequency and modulation effects are discussed further below.

Constantly feeling down or depressed was also only related to cordless phone use, not cellphone use (although there was an association with the use of either sort of cellphone headset.) Only six participants reported feeling chronically down or depressed so this category needs to be interpreted with caution; for instance, it may be that feeling down or depressed went along with a tendency to ring a friend for a long talk. It is worth noting though that prevalence was proportionally tenfold higher in those who had a headset than those who did not.

As reported elsewhere (Mohler et al., 2012), I found no significant associations between cellphone or cordless phone use and being tired at school. However, here also there was a statistically significant increased risk depending upon particular cordless phone carrier frequencies and modulation protocols, discussed below.

9.6.2 WiFi

The only well-being indicator significantly related to having WiFi at home was a reduced likelihood of waking in the night. At the time of my survey, New Zealand home WiFi systems operated in the 2.4 GHz or 5.8 GHz range, using a frequency-hopping modulation. Both result in a 10Hz extra low frequency (Kühn and Kuster, 2006). I note that 10 Hz falls within the alpha range of brain activity typical of a sleepy state encountered when resting (Hung et al., 2007).

This variable had a low response (< 50%) and the distribution is not properly representative of the whole group, so this is a tentative result.

9.6.3 Frequency-dependent associations

A few associations with well-being were frequency-dependent. Since the exposure from both WiFi and cordless phone bases is passive, in that they are always transmitting irrespective of whether they are being used, the most likely explanation is the RF frequency exposure. Although exposures from DECT and WiFi are low to very low (WiFi exposure is orders of magnitude below the thermal threshold), measurements taken by the bed in an Austrian study indicate values were up to 1400 times higher in those with the cordless base nearest the bed (Tomitsch et al., 2009). Joseph et al. reported that WiFi (without data traffic) and DECT cordless phone and base emissions were the dominant RF contributors indoors: 3.4% and 28.9%, respectively (Joseph et al., 2012).

Daytime sleepiness (fatigue) showed a significantly increased prevalence with all types of cordless phone at home *except* those operating on 2.4 GHz and those using a frequency-hopping system. Frequency hopping systems are quite different than others as they utilise a wider frequency range and jump around randomly among the available frequencies. Because daytime sleepiness was related to phone type but not phone use, it suggests that the responsible RFs were those constantly emitted from the cordless phone base, not the handset. If effects do differ with frequency, this may explain conflicting results as until now studies that have included cordless phone exposure at all have not accounted for their different operating frequencies and modulations.

Tinnitus was another frequency-specific effect related only to 1.8-1.9 MHz and 5.8 GHz cordless phones. Tinnitus is related to elevated intracellular calcium levels and local oxidative stress which are expected to affect the cochlea in the inner ear (Pall and Bedient, 2007). Intracellular calcium levels are affected dependent upon specific frequency 'windows' (Blackman et al., 1979; Zhang et al., 2010) and there have been reports of oxidative stress induced in mitochondrial DNA of cortical neurons by exposure to 1.8 GHz cellphone exposure (Xu et al., 2010).

The only real alternative explanation would be an expected ill-effect on well-being (whether conscious or sub-conscious). A 'nocebo' effect has been proposed elsewhere (Rubin, 2010). I doubt this affected my study, in which well-being questions were given a low profile and introduced last. Participants were invited to comment on the well-being questions if they wished. No-one indicated a belief that RF exposure of any kind may be associated with their level of well-being or health, although a few had noticed a high pitch while near a television or when sitting at the computer. On the other hand, several denied any association, providing comments such as, "Feeling down not cos of phone", while others provided reasons why they considered their symptoms were not related to their phone use, such as, "Fo d iv been sick and had very bad headaches" [Translate as "For days(?) I've been sick and had very bad headaches"].

Another possible explanation is misclassification by the participants. This could happen if the questions were misunderstood. The risk of this was minimised with pilot studies and consultation, by reading the questionnaire aloud, and allowing participants to ask questions to clarify the meaning.

9.6.4 Personal dosimeters versus self-reporting

Both self-reported extent of phone use and measured levels of personal exposure have disadvantages. Body-worn dosimeters are likely to underestimate daytime exposure due to the influence of the body's own electric activity and night-time measurements are problematic, giving inaccurate readings due to lack of movement (Thomas et al., 2008). On the other hand, estimated phone use, and related RF exposure, has been criticised as unreliable due to inaccuracies of estimation (Inyang et al., 2009b). This thesis presents a forecast method at chapter 9 to reduce these inaccuracies.

While the models used in this analysis took several confounding factors into account, it is most likely that there are several others that impact on the measured outcomes. Further, as this is a cross-sectional study it cannot establish cause and effect, but provides correlations on the day. There may be other methodological biases that have not been considered.

9.6.5 Strengths and limitations

My study had several strengths. The sample was representative of the region and there was a high response-rate. Data collection and entry were carried out by me thereby eliminating inter-rater-error.

There were some limitations. Using school decile as a surrogate for SES would have resulted in some misclassification of individual SES. There were missing data for the cordless phone frequency (n=152) and transmission system (n=145), with the low and high SES groups under- and over-represented, respectively. WiFi also had incomplete data due to low parental responses (n=139), leaving the high SES responses over-represented.

I did not ask about existing medical conditions or medications. Neither did I ask about the distance of the cordless phone base from the bed. Future research assessing effects from cordless phone exposure should adjust for this. It is possible that extensive use of wireless phones is in some cases a result of being home with the flu or feeling down or depressed, rather than a cause. The sequence cannot be determined in a cross-sectional study.

9.7 Conclusion

Both cellphone and cordless phone use indicated an increased risk for many of the well-being measures. My findings suggest the need to explore further the effects of cordless phone protocols (operating frequency and modulation system). An advantage of examining cordless phones is that individual phones almost exclusively employ only one frequency band and one modulation type, unlike cellphones which commonly use several frequency bands and more than one modulation depending upon circumstances such as data traffic or terrain. Future research involving children's health and well-being and exposure to RF should include cordless phone exposure. This is particularly important in New Zealand where young people have a strong preference for using the cordless phone for long calls. It is also desirable that such studies should consider frequency and modulation. Research could also explore brain wave entrainment to 10 Hz from WiFi exposure during resting and non-resting wakefulness and during different stages of sleep.

Passive exposure at home can be reduced substantially by placing cordless phone bases and WiFi routers in an area of the house remote from the bedrooms. To safeguard young people's well-being, I suggest it would be prudent to restrict their use of cellphones and cordless phones, with or without headsets, to less than 15 minutes daily. Corded landlines offer an alternative for extended calling and outlets in each room allow the phone to be moved easily. If parents were to require cellphones, cordless phones and other RF transmitting devices not to be in bedrooms overnight, this would remove a source of RF and remove the significant likelihood of calls or texts causing broken sleep.

10 Conclusions and Recommendations

> "Promoting science is about ensuring that facts and evidence are never twisted or obscured by politics or ideology. It's about listening to what our scientists have to say, even when it's inconvenient - especially when it's inconvenient."
> Barack Obama, 44th President-elect of the United States, 20 December 2008

10.1 Introduction

This concluding chapter presents an overview of the research findings in context with the literature, the evidence for increased vulnerability in young people, and the international advice and action regarding young people's use of wireless phones. Policy and other recommendations are made regarding young people's use of wireless technology in New Zealand.

10.2 Summary

10.2.1 Original research in context

This research set out to assess the extent of cellphone and cordless landline phone use by adolescents in the Wellington Region and to evaluate its significance in relation to participants' subjective well-being and other researchers' previously published relevant case-control tumour studies. I explored the characteristics that may make children more vulnerable to RF than adults and reviewed the action and advice being given and followed internationally. This allowed me to put my results and New Zealand's current policy stance into a broad, international context.

A large majority of participants used either a cellphone and/or a cordless phone. The cellphone was a constant companion for a fifth of cellphone owners, who tended to carry it most of the day, have it in or by the bed at night, and be woken by it regularly. However, cordless phones were most popular for long calls made from home. Heavy use of a cellphone was positively associated with heavy use of a cordless phone also. This was consistent with my analysis of the Australian MoRPhEUS data (Redmayne et al., 2010). By mid-2013, when their mean age will be 16.3 years, 46% of participants will have had ten or more years of cordless phone use.

The CEFALO (brain tumour) study reported on years since first use of cellphones, but their data were simply categorized, with the top category being > 5 years (Aydin et al., 2011c). It does not appear that other studies of young adolescents have reported on the age by which adolescents reach 10 years' use of either phone type.

The number of years' use appears to matter. A critical analysis of studies of cellphone and/or cordless phone use and brain tumours found that many of them reported that extended wireless phone use (≥ ten years) was consistently related to increased risk of glioma on the same side of the head as that generally used for the phone (Levis et al., 2012). Positive associations were more common in studies with publicly-funded, blind protocols than those with industry-funded or co-funded non-blind protocols, but even in these studies patients with ≥ ten years' wireless phone use have often evidenced an increased risk.

Although some Interphone country analyses found such associations with extended use, the overall 13-country analysis did not. However, the Interphone design protocol has received considerable negative critique e.g. (Levis et al., 2012; Hardell et al., 2008; Morgan, 2009) including their non-blind approach, the low number of participants with ≥ ten years' wireless phone, the very low definition of regular use for the "exposed" as using the phone "at least once a week for at least six months", and low participation rates of both cases and controls.

In the current study, although the majority used wireless phones rather little, there was a sub-group whose use was extensive. Almost one fifth of the participants spent half an hour or more daily on a cordless phone, with 5% of the total also making 20 or more calls weekly on a cellphone; 13% (47) averaged at least one hour of cordless phone use daily; and 6% (23)reported spending between 1¼ and 4 hours daily. Cellphone use was additional.

While direct comparisons cannot be made due to different study designs, this last extent of use is in line with those studies which have found increased risk of some brain tumours within those with the most intensive and most extended use (Interphone Study Group, 2010b; Hardell et al., 2011a; Hardell et al., 2006b). Some of these included an increased risk from cordless phone use, such as Hardell et al, 2011, in which those who began use before the age of 20 were at highest risk.

There has only been one cellphone brain tumour study of adolescents published to date (Aydin et al., 2011c). The authors reported that they "did not observe that regular use of a mobile phone increased the risk for brain tumors in children and adolescents" despite data indicating several significant dose-response relationships as seen in table 5 of the paper cited here.

Wireless phone use and well-being were associated in the current research. This is the first study of New Zealand adolescents' phone use and well-being. The extent of use of both phone types was significantly related to frequent headaches, having a sore thumb, and frequently having difficulty falling asleep. Previous studies examining cellphone use and well-being have most consistently pointed to a link with headaches (Söderqvist et al., 2008; Hillert et al., 2007; Chia et al., 2000). Others have also found a link between GSM exposure and delayed sleep onset (Hung et al., 2007).

In my study, some outcomes were only significantly related to one or other phone type. Waking in the night at least weekly was significantly associated only with cellphone use, although results were very close to a statistically significant positive association for the extent of cordless phone use, especially for those who woke more often.

Chronic tinnitus and always feeling down or depressed were only associated with the extent of cordless phone use, This is interesting viewed in light of cordless phone RF, as tinnitus was only significantly associated with those that operated on 1.8– 1.9 GHz or 5.8 GHz frequency bands, whereas feeling down or depressed was associated with those that operated at 900 MHz or below. In the analysis, the latter category included phones that operate on 30-40 MHz. Adolescents who are approximately 1.5 metres tall have whole body resonance with 40 MHz RF when standing up. [45]

[45] See Chapter 2 section 5

Associations between specific cordless phone frequencies or modulation types and some aspects of well-being are an important novel result. Other frequency and modulation relationships were between being tired at school at least weekly and all frequencies and modulations except 2.4 MHz and frequency hopping systems (FHS). All logistic regression models were tested with adjustment for several confounders such as gender, age, socio-economic school rank, and having had a cold or flu in the last month. Those that improved the model were included.

Only 2.4 GHz cordless phones were not significantly related to any well-being outcomes. At the time of the study, this was the default frequency for WiFi in New Zealand. Those with WiFi at home were 5-fold less likely to wake every night than those without. WiFi also operates in the 5.8 GHz bands. Both types have a 10 Hz modulation-related component that falls within the brain's alpha band, which is typical of a relaxed and dozy state. The frequency-dependent effects found here support those found in EEG studies such as that by Leung's group (Leung et al., 2011).

The interaction of RF with sleep and tiredness is not consistent in the literature, but many studies have found a significant increase in brain alpha activity (Lowden et al., 2011; D'Costa et al., 2003; Croft et al., 2008b; Croft et al., 2010; Vecchio et al., 2010; Leung et al., 2011; Curcio et al., 2005; Borbély et al., 1999). These studies used a 2G signal (≈ 900 MHz carrier) and associated extremely low frequencies from modulation and the battery, and a 3G signal (≈ 1.9 MHz) exposure also. The common features appear to be related to age, with response increasing from adolescence to young adults, then decreasing in older people.

A more obvious association that I found was between the number of times students were woken by the cellphone and their tiredness at school. This could be a relatively easy problem to overcome if family rules on keeping transmitting devices out of the bedroom at night were introduced early enough. This is an important consideration quite separate from one of RF exposure. Good sleep quality is necessary for healthy growth, and tiredness at school will impair the ability to concentrate and learn at school.

The school census about cellphone rules allowed an analysis which compared school rules with students' responses. All schools banned private use of cellphones during class.

Contrary to principals' beliefs, the cellphone rules were routinely broken. For instance, almost half the participants admitted texting in class, most from within a pocket.

Private cellphone use during class is bound to disrupt the learning of the texter, but is also likely to distract adjacent students. It is therefore in the interest of students, schools and the Ministry of Education to prevent cellphone use during class[46].

A high-exposure group of risk-takers was identified for whom prohibited in-school use was positively associated with high texting rates, carrying the phone switched-on more than10 h/day, and in-pocket use. Because this occurred covertly against the abdomen or in the pocket, bringing the RF emissions close to the reproductive organs, I reviewed the relevant fertility literature. There was nothing available regarding female fertility and cellphone exposure, but the literature on the impact of RF on sperm, along with the advice of fertility specialists who had carried out the research, was sufficiently concerning to recommend that schools should have and enforce policies that would remove cellphones from students' pockets during the day. Such policies could require cellphones to be handed in, or to be visible and on the desk.

Two unanticipated papers resulted from the survey data. A problem encountered in case-control studies considering cellphone use and brain tumours is the large variance in estimation of use. Since I had students' billed and estimated texting rates, we were able to develop a model to reduce estimation bias. During development, it was realised that using a regression approach to calculate relative risk seriously warps the results due to the large variance in recall data. The Bayesian-based method for reducing estimation bias in recall data may be applicable for the international MobiKids project in which New Zealand is currently participating. It could also be applied post-hoc to completed studies.

The data also enabled some discovery science. I observed unexpected and apparently illogical patterns in students' estimates of their extent of cellphone use: individuals' estimated use over long periods was proportionally smaller than expected compared to their estimates for shorter periods. The same tendency applied to heavy use compared to light use estimates for the whole group. Parallels with the psychology literature on magnitude estimation suggested that the process of recalling numbers of events used a

[46] Except where this is specifically permitted for research during a lesson

mental logarithmic scale; it was by ratios and not linear. Comparison of the distribution of both sets of data clearly supported this despite both having a log-normal or exponential distribution overall. This mental recall process occurs when people estimate *observed* numbers of objects, but has not previously been connected to recall. These findings carry important implications for epidemiological methods. Specifically, it provides empirical justification for log-transforming recalled numerical data prior to analysis. It also indicates that the geometric mean is a more realistic average than the arithmetic mean when study participants have estimated a range of numbers. Once this finding has been verified for recall of other event-types, these approaches could gainfully be applied to other epidemiological studies in which patients are asked to recall numbers or quantities.

The use of the geometric mean for data given as a range will lessen introduced misclassification. In the current study, the use of the arithmetic mean of estimated cordless phone time daily would have led to almost 5% of participants being assigned to the wrong category if the data were then categorised into tertiles (approximately 14% provided this data as a range). In the final Interphone report, data were categorised into deciles, approximately 42% provided a range rather than a specific estimate, and the arithmetic mean was assigned in these cases (Interphone Study Group, 2010b).

10.3 Confusion of thermal standards and non-thermal outcomes

> "It will be helpful if the causation we suspect is biologically plausible. But this is a feature I am convinced we cannot demand. What is biologically plausible depends upon the biological knowledge of the day."
> Sir Austin Bradford Hill (1965)

Part I began by giving an overview of the issue of wireless phone safety. This is a contentious subject. In part this is because there has been considerable confusion of the thermal versus non-thermal risks and exposures.

Thermal risk is guarded against by existing standards. In New Zealand the Standard is based upon the ICNIRP guidelines, published in 1998.The current method for testing cellphone compliance assesses peak spatial average SAR (psSAR). Although the amount of energy absorbed by some individual tissues varies greatly between adults and children, age-dependent dielectric tissue values do not lead to systematic changes in psSAR (Christ et al.

2010). This suggests that psSAR may not be the most suitable measure of thermal heating from RF absorption.

The ICNIRP guidelines seek to prevent acute (i.e. short-term) thermal injury. They were set at a time when cellphones were largely an expensive business tool. It was not envisioned that in only a decade they would be in common use by adolescents, and in some cases used extensively by them. Neither did the guidelines allow for cellphones having the ability to run several functions concurrently including those online, increasing the energy output accordingly, or becoming small enough to carry all day against the body in a pocket or tucked into underwear.

Although there was a considerable amount of research published before 1998 indicating non-thermal cellular effects, these were not regarded as relevant for Standard-setting in the West for two reasons. First, most effects from brief exposures self-corrected after exposure stopped. This did not therefore constitute what had been defined as a health effect. Second, conservation of energy does not allow that thermal effects are possible within the strictures of the ICNIRP guidelines. The fact that they had been observed was discounted due to lack of replication (ICNIRP, 1998). Replication of studies involving RF and living cells is notoriously difficult due to the numerous aspects that need to be controlled with regard to both electromagnetic exposures and living cells. Even so, power intensity and frequency 'windows' had been found and replicated in several laboratories over the previous two decades. These showed that in some circumstances there was not a linear increase in effects with increased exposure, and that some frequencies were more bio-active than other, sometimes higher, ones. In other words, research has shown that "lower intensity is not necessarily less bioactive, or less harmful" (Blackman, 2009).

Confusion is introduced when results from studies involving non-thermal exposures are reported along with a statement relevant only in thermal exposure terms such as, "Measured exposure levels were on average far below the current ICNIRP reference levels" e.g. (Heinrich et al., 2011). Referring to a thermally-based safety limit when reporting non-thermal effects raises a smoke-screen (most likely unintentionally), suggesting the exposure conditions were safe when this may not be the case. The two are different issues. Conforming to one set of rules does not make breaking a different set of rules safe. If we use an analogy of bathing a toddler, one can observe the rules to ensure the child is not burnt, but one also needs to observe another set to ensure the child does not drown. The precautionary approach currently in use in some countries is merely a set fraction of a thermal standard. As such it does not specifically address non-thermal issues, but would (by default) reduce the number of bio-active power intensity 'windows' to which the public is exposed. It is therefore a blunt tool, but the only one currently available while adhering to the Western approach.

It is increasingly clear that extremely low exposure can cause possibly harmful bio-effects *in specific circumstances*. Research appears to be closing in on at least one 'non-thermal' mechanism but it is not vital to know the mechanism to begin addressing the problem. The issue is more to do with not knowing the *circumstances* under which potentially health-threatening bio-effects occur. "It is critical to determine which combinations of EMF conditions have the potential to cause biological harm and which do not" (Blackman, 2009).

This requires methodical testing and documentation of commonly used carrier frequencies and associated ELFs. Key effects to be tested need to be agreed upon, but some which occur commonly, but only under specific circumstances, are increased protein synthesis and oxidative stress.[47] The following papers could offer a starting point (Gerner et al., 2010; Friedman et al., 2007). Leszczynski has recommended using 'high-throughput screening' to find out which genes, proteins and metabolites respond to RF (although his purpose in this suggestion was to provide the base material upon which to base a non-thermal mechanism theory) (Leszczynski, 2012, 31 October).

The cells to be tested also need to be determined. While some, such as fibroblasts, can be affected in the short term, they have been seen to adapt after extended exposures (Markova et al., 2009); the same study suggests this may not be the case for stem cells which were shown to have increased inhibition of DNA repair foci after GSM and UMTS exposure, but did not adapt to chronic exposure (Markova et al., 2009).

Such testing and methodical documentation is urgently needed. Suggestions for relevant considerations, gleaned through reading the literature, are given in the right column of Table 10.1. The sooner this is done, the sooner we can develop a standard that will address

[47] In themselves, these do not constitute a 'health effect' but these could be the precursor to disease when there is chronic exposure which does not allow unexposed intervals for the body to undertake repair.

non-thermal insult and injury specifically. Returning to the toddler and bath analogy, however tepid we make the water this action will not prevent the child potentially drowning. Currently we have hundreds of millions of the world's young people 'in the bath' with no guards against 'drowning'.[48]

Table 10.1 Some considerations necessary for thermally- and non-thermally based exposure guidelines and the development of a Bio-Standard.

Relevant thermal considerations	**Relevant non-thermal considerations**
Total exposure	Magnitude of peak exposure
Carrier frequency	Specific bio-active frequency 'windows' * (or combinations) of the carrier frequency and extremely low frequencies resulting from modulation and the battery
Energy/cm^2/time	Specific bio-active energy windows*
Acute exposure	Chronic exposure / Duration of exposure
Peak spatial average SAR	Specific tissue SAR
Whole Body SAR	Type of cell and stage of cell-cycle when exposed
1g and 10g averaging	Individual responses of particular cell-types or cell components
	Particular vulnerability (age, state of health, genetic)

* Relevant for the relation of frequency and flux density of parallel magnetic field, the flux density of the static magnetic field and charge-to-mass ratio of ions of biological relevance (Blackman et al., 1995; Blackman et al., 1999)

Until these parameters have been methodically tested and recorded, "… the primary reason for recommending precautionary action is not what we know but what we do not know because we did not study it" (Leszczynski, 2012).

10.4 Future epidemiological wireless phone studies

The assumptions of some epidemiological studies make it hard to ascertain effects if biological interaction is frequency-specific. In this event, the results are likely to be 'diluted' if specific RFs are not taken into consideration. Other aspects of epidemiological cellphone studies have already received this critique (Cardis and Sadetzki, 2011). Frequency considerations are more challenging as cellphone companies adopt a wider range of carrier

[48] People in countries that have precautionary or other extremely stringent Standards are likely to be somewhat less vulnerable to bio-effects than those without. See 11.6.1 for explanation.

frequencies (including use of multiple bands by one phone) and more complex ways of transmitting their signals.

Cordless phones offer a much more stable RF exposure environment to monitor. Most function on full power when in use and each cordless handset generally utilizes only one frequency band and modulation approach. This means the energy output can more accurately be estimated, although the proportion of radiated RF that is absorbed can only be approximated due to variations resulting from the angle and distance at which the phone is held with relation to the head or body, and variability of head shape and skull thickness. Considering cordless phone exposures also makes it less complex to compare tumour and well-being associations with different frequency bands and modulation approaches.

10.5 International approaches and policy

International approaches to controlling public exposure to non-ionising radiation vary considerably according to each country's approach to the relevance of dose considerations, stance on the precautionary principle, and an understanding of what constitutes 'health effects'. East European countries have traditionally taken a stringent, biological approach to RF guidelines based on their research. In the West, a less stringent, thermally-based approach has been widely used. Western scientists exploring non-thermal responses to RF have made well-supported calls for Standards to be based on biology rather than dosimetry (Levitt and Henry, 2010; Blackman, 2009).

Other powerful, non-scientific, aspects affecting RF exposure guidelines or legislation include an undercurrent of political, financial and industry-related considerations. For instance, 'harmonisation' efforts instigated by the WHO to protect public health and reduce public anxiety (Repacholi, 2001), were supported by the Council of the European Union (EU) who issued Recommendation 1999/519/EC (12 July 1999) for member states to adopt guidelines exactly in line with those of ICNIRP, even when this meant making their exposure Standard more lenient. This counter-intuitive approach has been criticised (Levitt and Henry, 2010).

In 2008, ten years after the 'harmonisation' drive began, the Chairman for ICNIRP stated, "The ICNIRP guidelines are neither mandatory prescriptions for safety, the "last word" on the issue, nor are they defensive walls for Industry or others" (Vecchia, 2008). By then, with the European Commission's backing, a large number of countries had already complied. However, several countries have subsequently also instituted an additional, much more stringent, Standard for sensitive sites such as those frequented by young people. In Western countries, the reason is usually given as 'precautionary'.

Among many countries whose guidelines did not previously acknowledge non-thermal effects and among researchers in this field, there has been a groundswell of change. The RF exposure Standards are highly relevant to personal exposures. Several governments, national radiation laboratories, organisations and research and health professionals have issued statements advising reduced use of cellphones by children and promoting a number of methods for reducing exposure to cellphone radiofrequencies. Although emissions from cellphones and cordless phones are very similar, there have been few such calls regarding use of cordless phones. This is relevant in New Zealand in particular as local area calls on cordless phones are free with the monthly line rental, and because they are used far more than cellphones by adolescents.

There have been some positive actions overseas towards educating the public about cellphone technology and RF exposure. Examples of two different approaches with the young are currently being pursued in the USA and Israel. Two examples of school programmes on cellphones and their use are being run in the USA and Israel.

Environmental Health Trust, EHT, a non-profit, science-based organization was founded in 2007 in Jackson Hole, WY. The following information was provided by Ms Levitz, who is in charge of administering their RF education programme (personal communication, Rachael Levitz, July 2013):

> EHT's school program was initially launched in 2010-2011 school year. The school program focuses on educating students about electromagnetic radiation from cell phones and other wireless devices along with providing students with methods to reduce their exposure to this type of environmental contaminant. A yearly Student Art, Science, and Technology Contest has been used to engage local student's in

> learning more about the possible health effects from RF exposure and to promote (among peers and members of the community) ways to reduce RF exposure.

The organization provides a variety of resources on their webpage. Ms Levitz advised me that EHT currently goes into schools to talk about electromagnetic radiation during lunch breaks. They are developing curriculum for the coming school year.

The programme in Israel is a formal series of school lessons that have been developed by the Gertner Institute for Epidemiology & Health Policy Research with the collaboration of the Ministry of Education. The following information was provided by Drs Hirsh and Sadetzki who are in charge of this programme (personal communication, Dr Galit Hirsh July 2013):

> During the last 2 academic years (2012-2013) we recruited 8 schools, a total of 80 7th and 9th grade classes and ~ 2500 eligible pupils. All the pupils participated in an educational program; this included 4-5 lessons of 1.5 hours duration each.
>
> The schools were selected randomly (according to the socio-economic score of the school) in central area of Israel.
>
> The program was identical for all ages and included;
>
> a) Information about electro-magnetic fields especially non-ionizing radiation and its association with cellular phones.
>
> b) The scientific arguments for and against possible health effects of the exposure to radiation from cellular phones.
>
> c) The "precautionary principle" and rules for educated use of cellular phones.
>
> d) Social effects of cellular phone use e.g. use in schools or during lessons etc.
>
> …
>
> All the students with informed consent completed a questionnaire which included: Demographic characteristics, cellular phone use (number of calls per day, duration etc.), knowledge regarding non-ionization radiation and perception of risk and policy regarding cellular phone use by children and in schools. This questionnaire was administered before the" educational program" started (September-October), and again 2 months after the program was completed (May-June) .

At the time of writing, the data on the programme's effectiveness had not been analysed.

There has been a call for a standardised educational approach for school children in Turkey (Hassoy et al., 2013).

10.6 Implications for New Zealand RF policy

10.6.1 RF Standard

Environmental RF exposure in places accessible to the public is in most circumstances a small fraction of what the New Zealand Standard 2772.1:1999 allows (World Health Organisation, 2012; Dirksen, 2012); in New Zealand this has often averaged somewhat over 10 μW/cm^2 (Rowley and Joyner, 2012). In thermal terms, this is extremely low. Such exposures do not apply in all situations. and there is no way for members of the public to readily assess where exposures might be higher.Even so, many New Zealand parents are very concerned about their children being subjected to involuntary, chronic [low intensity] RF exposures (Local Government and Environment Committee, November 2009). Introducing an environmental exposures tier[49] to the Standard at the commonly used precautionary level of 6 V/m and 10 μW/cm^2 is achievable (as demonstrated by countries that have this Standard and by New Zealand having averages in many places that are only slightly higher) and would demonstrate compliance with clause 10(d) of the New Zealand Standard. This clause requires, "Minimizing, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided that this can be readily achieved at modest expense" (Gledhill, 2002), as suggested by the Austrian Federal Office of Communications (Coray et al., 2002).

This would provide reassurance for the public and should at least apply in all places used by young people and pregnant women.[50] It would also reduce the range of possible power intensity 'windows' of non-thermal bio-effects to which these people are exposed. Setting a minimum permitted distance of base station transmitters from these locations may be psychologically reassuring, but is technically unnecessary providing they comply with the precautionary standard in all publicly accessible places.[51]

10.6.2 Official personal RF exposure advice for families

[49] As discussed in Chapter 3

[50] It would also be desirable for this to apply to retirement homes, hospitals and other health-care facilities

[51] This refers to fixed antennae in areas legally accessible to the public. The maximum exposure from a typical base station at ground level on flat land is approximately 100m from the transmitter.

This thesis has principally considered personal RF exposures, particularly from cellphones and cordless phones. Looking to the larger picture, there are several reasons why it would be advisable for New Zealand to be more proactive in its recommendations regarding young people's use of wireless phones and other personal RF emitting devices (suggested recommendations are made below). From parents and children's perspective, this would show a level of concern in line with current research, a large body of scientific opinion, and the precautionary approach of many other countries. From a legal and governmental perspective, it would help meet the obligations already agreed to in existing law and policy. And from a Public Health perspective, even if individual risk is low, it could reduce a considerable financial burden in the health sector in years to come if undesirable health outcomes eventuate since at least 90% of our young people use wireless phones regularly.

In 2010, the WHO identified areas most in need of research into effects of RF exposures on young people. They placed a high priority on the following outcomes and actions:

- Behavioural and neurological disorders
- Cancer
- Monitoring brain tumour incidence trends
- Identifying neurobiological mechanisms underlying possible effects of RF on brain function, including sleep and resting EEG
- Effects of early-life and prenatal RF exposure on development and behaviour (World Health Organisation, 2010)

10.6.3 Education

New Zealand currently makes no attempt to educate young people about wireless technology. The following circumstances considered together make a strong case for introducing an educational programme:

- the results of the current research,
- the evidence currently available for bio-effects some of which appear to not self-correct (Markova et al., 2009),
- extensive expert advice to limit children's use of wireless phones, and
- New Zealand's existing precautionary policies.

An education programme should be available to schools and their communities (details are provided below). It should include informative materials on ways to reduce personal RF exposure when using a wireless phone, available in a range of locations such as schools and doctors' offices.

10.7 Closing comments and recommendations

My recommendations fall into two categories – future research focus and policy. These will be commented upon and presented in this order.

10.7.1 Future research focus

- More research is needed on the well-being outcomes explored in this thesis, controlling for specific RF and the distance of the cordless phone base from the bed. It was concerning that so many young people experienced headaches several times a week, but headaches have many causes. A larger study would allow a wider range of confounders to be taken into account.
- Another aspect to explore with larger groups would be the apparent link with particular cordless phone frequencies and chronic tinnitus.
- It would be interesting to explore the use of wireless phones and depression over the course of a year or two. This may help establish the direction of the effect, whether phone use provides emotional help (or otherwise) for those with depression, or whether the depression seems to be as a consequence. The quality and type of phone interactions would ideally also be taken into consideration.
- Case-control tumour studies need to control for the specific RF employed by the patients' wireless phones and other regular RF exposures. New Zealand studies in particular should include cordless phone use due to such a high proportion of wireless phone exposure coming from them (see chapter 5).
- Tumour studies so far have only considered those in the head. Children's cancer studies could explore Ewing's sarcoma, osteosarcoma, and fibrosarcoma of bone, all of which occur most often in young people, originating in a part of the body where the bone is rapidly growing and adjacent to where a cellphone is commonly used or carried.
- There is a real need for methodically identifying circumstances under which currently permitted RF exposures cause permanent biological changes, including after repeated or extended exposures. Current use of some types and frequencies of non-thermal RF exposure for therapeutic purposes indicates clearly that non-thermal effects exist and that these can be beneficial. Identifying those with detrimental effects would allow a Bio-Standard to be developed that avoided these.

10.7.2 Policy: Standards and telecommunication networks

The development of wireless technologies (and their operating and transmission protocols) has occurred at a remarkable pace during the three and a half years since my data was collected. At that time, tweeting was very new; the iPhone had only recently been launched in New Zealand; and iPads, iBooks and iPads were still to come. This brings to mind a passage in The Little Prince:

> "I follow a terrible profession. In the old days it was reasonable. I put the lamp out in the morning, and in the evening I lighted it again. I had the rest of the day for relaxation and the rest of the night for sleep."
> "And the orders have been changed since that time?"
> "The orders have not been changed," said the lamp-lighter. "That is the tragedy! From year to year the planet has turned more rapidly and the orders have not been changed!"
> p.60 (de Saint-Exupéry, 1973) First edition 1943

The 'orders' we currently follow in New Zealand were published in 1998 and 'from year to year the planet has turned more rapidly'. That is, research has increasingly demonstrated non-thermal bio-effects and technology has rapidly diversified. It is becoming clear that the 'orders' need to change. Until research is sufficiently advanced to formulate preliminary guidelines based on non-thermal RF exposure parameters, the precautionary option taken in countries such as Switzerland, Italy, and Israel is the best option.

Chapter 1 outlined the New Zealand policies that take 'low probability but high potential impact' risks into consideration. The first is the Precautionary Principle and the second is New Zealand's Resource Management Act (New Zealand Government, 1991). Reiterating the latter, it states that: (2) …sustainable management means managing the …development… of … [e.g. wireless] resources in a way, or at a rate, which enables people and communities to provide for their …health and safety while – (c) avoiding, remedying, or mitigating any adverse effects of activities on the environment. 'Environment' includes: …people and communities (2)(1), and 'Effect' includes: 3(f) any potential effect of low probability which has a high potential impact.

This thesis has demonstrated that New Zealand's relevant precautionary policies are not being satisfactorily met (either in terms of RF exposure or advice) under the current state-of-knowledge about RF, and children's particular vulnerabilities.

Recommendations include the following actions: [52]

1) a more stringent precautionary tier to Standard 2772.1:1999 (modelled on that of Israel, Italy and Switzerland) until a non-thermal standard is available. This should apply to residential areas, education facilities, playgrounds, and all other facilities for children and pregnant women (excluding medical exposures);
2) permitting only wired networks in pre-school, primary and secondary educational and care facilities;
3) recommending wired broadband internet in family homes or routers with an eco-function that can be programmed to turn off during night hours;
4) maintaining the plug-in corded telephones network;
5) issuing the following advice regarding children's use of wireless phones: delay onset of cellphone and cordless phone use as long as possible; minimise calls by the head or with any type of headsets; use texting in preference to calls; do not operate any RF equipment while it is against the body; adolescents keep calling to no more than 15 minutes total in any one day; carry cellphones elsewhere than on the body (or put in flight-mode first); do not have the cellphone or cordless phone or its base in the bedroom at night.

10.7.3 Policy: Education

In 1990, Becker wrote, "Many important policy decisions [about electromagnetic fields and radiofrequency exposures] will soon need to be made. They should be made by an informed public, not by politicians, bureaucrats, or scientists who are blindly obedient to

[52] Under the current system, changes to recommendations regarding RF exposure are initiated by the Interagency Advisory Committee on the Health Effects of Electromagnetic Fields, whose terms of reference require "that it inform the Director General of Health of any developments which affects policies, guidelines and advice promulgated by the Ministry of Health and Ministry for the Environment" GLEDHILL, M. EMF exposure standards in New Zealand/Australia. WHO meeting on EMF biological effects and standards harmonization in Asian & Oceania, 22-24 October 2002 Seoul. WHO. The full terms are at Appendix 7. The likely body to issue such advice is the National Radiation Laboratory.

the tenets of their faith" (Becker, 1990). More than two decades later, the New Zealand public is still poorly informed about RF and related research.

As mentioned above, the New Zealand National Radiation Laboratory recommends that the "Use of cellphones by children should be a matter for informed choice by parents" (National Radiation Laboratory, 2012). This requires parents who are informed, but providing 'dos' and 'don'ts' only is insufficient. Information on how to reduce RF exposure is likely to be more readily accepted where the reasons are understood, especially in a well-educated population.

However, the route to enabling good parental decision-making also includes the following challenges (McCallum and Anderson, 1990):

- Provision of information when science is uncertain
- Explanation of the risk assessment process
- Accounting for differing concepts of an 'acceptable' level of risk
- Provision of information that assists in personal decisions and informs opinions on policy.

The **recommendations** are that:

1) All these issues could helpfully be addressed in school programmes for parents, teachers and the Board.

2) Other potential avenues for education include public seminars for professionals and workplace workshops for all employees regularly using or exposed to transmitting equipment as a co-operative arrangement between Health and Safety and Professional Development.

10.7.3.1 Education in schools

Education can take place in many settings. School communities provide an obvious first choice. Lessons about the use of wireless technology are not required by the New Zealand school curriculum (Ministry of Education, 2007). However, the curriculum would not need changing for such lessons to be included, readily fitting within the current science, technology and health curricula. There is a sample lesson plan on the data-CD inside the back cover.[53] This was successfully delivered as a science lesson to all classes that participated in the survey.

The **recommendation** is:

1) that lessons on wireless technology should be a requirement for Intermediate school students, and recommended at Primary and Secondary levels. The following is a suggested way of incorporating them into the curriculum:
   a) Year 2: factual training and practice to develop habits that minimise RF exposure, forming part of their health education on lifestyle factors that influence their health. (Health and Physical Education curriculum: Healthy Communities and Environments strand)
   b) Intermediate school (Years 7 or 8): learn the basics of the electromagnetic spectrum, electromagnetic waves and amplitude; identify phones and other personal equipment that emits RF; explore and discuss RF emissions or reflections within the school setting; identify the conditions under which energy emission from cellphones increases; and explore ways to reduce personal exposure in school and home settings. (Science curriculum: the Physical World strand).
   c) Year 11: a unit within the Technology curriculum to foster a clearer understanding of how wireless technology operates (Technological Practice strand); and consider and critique the impact on society, particularly that part with which students interact (Nature of Technology strand).
   d) Alternatively at year 11: a science unit providing more detailed understanding of the nature of the electromagnetic spectrum, transmission of RF; basics of modulation; and conservation of energy (The Physical World strand), along with a science, technology or health research project related to wireless technology.

10.7.3.2 Education in healthcare

Standard 2 of the draft New Zealand Standards for the Wellbeing of Children and Adolescents Receiving Healthcare (The Paediatric Society of New Zealand, 2002) states:

> All attendances for healthcare shall be used to promote, and advocate for …wellbeing of children, adolescents, and their families/whanau[54]....Activities to

[53] I taught this lesson for each class that took part in the survey. It was enthusiastically received and several schools asked me to stay on to continue after lunch.

improve health status e.g. … behavioural guidance or accident prevention advice should be part of models of care across all settings. (p.11)

Having health providers, especially family doctors, who are well-informed about how and why to reduce one's exposure to RF would equip them to uphold the requirements of Standard 2 (with respect to RF exposures).

The **recommendations** are:

1) for the provision of education for medical students, general practitioners and paediatricians about RF emissions from wireless equipment, thermal effects, regularly demonstrated and replicated non-thermal bio-effects, a range of informed international advice, and ways to reduce personal exposure in order to equip them to advise their patients;
2) for the free provision of pamphlets: when purchasing a new cellphone; in doctors' waiting rooms; and at school front desks (see an example at appendix 8).

[54] Maori for 'extended family'

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Appendices

Appendix 1: Redmayne et al. (2010) paper drawing on MoRPhEUS data

Background

During my Master's year in 2009, I spent several weeks on a practicum at Monash University[55], Melbourne, Australia, under the guidance of Professor Michael Abramson, who was leading the Mobile Radiofrequency Phone Exposed Users Study (MoRPhEUS). This cross-sectional study collected data on both cellphone and cordless phone use from students with a median age only 9 months more than that of my subsequent survey in New Zealand undertaken for my Master's research, but upgraded to a PhD. While there, I analysed the extent of participants' cordless phone use and examined it in comparison to their cellphone use.

This chapter comprises the paper that resulted. It has been published as a perspective in the Journal of Environmental Monitoring (Redmayne et al., 2010). It also features in the Journal of Environmental Monitoring 2010 Review Articles available at http://pubs.rsc.org/en/journals/articlecollectionlanding?sercode=em&themeid=wc51478669a7932730b1c745cc4bc758d06

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http://pubs.rsc.org/en/content/articlelanding/2010/em/b920489j

The paper had 9 citations in peer-reviewed journals as of 18 September 2012.

Environmental impact statement

Humans utilise most electro-magnetic frequencies occurring naturally in our environment. Radio frequencies (RFs) are barely represented among these and pulse-modulated ones typically emitted by wireless phones are not represented at all. Most of the world's population is now exposed to these. While far-field effects of RF are well understood,

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research on biological interaction from near-field pulsed RF transmission is less well developed. Since pulsed RF environmental exposure is so recent and pervasive, it is important that epidemiological research is designed to accurately assess possible health effects. This paper suggests that research focussing solely on mobile phone use and disregarding cordless-portable phone exposure will reduce the chance of doing so and may give false reassurance of wireless phone safety.

Abstract

Cordless and mobile (cellular) telephone use has increased substantially in recent years causing concerns about possible health effects. This has led to much epidemiological research, but the usual focus is on mobile telephone radiofrequency (RF) exposure only despite cordless RF being very similar. Access to and use of cordless phones was included in the Mobile Radiofrequency Phone Exposed Users Study (MoRPhEUS) of 317 Year 7 students recruited from Melbourne, Australia. Participants completed an exposure questionnaire – 87% had a cordless phone at home and 77% owned a mobile phone. There was a statistically significant positive relationship ($r = 0.38$, $p < 0.01$) between cordless and mobile phone use. Taken together, this increases total RF exposure and its ratio in high-to-low mobile users. Therefore, the design and analysis of future epidemiological telecommunication studies need to assess cordless phone exposure to accurately evaluate total RF telephone exposure effects.

Introduction

In the last ten years, there has been a substantial increase in the prevalence of wireless technology and its accompanying radiofrequency (RF) emissions. These emissions are often referred to as microwaves, and comprise the shorter wavelengths / higher frequencies of the RF range.

Cordless telephones have become normal household appliances, while concurrently the use of mobile (cellular) phones has become integral to everyday life. This has led to many people being exposed to background RF radiation 24 hours-a-day from transmitters both outside and inside their schools, workplaces and homes.

Cordless phones put a base station inside the user's home and are often the strongest source of RF in the home (German Federal Agency for Radiation Protection, 2006). Transmissions of the base and handset are most commonly digital and employ several frequency bands, usually 900 MHz, 1.8 – 1.9 GHz, 2.4 GHz, and 5.6 or 5.8 GHz (Hännikäinen et al., 2002). While some 900 MHz models are still analogue with digital features, most use Digital Enhanced Cordless Telecommunication (DECT). The more recent cordless phones operate on the two highest frequency bands using Digital Spread Spectrum (DSS).

Standards currently used in most countries to regulate human exposure to RF were not designed for and do not consider short-range transmitters inside buildings nor the possibility of close proximity to people (Kühn et al., 2005). If a person sleeps or works half a metre away from a cordless phone base, his/her on-going background exposure can be more than 100 times greater than that from a nearby mobile base station (following from Kühn et al.(Kühn et al., 2005)), and within adjacent rooms the electric field has been shown to be around the 95th percentile of fields encountered near cellular base stations in residential areas (Haumann and Sierck, 2002).

Near-field exposure from cordless and mobile handsets is additional to this. During calls, DECT handsets have a time-averaged 10 mW output power delivered in bursts at the maximum transmit power of 250 mW (Kramer et al., 2005). DSS phones in the US are permitted 100 mW output power, operating at a transmit power of up to 1W (Cokenias, 2002). This is the same transmit power as for 900 MHz mobile phones (Lönn et al., 2004).

For most portable telephone models, output power does not vary with distance from the base. On the other hand, mobile phones adjust their power output according to the clarity of signal by using adaptive power control (APC). This means the output power varies considerably according to phone type, the network provider, and a variety of conditions including network user-load, obstacles, handover between cells, and proximity to a base station (Lönn et al., 2004). While the phone is establishing a connection and sending text messages (SMS) it functions on or near full power. At other times, APC may scale the time averaged maximum output power from 250 mW at 1800 MHz or 125 mW at 900 MHz down to as low as 1-2 mW according to conditions (Lönn et al., 2004).

Other sources have measured time-averaged output power of mobile calls variously at below 1mW for three minutes in suburban areas (Black, 2007), and, most recently, at 128 mW (900 MHz) or 63 mW (1800 MHz) for calls longer than one minute averaged across all locations (Vrijheid et al., 2009b). This multicentre study found that output power decreased with increasing call duration. However it only accounted for exposure during speech; as APC reduces power output when the caller is listening, this study almost certainly over-estimated actual mean exposure.

This means that, averaged over the course of conversation, a cordless DECT handset can expose the user to a higher RF output than would a mobile handset with consistently good reception. Thus exposure to cordless phone bases and handsets may make a considerable difference to total RF energy exposure from telephones, and for those living in good mobile reception areas the exposure from cordless phones is likely to be comparatively more substantial.

Due to considerable debate about whether cordless phone use should be assessed in epidemiological studies (Hardell et al., 2008; Herberman, 2008b; Morgan et al., 2009), such as the forthcoming Mobi-Kids study(Cardis, 2009), it is important to find out whether treating those with only cordless phones as 'unexposed' is likely to bias associations between wireless phone use and cancer incidence. As well as establishing the extent of cordless phone use generally, we also need to know whether there is a correlation between mobile and cordless phone use since a positive correlation would have a compounding effect on total RF exposure. This means that if health effects exist, the risk ratio for the high user group would be increased.

We examined the proportion of an adolescent sample with cordless telephones at home, and the proportion of these that did not own a mobile phone, and asked how prevalent cordless phone use was in this sample and whether it was related to their mobile phone use.

Methods

Sample

The current analysis draws on data collected for the Mobile Radiofrequency Phone Exposed Users Study (MoRPhEUS), the methods of which are described in detail elsewhere (Abramson et al., 2009). Briefly, a cross-sectional clustered study was conducted during 2005/2006. We recruited 13 government, 4 Catholic and 3 independent secondary schools from around Melbourne, Australia. The numbers of schools were chosen to represent the proportions of secondary students attending each sector in the state of Victoria. At each school, one Year 7 home-room class (typical age 12 to 13 years) was selected at random to participate. Parents or guardians of children in the selected class were sent information packages, explaining the study.

Questionnaires were completed by participating children and their parents. Exposures to mobile and cordless telephones were assessed with a modified version of the Interphone questionnaire (Cardis et al., 2007).

Ethics

MoRPhEUS was approved by the Standing Committee on Ethics in Research Involving Humans at Monash University, the Department of Education & Training, the Catholic Education Office and the principals of all participating schools. Children and their parents/guardians gave written informed consent.

Statistical Analysis

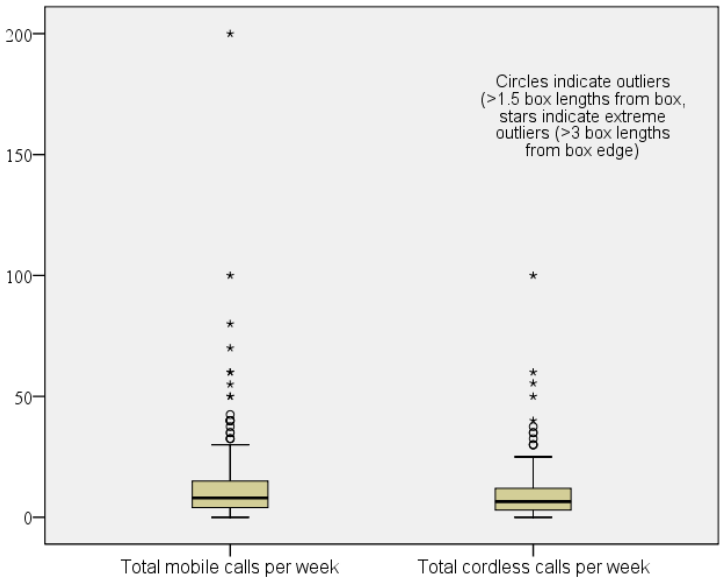
Data analysis was performed using SPSS version 15.0 (SPSS Statistics 17.0.1, 2008). Calls made and received per week were totalled, using the arithmetic mean when a range was given. Cordless and mobile total calls were each then log transformed, with an offset of 1 to include valid zeroes; this achieved normal distributions. Independent sample t-tests, Pearson (r) and Spearman's rank (rho) correlations were used for analysis. All p values were two tailed and $p < 0.05$ was considered statistically significant.

Results

Of the 479 students invited, 317 (66%) participated in the study. We recruited 145 (46%) boys and 172 (54%) girls. The median age was 13 (range 11 – 14) years. A large majority (274 or 87%) of the 317 students had a cordless phone at home, and 243 (77%) owned their own mobile phones, although 252 (80%) currently used a mobile. All but 10 (3.2%) reported having access to one or other type of phone. Age was normally distributed, but the reported number of calls per week on both types of phone were right skewed (Figure 5.1).

Of the 74 (23%) participants who did not own a mobile phone, 62 (84%) had a cordless phone at home and 22 (33%) of them used it more than the median of the entire group. Ten (3%) of those with a cordless telephone at home reported not using it.

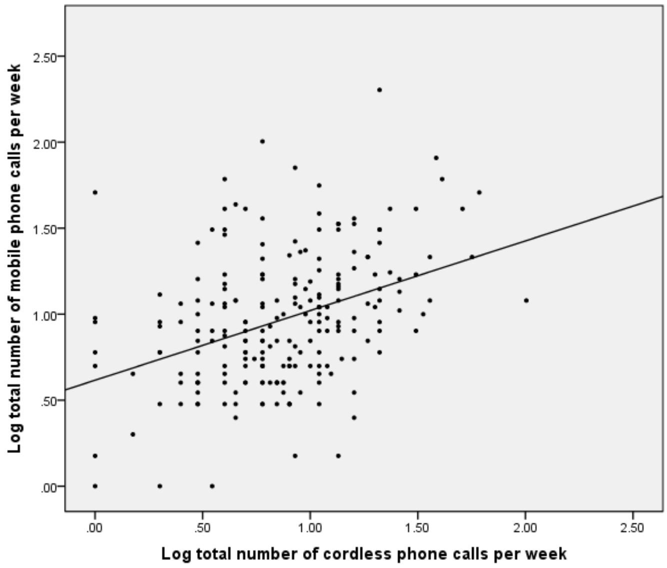
Figure 1 Box plots of total mobile and cordless phone calls per week



Looking at the whole sample, the reported total number of calls on cordless phones was, a little lower than that on mobile phones, with the respective medians and Interquartile Ranges (IQRs) being 6 (IQR 3 – 11) and 8 (IQR 4 – 15). The reported extent of cordless phone use was not related to age (rho = -0.027, p = 0.7) and there was no significant difference in use between males and females (t = -0.283, p = 0.6).

The Pearson correlation between the total number of calls reported on cordless and mobile phones was 0.38 ($p < 0.01$). This positive association is apparent in the scatterplot (Figure 5.2).

Figure 2 Scatterplot of total weekly cordless and mobile calls using log transformed data.



Discussion

MoRPhEUS is one of very few epidemiological studies to consider access to and use of cordless phones, especially among young people. We found that a large majority of adolescents had cordless phones at home and one fifth had a cordless but did not own a mobile. Almost all of them used either cordless or mobile phones. There was a positive association between the uses of the two phone types.

A Swedish study of 7 to 14 year olds (Söderqvist et al., 2007) found a similar proportion of students had cordless phones at home (83.8% of the 1423 respondents compared with 87% here). In that study, use of both phone types increased rapidly with age. The German MobilEe-study (Thomas et al., 2008) asked participants for estimates of time spent on both phone types. Specific results for this were not given as this was not their main focus, although they recorded that adolescents used DECT phones more than children. The MoRPhEUS study had a narrow age range (97% aged 12 or 13), which perhaps explains the lack of association between age and use.

We explored whether access to a cordless phone would reduce an adolescent's use of a mobile phone. Perceived reasons for this possibility were that cordless phones are generally cheaper to use, afford the same privacy if desired, and are less likely to be regarded as a health threat due to lack of media focus on cordless phones in Australia. However, this expected negative relationship was not confirmed. On the contrary, there was a moderate positive relationship between adolescents' number of cordless and mobile phone calls. In another study of adolescents aged 15 to 19 (Söderqvist et al., 2008) it was similarly found that regular mobile phone use was associated with regular cordless phone use, although this was assessed in reported call duration rather than the number of calls. In the German MobilEe study adolescents reported a longer daily use of cordless phones than mobile phones (S.Thomas, personal communication 17 September 2009).

Söderqvist et al.(Söderqvist et al., 2007) also reported a significant positive association between regular mobile use (defined as talking ≥ 2 minutes a day) and cordless use in 7 to 14 year-olds. This result is not directly comparable either as they also assessed participants' reported call duration. Duration tends to be overestimated and is recalled less accurately than the number of calls (Parslow et al., 2003; Vrijheid et al., 2006a), particularly by those with short to medium call durations (Timotijevic et al., 2009).

Estimation tendencies are different when reporting the number (rather than length) of mobile phone calls. The latter study (Timotijevic et al., 2009) compared the number and duration of actual and recalled calls over periods of 24 hours and 3 days. They found a significant difference (p=0.001) between recall accuracy of the number of calls by high and low users, with high users tending to underestimate and low users tending to overestimate. If these findings apply to the current study, the significance of the correlation between cordless and mobile calls may be stronger than reported here, as it would increase the actual range of calls made and received.

The very high proportion of adolescents who have a cordless phone at home indicates that many people have a higher level of total RF exposure from telephones than considered by most mobile phone studies to date. The largest of these is the 13-country Interphone study which treated those who used cordless but not mobile phones as unexposed (Cardis and Kilkenny, 2001).

The statistically significant positive correlation found between the use of the two types of telephone alters the ratio of RF exposure between high and low mobile users. Furthermore if generally applicable, the 33% of those who do not have a mobile, but use a cordless more than average, would potentially confound the interpretation of mobile phone studies that do not consider cordless phone exposure. This could lead to incorrect and under-estimation of RF exposure when cordless portable use is not included. Ultimately this would affect the conclusions drawn about the severity or existence of health effects.

Strengths of the MoRPhEUS study relevant to the current analysis lie in cluster sampling across all school sectors and a high participation rate providing a representative sample (Abramson et al., 2009). The main limitation was the reliance on self-reporting of exposure. Reliability of estimation is known to be affected by the time-span over which participants are asked to recall information. Timotijevic et al. found an increased tendency to underestimate call numbers after three days compared to one day (Timotijevic et al., 2009). It is not clear how this interacts with the effects of recall on high or low numbers of calls, or whether recalling an average week, as in the current study, is more or less reliable than recalling the last three days. Differences in age or sex appear not to play a part (Parslow et al., 2003).

Conclusions

This study found that a large majority of Australian adolescents have a cordless telephone at home, and almost 20% have a cordless phone at home but do not own a mobile phone. Cordless telephones are single-cell mobile phones whose bases emit RF at all times, and whose handsets have a very comparable type of emissions to mobile phones, but without the ability to adjust output according to need. For these reasons, extended proximity to the base or use of the handset can appreciably increase total RF exposure. We also found a statistically significant positive relationship between the extent of cordless and mobile phone use. When taken into consideration, this changes the ratio of total RF exposure of high users compared to low users. We conclude therefore that when designing and analysing epidemiological mobile phone studies, it is important to also assess cordless phone handset and base exposure in order to accurately evaluate total RF telephone exposure effects.

Appendix 2: Ethics Approval

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

MEMORANDUM

Phone 0-4-463 5676
Fax 0-4-463 5209
Email Allison.kirkman@vuw.ac.nz

TO	Mary Redmayne
COPY TO	Dr Sean Weaver, Supervisor
FROM	Dr Allison Kirkman, Convener, Human Ethics Committee

DATE	March 19, 2009
PAGES	1

SUBJECT	**Ethics Approval: No 16299, Cell phones and the living cell: adolescent cell phone exposure and user habits.**

Thank you for your application for ethical approval, which has now been considered by the Standing Committee of the Human Ethics Committee.

Your application has been approved from the above date and this approval continues until 30 March 2010. If your data collection is not completed by this date you should apply to the Human Ethics Committee for an extension to this approval.

Best wishes with the research.

Allison Kirkman
Convener

Appendix 3: Parent Questionnaire

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

Mobile and Cordless Phone Study (Year 7 and 8) Questionnaire: *Part A.*

ID
Today's Date
.... / .... / ....   dd mm yy

To be completed by the Parent/Guardian and returned to the school. In the questions, 'your child' refers to your year 7 or 8 student who is taking part in the study

Have you read and signed the consent form? Please do so before you complete this form.

A1. What is your child's date of birth? ☐☐ Day ☐☐ Month ☐☐ Year

A2. What is the sex of your child? ☐ Male [1] ☐ Female [2]

A3. How many older brothers and sisters does your child have? ....

A4a. Do you have a cordless portable phone at home (this is a phone which has a base that plugs into the phone line and a power point, but the handpiece has no cord and can be carried around the house)?

☐ Yes [1] ☐ No [2]

A4b. If you answered Yes, how many years have you had this type of phone at home?

.... years

A4c. What is the make and model please?...

A5. Do you have a wired landline phone (one you **can't** carry around the house)

☐ Yes [1] ☐ No [2]

A6. Do you think **mobile phones** carry any health risk for you or your family?

☐ None [1] ☐ Low [2] ☐ Moderate [3] ☐ High [4] ☐ Don't know [-9]

Please turn over

Victoria University of Wellington
School of Geography, Environment and Earth Sciences
PO Box 600, Wellington

A1

A7. Do you think **cordless portable phones** carry any health risk for you or your family?

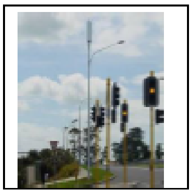
☐ None ☐ Low ☐ Moderate ☐ High ☐ Don't know

1 2 3 4 -9

A8. Do you have wireless broadband at home? ☐ Yes ☐ No

A9. About what distance from your home is the nearest cell phone transmitter? (see examples)

______________________________meters ☐ Don't know





A10. Does your child have a cell phone?

☐ Yes ☐ No (There are no more questions if you ticked this box)

B41. Do you have a <u>post-paid account</u> that includes the costs of a cell-phone belonging to your child (i.e. you get a bill for it)

☐ No (There are no more questions if you ticked this box)

☐ Yes

It would be a great help to the research if you'd provide the following information <u>for your child's phone</u> from a recent bill. It is likely to be on the bill's <u>summary page.</u>

There were............................. texts sent in total from my child's cell phone.

My child's cell phone calls totalled .... minutes of calls.

Please tick the relevant box below:

☐ This covers calls and/or texts to any network

☐ This only covers calls and/or texts to our own network which is ....

When you have finished, please return the questionnaire and the signed consent form in the envelope provided. Thank you for taking part.

Victoria University of Wellington
School of Geography, Environment and Earth Sciences
PO Box 600, Wellington

Appendix 4: Student Questionnaire

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI VICTORIA UNIVERSITY OF WELLINGTON	*Cell and Cordless Phone Study(Year 7 and 8) Questionnaire: Part B*	ID #

To be completed by the Participant (Student) at the school. Please ask if you need any explanations. For answers with boxes, please put a tick in the one of your choice. For numbers or written answers, please write clearly so it is easy to read correctly

Today's date: / /09

B1. Have you ever used a cell phone to make or receive calls? ☐ 1 Yes ☐ 2 No

B2. Do you <u>own</u> a cell phone? ☐ 1 Yes ☐ 2 No

B3. Do you <u>use</u> a cell phone? ☐ 1 Yes ☐ 2 No

If you do not currently <u>own or use</u> a cell phone, go now to Q B28a p.5

B4. If you currently own or regularly use a cell phone, what is the:

Make (Eg Nokia, Panasonic etc.)	Model (look on the phone, under the battery)	Service Provider (Eg Telecom, Vodafone, Telstra)

☐ -9 Don't know

B5. How old were you when you first started using a cell phone? __________ years

B6. What is the average number of phone calls you **make** per week on your cell phone? You can give me a range if that's easier. ______________________ calls per week.

B7. What is the average number of phone calls you **receive** per week on your cell phone? You can give me a range if that's easier.______________________ calls per week.

B8. How many calls (made or received) on your cell phone each week would be more than 10 minutes?_____________________________

1

B9. When using the cell phone for calls do you usually:

☐ 1 Do most of the talking

☐ 2 Do most of the listening

☐ 3 About equal talking and listening

B10. What functions do you use your cell phone for? <u>Please tick the relevant box in each row.</u>

	-8 My phone can't do this	0 Never	1 Hardly ever	2 Sometimes	3 Often	4 Very Often
Making phone calls						
Receiving phone calls						
Texting						
Online Games/Music/Internet						
Taking photos or video						
Sending e-mail						
Other functions (please name them)						

B11. What is the average number of text messages you send? You can give a range if that's easier.

_____________ per day OR _____________ per week OR _____________ per month

B12. What is the average number of text messages you receive? You can give a range if that's easier.

_____________ per day OR _____________ per week OR _____________ per month

B13. Please write the numbers 1 to 4 in the following boxes for people you send texts to (1 = most, 4 = least)

☐ 1 Parents or caregivers ☐ 2 Other relative ☐ 3 Friend ☐ 4 Someone else

2

To remind you, your answers are <u>strictly confidential</u> and will NOT be available for your teachers, parents or anyone but the researcher to see.

B14a. Do you bring a cell phone to school?

☐ 1 Never ☐ 2 Sometimes ☐ 3 Always

B14b. If you bring a cell phone to school, do you hand it in for the day?

☐ 1 Never ☐ 2 Sometimes ☐ 3 Always ☐ -8 This isn't an option we have

B15. This year have you ever used a cell phone during school lessons?

☐ 1 Never ☐ 2 Sometimes ☐ 3 Often

B16. Do you send texts at any time (including at school) from

a. in your pocket ? ☐ 1 Never ☐ 2 Sometimes ☐ 3 Often

b. How often? ____________________________times a day

c. in your lap? ☐ 1 Never ☐ 2 Sometimes ☐ 3 Often

d. How often? ____________________________times a day

Now three questions about accounts and plans

B17. Please tick the type of payment that applies to your cell phone:

☐ 1 Parent's monthly account ☐ 2 Pre-pay / Top up

B18. If there's a call or text 'plan' or Add-Ons for the phone (such as Telecom's $10Txt or BoostTxt2000, or Vodafone's Txt2000) please name it (tick a box if you don't know or there isn't one)

....or ☐ -9 Don't know ☐ -8 No plan

B19. Do you usually run out of texts on your pre-paid plan during the month?

☐ 1 Yes ☐ 2 No ☐ -9 Don't know

The next few questions are about where you carry or store your cell phone

B20. When you're not at school, where is your cell phone mostly? **(Tick 1 or 2 boxes)**

In a pants/skirt pocket : ☐ 1 Front pocket? or ☐ 2 Back pocket?

☐ 3 In a hoodie or jacket pocket (at hip or stomach level)

☐ 4 In your hand

☐ 5 In a bag

☐ 6 In a cell phone case on a belt

☐ 7 Elsewhere (say where and how far from your body)

____

B21. Where is your cell phone usually at night:

☐ 1 Under the pillow

☐ 2 Beside the bed

☐ 3 Elsewhere (say where)__________________________

B22. Is your cell phone turned on or off at night?

☐ 1 On

☐ 2 Off

B23. Are you woken by calls or texts at night?

☐ Yes. If so, how often does this happen? ________times a week

☐ 0 No

B24. Do you use an ear piece or headset for phone calls?

☐ 1 Yes, with a cord to the phone ☐ 3 No

☐ 2 Yes, a cordless earpiece

4

B25a. On weekdays, how many hours per day is the cell phone in your hand or pocket and turned on?

☐ 1 Up to 2 hours ☐ 2 >2 and up to 6 hours ☐ 3 >6 and up to 10 hours ☐ 4 > 10 hours

B25b. On weekends, how many hours per day is the cell phone in your hand or pocket and turned on?

☐ 1 Up to 2 hours ☐ 2 >2 and up to 6 hours ☐ 3 >6 and up to 10 hours ☐ 4 > 10 hours

B26. What mode do you usually keep the cell phone in when you're not using it?

☐ 1 Off ☐ 2 On with sound ☐ 3 On in silent or vibrate mode

B27. If you hand your cell phone in during the school day, what do you do with it when you get it back?

☐ 1 Turn it on & check or use it ☐ 2 Turn it on but not check or use it ☐ 3 Leave it turned off

The following questions are about portable cordless phones. If you do not have a cordless phone at home then go now to question B33

B28a. Do you ever use a portable cordless phone at home? ☐ 1 Yes ☐ 2 No

B28b. If yes, how old were you when you first started to use a cordless phone? _______ yrs old

B29. What is the average number of phone calls you **make** per week on a cordless phone? You can give me a range if that's easier. ________________________ calls per week.

B30. What is the average number of phone calls you **receive** per week on a cordless phone? (This means calls for you, not someone else) You can give me a range if that's easier.________________________ calls per week.

B31a. How many calls (made or received) on a cordless each week would be more than 10 minutes?________________________________

B31b. How long do you spend on the phone between the end of school and when you go to sleep? ____________________________on an average day

B32. When using a cordless phone do you usually:

☐ 1 Do most of the talking

☐ 2 Do most of the listening

☐ 3 About equal talking and listening

B33. For long calls, do you prefer to use a landline with a cord, a cordless or a cell phone?

☐ 1 Landline with cord, because ________________________________

☐ 2 Cordless phone, because ________________________________

☐ 3 Cell phone, because ________________________________

☐ 4 Don't mind, or depends on ________________________________

Lastly, a few questions about your health and lifestyle:

B34. Over the past month have you:

	Circle the relevant box in each row 1	2	3	4	
a. had trouble falling asleep?	No, hardly ever	1 or 2 times a week	3 or 4 times a week	Most nights	This survey is confidential so your response won't be followed up. If you have a problem with any of these affecting your everyday life, be sure to ask someone such as your parent, doctor, school counsellor, or What's Up (0800WHATSUP)
b. been waking up in the night ?	No, hardly ever	1 or 2 times a week	3 or 4 times a week	Most nights	
c. felt tired during school time?	No, hardly ever	1 or 2 times a week	3 or 4 times a week	Most days	
d. had headaches?	No, hardly ever	1 or 2 times a week	3 or 4 times a week	Most days	
e. been feeling down or depressed?	No	Yes, sometimes	Yes, often	Yes, all the time	
f. experienced tinnitus (ringing or buzzing sounds in your ears)	No, hardly ever	1 or 2 times a week	3 or 4 times a week	Most of the time	
g. had a painful texting thumb	No	1 or 2 times a week	3 or 4 times a week	Most of the time	

If you want to provide comments on any of these please use this space:

B35. Have you had a cold or flu in the last month

☐ 1 Yes ☐ 2 No

B36.What time do you usually settle down to go to sleep? ____________________

B37. During the past week, how many times did you exercise, such as jogging, dancing, skipping or playing any active sport such as soccer or netball?

☐ Not at all 1 ☐ 1 or 2 times 2 ☐ 3 or 4 times 3 ☐ 5 or more times 4

B38. On an average weekend (Saturday and Sunday), how long would you spend **in total** watching television and/or DVDs and/or computer gaming and/or playing Playstation, X-box, etc?

☐ < 1 hour 1 ☐ > 1 hour and up to 4 hours 2 ☐ > 4 hours and up to 10 hours 3 ☐ > 10 hours 4

B39. Do you have a computer with wireless broadband in your bedroom or through the wall from your bed?

☐ 1 Yes ☐ 2 No

B40. Do you have a TV in your bedroom?

☐ 1 Yes ☐ 2 No

Turn over and do the last page if you've got a cell phone

If you don't have a cell phone, check that you've done questions B1 to B3, and B28a to B40.

Leave your questionnaire on your desk and come and collect the comprehension sheet from the front if you haven't already got it

B41.

Are you with:

☐ Telecom ordinary network

☐ XT new network

☐ not with Telecom (see below if you have Vodafone txt 2000)

If you have Telecom Prepay, phone *333 (it's free, you don't need credit ☺)
My phone says,

"As of ....you have ....texts remaining on ....(plan type)

vodafone

vodafone

If you've got Vodafone txt2000, text <u>myaddons</u> to 756. Follow instructions for finding your text balance (how many you have left). Write your text balance and the date it recurs (NOT today's date but the date you get another 2000 texts credited each month).My phone says,

Your text balance is.....................and recurs on ....

If you've got no texts left, about when did this happen?......................

Lastly, **Everyone with a cell phone do this:**

<u>Measuring normal texting distances</u>
If you don't send texts from your lap or in bed then put n/a in the space.

B42. Distance from the face of the phone to your face when <u>sending</u> a text from your **normal position**...........cms

B43. If you ever send texts while you're sitting with the **phone in your lap** : Measure from the bottom of the phone to your abdomen ....cms (closest normal distance)

B44. If you ever send texts while **lying in bed**: Distance from the front of the phone to your eyes............cms

☺ That's all - Thanks

Appendix 5: Chapter 6 Supplementary Material

Supplementary Table 1. Data for Fig.1 in paper - comparing students' handing-in behaviour with their school policy on where cellphones should be kept at school. Percentage totals are by column.

	Should hand in	%	Not in class May hand in	%	Not in class Can't hand in	%	Choose location May hand in	%	Choose location Can't hand in	%	Total
Never hand in	65	44.5	18	60.0	11	100	12	50.0	68	100	174
Some-times hand in	43	29.5	9	30.0	0	0.0	10	41.7	0	0.0	62
Always hand in	38	26.0	3	10.0	0	0.0	2	8.3	0	0.0	43
Total	146	100	30	100	11	100	24	100	68	100	279

Supplementary Table 2 Handing-in behaviour by those who take their cellphone to school compared with 1st consequence for non-compliance. Percentage totals are by rows. Exclusions are those who do not own a cellphone, those who never bring one to school, and missing data. For data at Fig. 2 in paper.

1st consequence and handing-in behaviour	Never hand in		Sometimes hand in		Always hand in		Total minus exclusions	Total
CP confiscated, parent to collect	10	27%	19	51%	8	22%	37	100%
Should hand in								
Others who may hand in	3	100%	0	0%	0	0%	3	100%
Cannot hand in	10	100%	0	0%	0	0%	10	100%
CP confiscated for day								
Should hand in	31	55%	10	18%	15	27%	56	100%
Others who may hand in	7	26%	17	63%	3	11%	27	100%
Cannot hand in	48	100%	0	0%	0	0%	48	100%
CP confiscated for week								
Should hand in	11	79%	2	14%	1	7%	14	100%
Others who may hand in	0	0%	0	0%	0	0%	0	0%
Cannot hand in	0	0%	0	0%	0	0%	0	0%
Other consequence								
Should hand in	0	0%	0	0%	0	0%	0	0%
Others who may hand in	0	0%	0	0%	0	0%	0	0%
Cannot hand in	23	100%	0	0%	0	0%	23	100%
Depends on circumstance								
Should hand in	13	33%	12	31%	14	36%	39	100%
Others who may hand in	5	56%	2	22%	2	22%	9	100%
Cannot hand in	13	100%	0	0%	0	0%	13	100%
Totals (should hand in)	65		43		38		146	
Totals (others who may hand in)	15		19		5		39	
Total (cannot hand in)	94		0		0		94	
Grand Total	**174**		**62**		**43**		**279**	

Supplementary Table 3. Handing-in behaviour by those who take their cellphone to school compared with 2nd consequence for continued non-compliance. Percentage totals are by rows. Exclusions are those who do not own a cellphone, those who never bring one to school, and missing data. For data at Fig. 3 in paper.

2nd consequence and handing-in behaviour	Never hand in		Sometimes hand in		Always hand in		Total minus exclusions	Total
CP confiscated for week								
Should hand in	6	67%	2	22%	1	11%	9	100%
Others who may hand in	0	0%	0	0%	0	0%	0	0%
Can't hand in	0	0%	0	0%	0	0%	0	0%
CP confiscated rest of term								
Should hand in	23	96%	1	4%	0	0%	24	100%
Others who may hand in	0	0%	0	0%	0	0%	0	0%
Can't hand in	0	0%	0	0%	0	0%	0	0%
No specified 2nd consequence								
Should hand in	5	27%	14	35%	15	38%	34	100%
Others who may hand in	7	64%	2	18%	2	18%	11	100%
Can't hand in	41	100%	0	0%	0	0%	41	100%
Other specific consequence								
Should hand in	9	21%	16	38%	17	41%	42	100%
Others who may hand in	0	0%	0	0%	0	0%	0	0%
Can't hand in	15	100%	0	0%	0	0%	15	100%
Confiscated, parent to collect								
Should hand in	22	56%	10	34%	5	10%	37	100%
Others who may hand in	23	54%	17	39%	3	7%	43	100%
Can't hand in	0	0%	0	0%	0	0%	0	0%
Phone banned at school								
Handing in facility	0	0%	0	0%	0	0%	0	0%
No handing-in facility	23	0%	0	0%	0	0%	23	100%
Total: Should hand in	65		43		38		146	
Total: Others who may hand in	30		19		5		54	
Total: Can't hand in	79		0		0		79	
TOTAL	**174**		**62**		**43**		**279**	

Supplementary Table 4 –A Chi-square test of relationship between the use of a cellphone during lessons and the first consequence for not complying with the rules (χ^2 (df 4, 324) = 14.05, $p = 0.007$) indicates a significant relationships (in bold). Confiscation for a week or an unspecified consequence that depends on the circumstances appeared to reduce in-class use. See penultimate paragraph of survey results in paper.

In class cellphone use * 1st consequence Cross-tabulation

		1st consequence					
		Removed parent collect	Conf. for day	Conf. for week	Other	Depends	Total
No	Count	26	77	17	11	55	**186.0**
	Expected Count	31.6	83.8	12.1	13.2	45.4	**186.0**
	Adjusted Residual	-1.7	-1.5	**2.3**	-1.0	**2.5**	
Yes	Count	29	69	4	12	24	**138.0**
	Expected Count	23.4	62.2	8.9	9.8	33.6	**138.0**
	Adjusted Residual	1.7	1.5	**-2.3**	1.0	**-2.5**	
Total	Count	55	146	21	23	79	**324.0**
	Expected Count	55.0	146.0	21.0	23.0	79.0	**324.0**

Appendix 6: Full tables for well-being results

Supplement to Table 9.1 Self-reported well-being symptoms and the use of wireless phones and accessories estimated by unconditional logistic regression. All models tested for sex, age, and SES which were included where this strengthened the model. Other confounders were included as described in chapters 4 and 9

	N†	OR (95%CI)	OR (95%CI)	OR (95%CI)
Headache		At least weekly	≥3 weekly	Most days
Cordless minutes+	338	1.05 (0.99, 1.11)	**1.08 (1.01, 1.15)**	1.08 (0.99, 1.18)
# long cordless calls¶	349	0.96 (0.80, 1.15)	1.07 (0.87, 1.33)	1.14 (0.86, 1.53)
Cordless calls made & received¶	354	0.96 (0.88, 1.06)	1.03 (0.91, 1.15)	1.07 (0.89, 1.28)
# long cellphone calls¶	347	1.02 (0.45, 2.31)	**2.51 (1.03, 6.14)**	**3.08 (1.09, 8.69)**
Cellphone calls made & received¶	350	1.12 (0.86, 1.45)	1.02 (0.70, 1.49)	1.50 (0.99, 2.24)
Any cellphone headset§	326/29	1.74 (0.76, 3.97)	**3.40 (1.27, 9.15)**	2.57 (0.52, 12.72)
Wireless cellphone headset§§	342/13	1.71 (0.53, 5.52)	**7.13 (2.07, 24.51)**	3.51 (0.39, 32.03)
Tinnitus		At least weekly	≥3 weekly	Most days
Cordless minutes+	337	1.04 (0.98, 1.10)	1.05 (0.99, 1.12)	1.06 (0.98, 1.15)
# long cordless calls¶	348	1.13 (0.95, 1.35)	1.17 (0.97, 1 41)	**1.27 (1.03, 1.57)**
Cordless calls made & received¶	353	1.07 (0.98, 1.16)	1.08 (0.98, 1.18)	**1.13 (1.02, 1.26)**
# long cellphone calls¶	346	1.26 (0.57, 2.81)	1.20 (0.46, 3.14)	1.72 (0.64, 4.66)
Cellphone calls made & received¶	349	0.90 (0.67, 1.20)	1.21 (0.87, 1.66)	1.26 (0.85, 1.85)
Any cellphone headset§	29/325	0.55 (0.24, 1.27)	2.33 (0.87, 6.28)	2.49 (0.74, 8.36)
Wireless cellphone headset§§	13/341	1.65 (0.49, 5.51)	2.71 (0.72, 10.20)	1.04 (0.35, 10.62)
<u>Cordless frequency</u> ǂ				
No cordless phone	29	1	1	1
≤ 900 MHz	19	2.29 (0.60, 8.74)	3.50 (0.52, 23.50)	2.50 (0.32, 19.42)
1.8-1.9 GHz	27	**3.41 (1.03, 11.28)**	3.74 (0.63, 22.11)	2.21 (0.34, 14.56)
2.4 GHz	52	2.20 (0.76, 6.34)	1.22 (0.20, 7.36)	0.26 (0.02, 3.46)
5.8 GHz	18	2.40 (0.64, 9.04)	**6.56 (1.06, 40.44)**	1.73 (0.19, 15.75)
<u>Cordless system</u> ǂ				
No cordless phone	30	1	1	1
DECT	41	2.64 (0.89, 7.89)	0.29 (0.04, 2.00)	3.23 (0.55, 19.04)
FHS	42	1.94 (0.66, 5.70)	1.29 (0.34, 4.93)	0.29 (0.02, 3.75)
Analog	26	2.50 (0.74, 8.37)	0.26 (0.86, 8.73)	1.54 (0.18, 13.58)
Feeling Down/Depressed	26	At least weekly	≥3 weekly	Most days
Cordless minutes+	337	1.03 (0.97, 1.09)	1.03 (0.95, 1.12)	**1.13 (0.97, 1.11)**
# long cordless calls¶	349	1.03 (0.87, 1.22)	0.95 (0.71, 1.28)	1.08 (0.55, 2.11)
Cordless calls made & received¶	353	1.07 (0.98, 1.16)	1.00 (0.86, 1.15)	1.14 (0.94, 1.39)
# long cellphone calls¶	346	1.32 (0.60 2.89)	0.95 (0.27, 3.36)	2.40 (0.62, 9.14)
Cellphone calls made & received¶	349	0.97 (0.74, 1.26)	1.01 (0.67, 1.51)	1.39 (0.73, 2.63)
Any cellphone headset§	30/325	1.53 (0.70, 3.37)	1.70 (0.48, 6.07)	**7.31 (1.01, 52.87)**
Wireless cellphone headset§§	13/343	**3.38 (1.06, 10.72)**	3.09 (0.74, 12.95)	**23.45 (3.03, 181.07)**

Cordless frequency ǂ				
No cordless phone	27	1	1	
≤ 900 MHz	20	**4.14 (1.13, 15.14)**	2.13 (0.25, 18.34)	indeterminate
1.8-1.9 GHz	27	2.96 (0.88, 9.96)	2.54 (0.34, 19.19)	
2.4 GHz	53	1.48 (0.50, 4.44)	1.36 (0.20, 9.14)	
5.8 GHz	18	1.50 (0.37, 6.06)	1.20 (0.09, 16.15)	
Cordless system ǂ				
No cordless phone	29	1	1	-
DECT	41	2.67 (0.88, 8.15)	3.14 (0.47, 20.86)	indeterminate
FHS	42	1.84 (0.60, 5.60)	1.32 (0.18, 9.81)	
Analog	27	2.93 (0.88, 9.75)	1.62 (0.19, 13.84)	
Sore texting thumb		At least weekly	≥3 weekly	Most days
Billed texts‡	148	**1.02 (1.001, 1.04)**	**1.025 (1.00, 1.05)**	1.021 (0.99, 1.05)
Cordless minutes+	337	1.04 (0.97, 1.11)	1.07 (0.97, 1.17)	1.09 (0.98, 1.21)
# long cordless calls¶	348	**1.26 (1.02, 1.54)**	**1.29 (1.01, 1.64)**	**1.38 (1.06, 1.80)**
Cordless calls made & received¶	353	**1.14 (1.03, 1.26)**	1.12 (0.98, 1.28)	1.14 (0.99, 1.31)
# long cellphone calls¶	345	1.51 (0.61, 3.77)	2.10 (0.69, 6.40)	0.43 (0.01, 34.79)
Cellphone calls made & received¶	349	**1.38 (1.02, 1.87)**	1.43 (0.92, 2.20)	1.18 (0.60, 2.33)

+ Per 10 daily; ¶ Per 10 weekly; ‡ Per 10 monthly; † N is total in model for continuous data or Less/More exposed for categorical data; § measured against those with no cellphone headset; §§ measured against those with no wireless headset; ǂ compared to reference category of no cordless phone

Supplement to Table 9.2 Self-reported sleep and tiredness symptoms, and wireless phone and accessories use and WiFi exposure estimated by unconditional logistic regression

Trouble falling asleep		At least weekly	≥3 weekly	Most days
Cordless minutes+	337	1.05 (0.99, 1.11)	**1.08 (1.01, 1.15)**	1.00 (0.92, 1.09)
# long cordless calls¶	342	1.10 (0.91, 1.33)	**1.21 (1.01, 1.45)**	0.94 (0.70, 1.25)
Cordless calls made & received¶	347	0.99 (0.90, 1.08)	1.06 (0.97, 1.17)	0.99 (0.87, 1.13)
# long cellphone calls¶	346	1.56 (0.68, 3.55)	**2.58 (1.00, 6.67)**	1.31 (0.49, 3.49)
Cellphone calls made & received¶	349	1.01 (0.78, 1.30)	1.10 (0.82, 1.48)	0.88 (0.57, 1.35)
Any cellphone headset§	28/326	0.60 (0.24, 1.48)	1.21 (0.45, 3.24)	0.88 (0.57, 1.35)
Wireless cellphone headset§§	12/342	1.12 (0.33, 3.82)	2.87 (0.75, 10.90)	2.85 (0.71, 11.48)
Wake in the night		At least weekly	≥3 weekly	Most night
Cordless minutes+	332	0.99 (0.93, 1.05)	1.05 (0.99, 1.12)	1.06 (0.99, 1.14)
# long cordless calls¶	342	1.05 (0.86, 1.27)	1.19 (0.98, 1.44)	1.01 (0.78, 1.31)
Cordless calls made & received¶	347	1.07 (0.97, 1.18)	1.09 (0.99, 1.21)	1.01 (0.89, 1.14)
# long cellphone calls¶	342	0.95 (0.43, 2.10)	1.40 (0.60, 3.27)	0.13 (0.007, 2.29)
Cellphone calls made & received¶	344	**1.36 (1.002, 1.85)**	1.16 (0.86, 1.55)	0.70 (0.39,1.26)
Any cellphone headset§	29/319	1.27 (0.55, 2.91)	1.15 (0.42, 3.12)	0.65 (0.17, 2.53)

Wireless cellphone headset§§	13/335	4.65 (0.97, 22.36)	2.53 (0.74, 8.63)	0.46 (0.11, 2.03)
Wifi at home‡	68/70	0.70 (0.36, 1.38)	0.48 (0.19, 1.20)	**0.19 (0.05, 0.74)**
Tired during school		At least weekly	≥3 weekly	Most days
Cordless minutes+	331	1.07 (0.98, 1.16)	0.97 (0.91, 1.04)	0.99 (0.92, 1.07)
# long cordless calls¶	341	1.04 (0.82, 1.31)	0.94 (0.78, 1.13)	1.05 (0.86, 1.27)
Cordless calls made & received¶	346	1.00 (0.90, 1.10)	0.96 (0.87, 1.06)	1.01 (0.91, 1.12)
# long cellphone calls¶	342	0.74 (0.32, 1.71)	1.02 (0.45, 2.34)	0.60 (0.19, 1.94)
Cellphone calls made & received¶	344	0.85 (0.63, 1.16)	1.10 (0.82, 1.46)	0.81 (0.56, 1.18)
Any cellphone headset§	30/317	1.08 (0.42, 2.78)	0.92 (0.37, 2.31)	1.25 (0.45, 3.48)
Wireless cellphone headset§§	14/333	1.51 (0.38, 6.03)	1.76 (0.52, 5.92)	1.56 (0.42, 5.82)
Wifi at home‡	69/70	1.83 (0.71, 4.70)	1.84 (0.86, 3.93)	1.78 (0.65, 4.87)
Cordless frequency ǂ				
Don't own	28	-	-	-
≤ 900 MHz	20	**5.38 (1.16, 25.01)**	0.54 (0.14, 2.05)	0.45 (0.09, 2.23)
1.8-1.9 GHz	25	**4.98 (1.22, 20.23)**	1.11 (0.35, 3.53)	1.62 (0.47, 5.67)
2.4 GHz	52	2.13 (0.75, 6.04))	0.57 (0.21, 1.58)	0.57 (0.18, 1.81)
5.8 GHz	18	**7.88 (1.37, 45.50)**	0.84 (0.23, 3.10)	0.98 (0.23, 4.17)
Cordless system ǂ				
Don't own	29	-	-	-
DECT	39	**4.69 (1.42, 15.42)**	0.78 (0.28, 2.23)	1.17 (0.38, 3.54)
FHS	42	1.75 (0.63, 4.89)	0.74 (0.27, 2.06)	0.60 (0.19, 1.89)
Analog	27	**4.69 (1.23, 17.93)**	0.31 (0.08, 1.17)	0.32 (0.07, 1.44)

+ Per 10 daily; ¶ Per 10 weekly; ‡ Per 10 monthly; † N is total in model for continuous data or Less/More exposed for categorical data; § measured against those with no cellphone headset; §§ measured against those with no wireless headset; ǂ compared to reference category of no cordless phone; ‡ Wifi operates on 2.4 GHz and/or 5.8 GHz and uses modulation protocols similar to FHS (spread spectrum)

Appendix 7: Terms of Reference for the Interagency Advisory Committee on the Health Effects of Electromagnetic Fields

(Interagency Advisory Committee on the Health Effects of Electromangetic Fields, 2004)

The [New Zealand] Interagency Committee on the Health Effects of Non-Ionising Fields (the Committee) will provide the Director General of Health with high quality, independent scientific and technical advice on any potential health effects from exposures to extremely low or radiofrequency fields including:

- the quality and completeness of information on which findings and recommendations have been made
- assessment and review of the impact of research and information published locally and overseas, on policies, guidelines and advice promulgated by the Ministry of Health, Ministry for the Environment or Ministry of Economic Development
- other technical, scientific and epidemiological matters in relation to the extremely low or radio frequency fields as may be required.

The Committee will report to the Director General of Health, with copies of meeting notes provided to the Chief Executives of the Ministry for the Environment and the Ministry for Economic Development. Should there be reasonable suspicion of health hazards, or other issues of significance, these will be brought to the attention of joint Ministers. Annual and/or occasional reports will also be provided to joint Ministers.

Composition of the Committee

The membership of the Committee will include representatives from the following agencies, organisations, and sectors:

- Ministry of Health (including the National Radiation Laboratory)
- Ministry of Economic Development (including Energy and Communications)
- Ministry for the Environment
- Occupational Safety and Health Service of the Department of Labour
- public health service

- local government (Local Government New Zealand)
- academics/scientists
- consumers
- electrical industry (transmission and supply): up to two representatives
- telecommunications industry: up to two representatives.

The Ministry of Health will provide the Chair and secretarial support for the Committee.

Appendix 8: Pamphlet

What is the SAR rating?

The amount of energy from a cell phone (or cordless phone) that can be absorbed by humans is called the Specific Absorption Rate (SAR). Australasian guidelines allow a maximum SAR of 2 Watts per kilo (W/kg) to the head. All cell phones sold here conform to this standard (which is set at this level to prevent heat damage); but some phones have a maximum level as low as 0.3 W/kg. Your phone manual may list its maximum SAR, or you may find it at

http://www.mobile-phones-uk.org.uk/sar.htm
or http://www.ewg.org/cellphone-radiation/

just so you know….
Low SAR will expose you to less microwave radiation than a high SAR

Industry and Government warnings: "Keep the mobile device and its antenna at least 2.5 centimeters from your body when transmitting" (from a Motorola cellphone manual, 2006)

Council of Europe, Parliamentary Assembly, 27 May 2011 – Recommendation to ban all mobile phones, DECT phones, WiFi or WLAN systems from classrooms and schools (Resolution adopted, clause 8.3)

An expert group of scientists commissioned by the British Government recommend that "use of mobile phones by children (under the age of 16) should be discouraged for non-essential calls."
Information from UK Department of Health pamphlet
http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4123979

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Cell phones

fyi…

- Cell phones operate using microwave 'radiation'. It's not ionising, like that from X-rays
- Cell phone microwaves aren't strong enough to cause much heating - safety testing and standards are designed to prevent this
- But even without heating there are proven biological effects from cellphone exposure
- Research has shown that cell phones affect the brain's alpha waves. When some cells are dividing, they're vulnerable to protein damage, increased oxidative damage and other damage
- Research indicates extensive use of cell and cordless phones may be linked to increased risk of brain tumour after some years. A cellphone used in a pocket may damage sperm and impair fertility

The strength of cell phone microwave emissions depends on the circumstances:

Microwave output only **stops** when the phone is turned off.

Microwave output is **relatively low** when:
1. The phone is in standby
2. You type txt messages
3. Reception is good
3. You are listening

Microwave output **increases** when:
1. Reception is poor. The worse it is, the more the power level goes up until it reaches the phone's maximum
2. You send txt messages
3. You're talking
4. You're in a moving vehicle
5. You're using online functions

Pic source: Gadgetophilia

The amount of microwave energy your body or head absorbs increases the closer the phone and the antenna is to your body or head.

How to reduce your microwave exposure (and your bill!)

1. Use a landline with a cord

But if using a cell phone:

1. Keep use to a minimum
2. Text rather than call; hold the phone loosely
3. Call back on a wired landline if you can
4. Use speaker phone or hold the phone a cm or two from your ear
5. Don't use in a moving vehicle or enclosed space such as a lift or rooms without windows
6. Stop calls if reception is poor
7. Keep phone away from body during use, including headset transmissions
8. Unless it's turned off, carry the phone in a bag or loose jacket pocket (NOT a trouser pocket, round your neck, or down your bra)
9. Use another gadget for music
10. Turn the phone off at night (get a regular alarm clock)

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Cordless phones

- Cordless phones are cell phones, except the base station is in your home and their range is smaller
- Being within a meter or so of a cordless phone base is similar to being about 100 meters from a typical cell phone base station
- Most cordless bases and handsets transmit microwaves all the time
- Over time, exposure from a cordless handset can be higher than from a cell phone with good reception

Suggestions to reduce your exposure:

1. Keep the main base in a room away from desks or bedrooms (note: microwaves go through walls)
2. Don't have a phone by the bed
3. Use speaker phone with phone on a table
4. Hold the phone away from your head
5. Don't listen in from the back of the handset (the energy is much higher)
6. **Use a landline with a cord (no microwaves)**