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The Role of Eye Gaze in Subjective Decision Making

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Submitted as a MSc thesis

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Abstract

Shimojo, Simion, Shimojo and Scheier (2003) provided preliminary evidence that eye movements have an active role in preference formation. In their study, subjects were presented with two faces and chose which was more attractive. By manipulating how long subjects were able to look at each face after an eye movement, Shimojo et al. (2003) showed that faces presented for a longer duration were more likely to be chosen as more attractive. However, a recent study from Nittono and Wada (2009) showed that an eye movement may not be necessary for this effect, as novel graphic patterns presented in the centre of the screen (thus requiring no eye movements) for longer durations were also more likely to be preferred. The purpose of the current study was to further investigate whether eye movements do have an active role in preference formation. The present study used the same paradigm as Shimojo et al.'s (2003) study. Subjects in Experiment 1 were presented with images of two real faces, alternatively (one for 900ms, one for 300ms) for six repetitions. There were 3 independent experimental conditions. One group were required to make eye movements to laterally presented faces and judge attractiveness (*lateral attractiveness* condition), a second were not required to make eye movements to centrally presented faces and judge attractiveness (*central attractiveness* condition). The third were required to make eye movements to laterally presented faces and judge roundness (*lateral roundness* condition). The findings indicated that subjects were more likely to choose the longer presented faces in the *lateral attractiveness* and *central attractiveness* conditions, but not the *lateral roundness* conditions. Experiment 2 was similar to Experiment 1 with the exception of the type of stimuli, which consisted of computer generated faces (CGFs). Subjects were more likely to choose the longer presented CGF in the *lateral attractiveness*, *central attractiveness* and *lateral*

roundness conditions. The findings of the present study were not in line with Shimojo et al.'s (2003) previous findings, who found that faces presented for a longer duration were only preferred in the *lateral attractiveness* condition of their study. It is possible that the faces that are presented for the longer duration in the current paradigm are preferred due to the increase in *exposure duration* irrespective of an eye movement (as per the findings from Nittono and Wada, 2009). As it is unclear as to whether eye movements play an active role in preference formation, the findings of the present study have not been able to contribute to computational models of decision making.

The Role of Eye Gaze in Subjective Decision Making

One is faced with decisions every day of one's lives. There can be many factors to consider when presented with these choices. For instance, a choice between purchasing a car or a motorbike may elicit a relatively objective decision with concrete informational comparisons such as practicality, cost and safety. On the other hand, in regards to what to eat from the menu at a restaurant, a decision between the steak and the lamb may elicit a more subjective evaluation. One may like both steak and lamb, and will rely on a more of a gut feeling as to which to choose.

In addition to objective and subjective properties, decisions can also range from the very simplistic to the complex. For example, decisions can incorporate a simple orientation of movement (e.g. making an eye movement to an abrupt onset of a stimulus in the visual field), choosing between one of two options (e.g. a foraging bird with a limited time is forced to choose between one of two types of food source; a seed or a worm) or perhaps just stating a preference (e.g. declaring who is your favourite James Bond actor). These examples respectively illustrate three well studied decision mechanisms in psychology, that is; *sensory-motor processing* (eye movement example), *forced choice* (the foraging bird example) and *subjective preference/liking formation* (James Bond example). Although these decisions appear to be qualitatively different, it is possible that they could rely on similar mechanisms to achieve the ultimate decision.

Neural computational models of decision making suggest that the decision mechanism is a process that acts to assign decision related activity to each respective option (Bogacz, 2007; Glimcher, 2003; Gold & Shadlen, 2007). This choice-related activity has two distinctive components: a) an escalation of activity, and b) a decision threshold for the activity to overcome in order for the choice to be made. There is accumulating evidence to now suggest that the decision mechanisms for *sensory-motor processing*, *forced choice* and even *subjective preference/liking formation* may all involve this escalation of activity reaching a threshold

The current study investigated subjective preference formation. The aim of the study was to provide evidence for a computational decision making mechanism when judging which face out of two faces is the most attractive. The current study was inspired by previous findings that indicated that eye movements could have a causal influence on preference formation when choosing which one of two faces is more attractive (Shimojo et al., 2003). An underlying computational mechanism that exists in all different types of decisions is a very intriguing prospect. A measurable computational basis for making choices can shed light on an underlying drive that is present in a variety of behaviours, that is, how one comes about choosing to do what one does.

Evidence of Computational Decision Making

There is compelling evidence for a computational decision mechanism from single cell recordings of the lateral parietal area (LIP) and the frontal eye field (FEF) during a *sensory-motor processing* task. Such evidence comes from monkeys that are required to make a saccade to target-related locations in visual space (e.g. a location that is determined by the direction of moving dots, Shadlen & Newsome, 1996, 2001; or a static target that differs from several distracters, Thomas & Pare, 2007). The firing of LIP and FEF neurones correspond to specific locations in visual space, with the location-specific firing occurring whilst an object falls into the receptive field of the neuron. During the decision process of looking towards target locations, an escalatory firing rate occurs in the same location-specific neurones. Essentially this escalation continues until a threshold is reached, upon which, the motor production of a saccade is generated.

This escalation is considered to be a functional decision related process for two reasons. Firstly, the escalation can occur after a delay from the onset of the stimulus (Trommershauser, Glimcher & Gegenfurtner, 2009), thus suggesting that the escalatory firing is decoupled from a sensory representation. Secondly, the escalation can be actively stopped before the threshold, with no resulting saccade (Hanes & Schall, 1996), thus suggesting that it is not a simple passive result of a pre-initiated decision and is fundamentally required to complete the action. In all, decisions on where to look appear to require an escalation of activity in location-specific neurones, which is reliant on reaching a threshold in order to initiate the movement.

Studying the activity in the LIP has also been useful to provide evidence for a computational decision mechanism during a *forced choice* task. When presenting monkeys with a choice between a large reward and a small reward option, Platt and Glimcher (1999) recorded initial sensory activity in the LIP that was proportionate to the values of the respective rewards. Interestingly, the behavioural response proportions also matched the values of the respective reward (e.g. rewards that were four times greater would be chosen four times more often overall). This behavioural response matches that for an *ideal free distribution* (IFD), an optimal survival model that suggests a species will proportionately distribute group members (in this case responses in an experiment) according to levels of food resources in particular locations (Fretwell & Lucas, 1969). Thus, such a finding indicates a link between the ecological requirements of decisions (IFD), the neuronal representations of these requirements (activity in the LIP) and a resulting behavioural decision that reflects both.

A further component that influences the amount of initial sensory firing is the quantity of stimuli in the visual array. Using single cell recordings in the LIP of monkeys, Churchland, Kiani and Shadlen (2008) found that as the amount of stimuli in the visual array increased, the neuronal representations of the items were characterised by a smaller firing rate. In terms of a computational decision mechanism, the researchers also found the increase in quantity of stimuli resulted in a slower escalation of neuronal activity up to the decision threshold. The escalation rate correlated with the reaction time for the saccade towards the target in such trials, therefore providing further evidence that a threshold of activity needs to be reached before the movement is initiated. The researchers proposed that the slower escalation was a result of a requirement to accumulate more evidence over time to accurately decide where to look out of the many competing stimuli.

Reaction time irrespective of neuronal recordings is also a useful tool to provide evidence for escalatory firing. For example, the *Linear Approach to Threshold with Ergodic Rate* (LATER) model (Carpenter & Williams, 1995) can be used to investigate different escalatory patterns during a decision task. The escalatory firing can be inferred from examining the nature of the Gaussian distributions of reaction times across many trials of a task that requires a speedy eye movement to a target. A reduction in reaction time without a change in the distribution is indicative of a general bias for choosing one option (due to a general increase in firing even before initiation of the escalation). This can be achieved by making one desired response being more likely than others during a set of trials. A reduction in reaction time with an accompanying change in the distribution (the proportion of *quick* trials increasing in relation to *slow* trials) occurs when the rate of escalation of activity is quicker. Such a shift is indicative of a sensitisation of the perceptual processing and response generation and will occur when one option is linked to a reward outcome. The LATER model has been shown to predict reaction time distribution in accordance to bias and reward manipulations, thus allowing a reliable inference of an escalatory computational decision mechanism. Such models are an effective indirect way to infer differences in escalatory firing during various decision tasks.

Gold and Shadlen (2007) suggest that subjective preference formation could also involve the same computational properties of decision making that are evident in the generation of sensory-motor eye movements and simple choice-related eye movements. Evidence of neuronal representations of subjective decision making has been limited to coding of the magnitude of a reward. For example, during a forced choice task using different types of juices, activity in the orbito-frontal cortex of monkeys was correlated with the subjective value of the eventual chosen item (e.g. a value that consisted of a trade off between quality and quantity of the reward). This encoding of the value occurred in the orbito-frontal cortex irrespective of the location of choice, type of option, or generation of the movement required (Padoa-Schioppa & Assad, 2006). The possibility of the existence of neuronal representations for comparing the values of two options irrespective of perceptual properties and motor responses can allow speculation about decisions based on internal subjective introspection.

Although escalatory firing has been captured in human studies using fMRI during decision tasks involving motor production (Rowe, Hughes & Nimmo-Smith, 2010), there have been no neuroimaging studies to date that have been able to capture this escalatory firing during subjective preference formation. However, several studies have provided indirect evidence of an escalating decision mechanism for subjective preference formation using cognitive psychology paradigms. The most prominent work has been carried out by Shimojo and colleagues (Shimojo, Simion, Shimojo & Scheier, 2003), who have found patterns of eye movements leading up to a decision point that indicate an active escalation of fixations towards eventual chosen items.

The Relationship between Eye Movements and Decisions

The gaze cascade hypothesis, originally developed by Shimojo et al. (2003), suggests that the decision process for a binary forced preference choice is similar to the escalatory-computational decision making seen in the aforementioned *sensory-motor* decision mechanism and the *forced choice* decision mechanism. Furthermore, they propose that one of the input mechanisms to the escalating decision process is the act of making a saccade to, and subsequent fixation on one of the options. Importantly, it is the fixation duration after a saccade that adds to the value assigned to the respective option. Therefore, it was proposed that the eye movement itself plays a causal role in the process of preference formation.

The evidence for the gaze cascade hypothesis is mainly indirect, but the prospect of such a mechanism is of interest for two reasons. Firstly, most empirical research on the role of eye movements has suggested a different causal relation, with high-level semantic features controlling the eye gaze. For example, the likelihood and the duration of gaze fixation on an object can be influenced by its semantic properties such as prior scenic/contextual information (De Graef, Christiaens & D'Ydewalle, 1990) and semantic consistencies between objects and its surrounding contextual scene (Henderson, Weeks & Hollingworth, 1999). Thus, an orchestrative role for eye gaze in conscious appraisal, as proposed by Shimojo et al. (2003), would pose a problem for attention theories that view eye gaze as a simple indexing of conscious informativeness. Secondly, the nature of a causal gaze cascade could lend evidence to a computational decision mechanism for preference formation. In contrast to decision value accumulation resulting in an eye movement, the gaze cascade hypothesis suggests that the eye movements are feeding into an accumulating decision value.

Evidence of Shimojo et al.'s (2003) gaze cascade comes from analysing where subjects are looking during a task that requires a decision as to which face out of two faces is the more attractive. Subjects freely looked at pairs of faces and indicated which face was more attractive via a respective button press. The gaze likelihood analysis revealed that, from approximately 600ms prior to decision, the gaze was more likely to be directed to the eventual chosen item. There was also a greater increase in probability as the duration before decision decreased, thus the probability of looking at the eventual chosen item is suggested to cascade up until the decision point (as depicted in Figure 1).

This cascading effect was also greater when the two faces were similar in attractiveness, thus indicating that as the difficulty of valuation increased, the valuation was becoming more reliant on the influence of the eye movement.

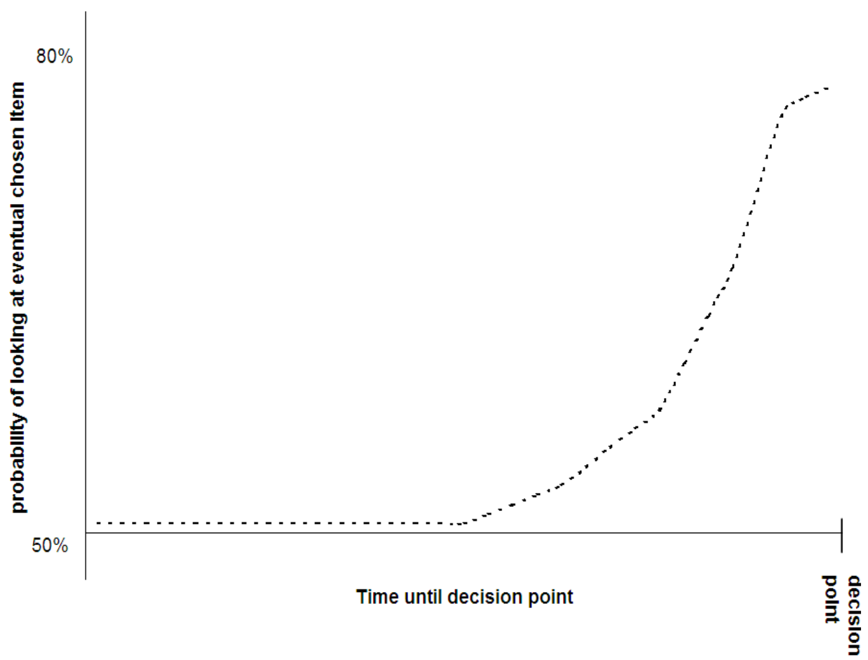

Figure 1. A graph depicting the gaze cascade effect. The probability of fixating at the eventual chosen item is plotted as a function of time leading up to the decision point.

It is intuitive to think that the gaze cascade may reflect post-choice eye movements of an already selected option, however there are several reasons as to why this is not the case. Firstly, the cascade does not occur for every decision task. When the task was to choose which face was more round or which face was more disliked, the gaze-likelihood analysis revealed that the probability of looking at the eventual choice did not increase as duration until the decision point decreased. Instead, the probability plateaued sitting around 60% for the remaining 600-800ms until the decision point. If the cascade was a simple reflection of an already made decision, the cascade would be expected to occur for every type of decision.

A counter-argument to this could be that the cascade does occur as a post-decision phenomenon, but only for preference judgements. However, this is not likely to be the case, as the cascade can start long before a decision is made. The start of the build up can occur between 1-2 seconds before the decision point when the images were viewed within a small gaze-contingent window (thus making the task more difficult and time consuming; Simion & Shimojo, 2006; Glaholt & Reingold, 2009) or by presenting an array of 8 stimuli to choose from (Glaholt & Reingold, 2009). If the gaze cascade was a simple reflection of a post-decision fixation during preference formation, the cascade would consistently initiate closer to the decision point.

Another possibility is that the gaze cascade may be a reflection of liking one of the particular stimuli (i.e. the eye movements were not an active part of the process, but a simple result of preferring to look at one option irrespective of the decision process). To rebut this claim, Simion and Shimojo (2007) randomly manipulated how long the stimuli were presented, so that in some of the trials the stimuli would disappear before the decision point (with a decision still needing to be made). When the stimuli disappeared before a decision had been made, the cascade would occur even after the stimuli had disappeared, with the fixations occurring in the location that the stimuli once were. This finding firstly indicated that the driving force of fixating towards one location was not due to a simple preference to look at the object. Secondly, the cascade was still present up until the point of a decision even the absence of stimuli, thus indicating the decision process was more reliant on the eye movements not the presence of the stimuli.

Further to this, the cascade disappeared immediately after the decision response, even when the stimuli were still present on the screen. This finding further indicated that the fixating towards the objects was not driven by the liking/preference of the object irrespective of the decision process, but was a key active functional component of the decision making process.

Although Simion and Shimojo (2007) claimed that the pattern of fixations was not simply a result of liking one more than the other irrespective of the decision process, they did acknowledge that *preferential looking* was a key part of guiding the fixations *during* the decision process. In particular, *preferential looking* along with an *exposure effect* is the cause of the cascade, with the resulting eye movements influencing the decision. *Preferential looking* is the concept that one prefers to look at what they like (predominantly studied using infants, Slater et al., 1998), whereas the *exposure effect* entails a repeated exposure of a stimuli producing an increase in the liking of the stimuli (Bornstein, 1989; Zajonc, 1968). Thus, *preferential looking* causes one to look at the preferred item, then the increased exposure of that item causes an increase in the liking of the item. This cycle acts as a positive feedback loop, which is the cause of the cascade until one option is prominently fixated on and the decision threshold has been reached. Specifically, it is not the cause of the cascade (*preferential looking* and an *exposure effect*) that influences the decision. Instead

Shimojo et al. (2003) propose that the decision is influenced by an affective state that has been manifested from the prolonged fixation themselves. This speculative proposition, assumes that emotion can be derived from behavioural acts which can then influence decision making, a concept in line with other emotional decision making models such as the somatic marker hypothesis (Damasio, 1996; Bechara, Damasio, & Damasio, 2000).

The somatic marker hypothesis postulates that somatic states (be it visceral, muscular or any other internal somatic states) can directly influence emotional states (positive or negative), which in turn can be used as a quick-reference guide to decision making. Damasio (1996) proposed that links between options, choices and consequences are all encoded in the prefrontal cortex as a *marker*. The subsequent presentation of the same options can elicit an outcome-related emotion, which in turn acts to guide decisions based on previous experience. In contrast to the somatic marker hypothesis, Shimojo et al. (2003) suggested that it is the duration of the fixations themselves that are guiding the subjective feelings towards the options, with longer durations of fixation resulting in a more positive state. However, in line with the somatic marker hypothesis, it is when these positive states are consciously attended to (i.e. in a decision making task), the affective state is consciously perceived as how much the item is liked. The ultimate decision can also be influenced by sensory-based and memory-based information as well, but when the options are even (same level of attractiveness), there is a greater reliance on the eye movements (and the resulting emotional state) to guide behaviour.

The prospect of the fixations being interpreted as preference is an intriguing one. A causal relationship between the orientation of eye movements and a resulting subjective feeling is in line with *bottom-up* models of emotion processing such as self perception theory (Bem, 1972; Laird, 2007). The principle of self perception theory is that subjective feelings are interpreted through physical behaviours. This theory is based on principles first proposed by James (1890) in regards to feeling emotions as a consequence of behaviour (e.g., "we feel sorry because we cry, angry because we strike, afraid because we tremble" p. 450). Empirical evidence has suggested that some subjective experiences can be influenced by physical states. For example, rating pictures for pleasantness can be influenced by positive and negative body positions whilst making the ratings (Schnall & Laird, 2003). In addition, placing a pen in between the teeth can force a participant to use the same muscles used for smiling, with a subsequent influence of increasing pleasantness ratings for short stories (Martin, Harlow & Strack, 1992) or video clips (Soussignan, 2002). Lastly, blocking positive facial-muscle activation can eliminate the effect of subliminary presented positive-words on ratings of how funny a cartoon picture is (Foroni & Semin, 2009).

In the case of the gaze cascade hypothesis, it is possible that the positive feedback loop of *preferential looking* and the *exposure effect* act implicitly to bias the gaze towards one item. This bias in gaze then produces a positive affiliation towards the biased object which is then emotionally interpreted as preferring the object (with the bias needing to reach a threshold before the ultimate decision is made).

Direct Evidence of the Causal Role of Eye Movements

As previously mentioned the gaze cascade hypothesis stipulates that as the options become more even, the decision is harder and becomes more reliant on the emotional interpretation of the bias in gaze. Krajbich, Armel and Rangel (2010) proposed a computational model that directly compares the difficulty of the decision with the dependence on the eye movements when forming preferences (equation 1).

The model takes into account the relative value of a decision option (*r*) whilst discounting any bias towards of the alternative choice (θ).

$$V_t = V_{t\text{-}1} + d\left(\mathrm{r}_{\text{left}} - \theta_{\text{right}}\right) + \varepsilon_t \qquad (1)$$

The resulting computation elicits an accumulating decision value for a given time (*Vt*) that increases as a function of the duration of the fixation (*d*) on the given option. The model also incorporates variance/noise (ε).This accumulating value will increase until the fixation is broken, and the alternative option is subsequently fixated on (thus increasing its respective *Vt*). A decision will be made when the accumulating value of one of the options reaches a threshold.

In an experiment that required a judgement of which face out of two was most attractive, Krajbich, Armel and Rangel (2010) manipulated the respective weights of the options (*r* vs θ) so that pairs of presented faces were either closely matched, moderately matched, or not matched for level of attractiveness. Fixations times and decision latencies were found to match the predictions of the model across the three different attractiveness conditions. Closely matched faces elicited slower decisions with more and longer fixations across the two faces, whereas faces that were not matched for attractiveness elicited quicker decisions with fewer and shorter fixations across the two faces. The model predicts that closely matched faces will slow down the escalation of the *Vt* for respective options due to the equality between the *r* and θ, thus requiring longer fixations to reach the threshold. The researchers argued that the match between the predictive model and results suggest evidence of the causal role of eye movements in the decision process.

Shimojo et al (2003) attempted to further illustrate the causal role of the eye movements in preference formation by directly manipulating how long subjects looked at faces during a forced choice task. When a face was presented, the subjects were required to make an eye movement (saccade) towards the face and then look at the face (fixation). The duration of this fixation is considered to be the *gaze duration*. The *gaze duration* lasts until a saccade is moved away from the face and the subject fixates on a different location. When subjects fixated on a face, it is possible that they could make smaller saccades (micro-saccades) within the boundaries of the face stimuli (e.g., fixating on the eyes and then making a saccade to the mouth). As long as the fixations all occur within the boundaries of the face stimuli, it is still considered to represent the same *gaze duration*. Subjects viewed two faces in different locations (one to the left and one to the right of the screen), one face at a time (one for 900ms, the other for 300ms). The exposures were repeated for 6 repetitions with the subjects required to make eye movements to the respective locations of the faces upon presentation. Subjects were more likely to prefer the face that was exposed for the longer duration (with a 60% probability).

This effect was not found when the faces were centrally presented for the same respective durations. The central presentation of the faces meant that the subjects were exposed to the faces, but did not need to make a saccade to the faces upon presentation (they were already fixating on the location of the face as it was presented). This fixation in the absence of an saccade is referred to as *exposure duration* (an important definitional note is that although *gaze duration* refers to the duration of looking an item, it is only considered a *gaze duration* if the fixation is from the result of a saccade from a position outside of the boundaries of the stimuli to within the boundaries of the stimuli. *Gaze duration* is considered a separate process to *exposure duration*, as *exposure duration* does not result from such an eye movement.)

This lack of an *exposure effect* indicated that the *gaze duration effect* was not due to *exposure duration* in the absence of an eye movement. Further to this, the gaze manipulation did not simply bias the subjects to respond left or right (irrespective of the task), because there was no *gaze duration effect* found in a control group that was required to perform the same task, but judge which face was most round. A roundness judgment acted as a good control task, as there was no gaze cascade effect found in the *free viewing* roundness judgment task (Shimojo et al., 2003), thus the gaze cascade hypothesis would predict no *gaze duration effect*. To ensure that the gaze manipulation was reliant on eye movements, an additional control group maintained fixation at the centre of the screen whilst peripherally viewing the faces (again 900ms and 300ms respectively) and judging attractiveness. There was no *peripheral duration effect* in this peripheral-viewing control group, thus indicating that the *gaze duration effect* was not simply due to the shifting of attention irrespective of eye movements.

Shimojo et al. (2003) suggested that the *gaze duration effect* was strong evidence of the causal role of eye movements during preference formation as preference for longer presented faces were at chance levels during *central* and *peripheral* presentations of the faces. Shimojo et al. (2003) suggested that this causal evidence of the role of eye movements during preference formation provided further evidence that the gaze cascade in a free viewing task was an active functional component of a computational decision. The cascading nature of the fixations is consistent with an escalating decision value, thus further supporting the gaze cascade hypothesis and computational decision making in subjective preference formation.

The Prospect of an Exposure Effect irrespective of Eye Movements

As previously mentioned, Shimojo et al. (2003) concluded that a *gaze duration effect* during attractiveness judgements was not simply due to an *exposure* *effect* as the effect was absent when the faces were centrally presented. However, there is a potential flaw in their experimental design, that is, the absence of an inter-stimuli mask. In a study looking at face recognition, Loffler, Gordon, Wilkinson, Goren and Wilson (2005) briefly presented subjects with a target face directly followed by a mask in the same location (backwards masking). Subjects had difficulty processing the target face when the mask was a different face, whereas there was no interference when replaced by random dots (noise). This face-mask interference only occurred when the target was presented for less than 150ms, thus indicating a 150ms face-processing threshold during recognition tasks in the presence of a face-mask. However, this processing-threshold can vary in accordance to the task involved. For example the threshold duration differs for when subjects are instructed to recognise the face compared to naming the face (Costen, Shepard, Ellis & Craw, 1994).

The processing-threshold required to form an accurate, reliable subjective attractiveness-judgement of a face, such as in Shimojo et al.'s study, is unknown. It is therefore important to consider the possibility that faces that are directly alternated in the same spatial location could act as backward masks that interfere with preference-formation processing. Backward masks that consist of noise (random dots) have been shown to substantially reduce facial-processing interference compared to backwards masks that consist of different faces. This reduction in the processing threshold is over 100ms (40ms down from 150ms) (Costen, Shepard, Ellis & Craw, 1994; Loffler et al., 2005). Therefore, it would have been advantageous to present an inter-stimuli *visual-noise* mask within the *centrally presented attractiveness* condition of Shimojo et al's (2003) study. This addition would ensure that inter-stimuli processing interference was not a possible reason as to why there was no *exposure effect* when faces were centrally presented

With the potential masking flaw in the Shimojo et al. (2003) *gaze duration effect*, it is important to clarify the effect by looking for further supporting evidence. There have been a limited number of studies that have further examined the gaze manipulation effect found by Shimojo et al. (2003). Further to this, none of the studies have been able to fully support the *gaze duration effect*.

Armel, Beaumel and Rangel (2008) replicated the gaze manipulation condition, replacing attractiveness judgements with preference judgements for food items. Although they found that longer presented items were preferred (in which they attributed to *gaze duration* adding to a decision value for the respective items), they did not use a centrally-presented control condition, thus the absence of *central exposure effect* could not be verified.

A further study (Nittono & Wada, 2009) replicated Shimojo et al's *lateral attractiveness* condition and *central attractiveness* condition but replaced face stimuli with preference for novel graphic patterns. Their findings indicated that longer presented items were only preferred in the *central attractiveness* condition (and not significantly differing from the *lateral attractiveness* condition). This finding contradicts Shimojo et al.'s *gaze duration effect* and suggests that the effect may only occur during preference judgements for specific stimuli (such as faces).

Experiment 1a

Direct evidence of *gaze duration* having an influence on preference formation irrespective of *exposure duration*, relies solely on Experiment 2 in Shimojo et al's (2003) paper. As the potential inter-stimuli interference cannot be ruled out as a possible reason for why there was no *exposure effect* in the *central attractiveness* condition, there is a strong need to replicate Shimojo et al.'s findings with the presence of an inter-stimuli mask. If, with the addition of the mask, faces that are presented for a longer duration in the *central attractiveness* condition are more likely to be preferred, in accordance to findings with novel graphic shapes (Nittono & Wada, 2009), the *gaze duration effect* could be possibly attributed to an *exposure effect* irrespective of an eye movement. Such a finding would not be line with the gaze cascade hypothesis and would have further implications in the development of computational models of decision making during subjective preference formation.

Further to this, the gaze cascade hypothesis (Shimojo et al., 2003) was derived from the escalating patterns of eye movements in a free-viewing setting, using real faces. The direct evidence of this causal role of eye movements came from a gaze manipulation paradigm that presented one option for longer than the other, using computer generated faces (CGF). Figure 2 shows an example of the real faces from the same database of faces used in Experiment 1 in Shimojo et al.'s (2003) paper and CGFs generated from the same software used in Experiment 2 of the same paper.

Figure 2. Example face pairs of real faces and computer generated faces created from the same software used in Shimojo et al.'s (2003) study.

The use of CGFs in the gaze manipulation task needs to be theoretically considered in more detail. When subjects make preference judgements between pairs of stimuli, they will make more and longer fixations towards the unique aspects of the respective stimuli (Sütterlin, Brunner & Opwis, 2008). Although CGFs appear reasonably life-like, real faces have many more unique aspects (e.g. wrinkles and various lesions). Therefore, it is possible that the gaze pattern towards *real* faces during a preference formation task will be different to CGFs. Thus, CGFs may not be a reliable set of stimuli to make inferences on how eye movements will influence preference formation for real faces.

Additionally, CGFs may be perceived differently than real faces. Mori (1970) proposed that the closer a simulated face gets to looking human-like, the more unsettling it is to view. Subjects will judge faces that are more human-like as being more eerie than non-human-like faces (Macdorman, Green, Ho & Koch, 2009). Thus, feelings of eeriness may be an important factor when subjects are forming preferences based on attractiveness of CGFs, which may not be appropriate for making inferences about preference formation in real faces.

It is therefore necessary to test the causal effect of the gaze cascade model by incorporating the same type of stimuli that elicited the gaze cascade effect into the gaze manipulation paradigm. Thus, Experiment 1a aimed to replicate the gaze manipulation experiment in Shimojo et al.'s (2003) paper, but using real faces. Further to this, it is also possible that the lack of an *exposure effect* in the *central attractiveness* condition in Shimojo et al.'s study could be due to inter-stimuli interference. Therefore, in the *central attractiveness* condition in the current study, there was an inter-stimuli noise-mask.

The gaze cascade hypothesis predicts that faces that are laterally presented for longer durations will more likely be judged as more attractive. In contrast, duration of the lateral presentations of faces will not have an effect on judgements of roundness of face. Lastly, duration of the central presentations of faces should not have an effect on judgements of attractiveness.

Method

Participants

There were 47 undergraduate psychology students from Victoria University of Wellington, New Zealand, participating in return for course credit. All participants had normal or corrected-to-normal vision. There were 10 males and 37 females[1].

Apparatus and stimuli

The recording of eye movements was obtained via the use of eye-tracker equipment (EyeLink® 1000 Tower Mount Head Supported System; SR Research Ltd., Ontario, Canada). This equipment is a video-based system that measures the corneal reflection (the left eye in this experiment) via an infrared camera, thus allowing the location of fixation to be obtained (spatial resolution: 0.01° of visual angle). The eye-tracker was utilised in conjunction with programming software (SR Research Experiment Builder, version 1.4.128 RC). The software was run on a 3-GHz Pentium D computer with the experiment being displayed on a 21” monitor at a resolution of 1024 × 768 pixels and with a refresh rate of 60 Hz. The eye-tracker equipment included a chin and forehead rest that ensured that the distance between subject’s eyes and the monitor was maintained at 57cm.

A lower case “x” (font style: Arial, font colour: black, size: 20) was presented as the fixation point in the middle of the screen at the start of a trial. Two databases were used for the face stimulus; The AR Face database (Martinez & Benavente, 1998) and the KDEF face database (Lundqvist, D., Flykt, A., & Öhman, A., 1998; The Karolinska Directed Emotional Faces - KDEF, CD ROM from Department of Clinical Neuroscience, Psychology section, Karolinska Institutet, ISBN 91-630-7164-9). Each face stimuli were standardised to fit into a 15°x15° visual angle square (whilst maintaining length-to-width proportions). Any differences in size were minimal. All faces were Caucasian with a neutral facial expression. The faces (specifically the centre of the faces) were either presented centrally, 9° visual angle to the left of centre, or 9° visual angle to the right of centre; depending on the experimental condition.

Prior to the experiment, 40 face stimuli from the AR face database (14 male and 26 female) and 61 faces from the KDEF face database (23 male and 38 female) were pre-rated independently by a further 16 undergraduate students. The subjects rated the faces for attractiveness and subsequently roundness (a score between 1-7; 1 being very unattractive or not-very-round respectively and 7 being very attractive or very round respectively). The means and standard deviations for attractiveness scores were calculated for each face. Any face that had a standard deviation greater than 1.25 for the attractiveness score was not used in subsequent conditions that required an attractiveness judgement due to a high degree of variation in scores among subjects in the pre-rating task. The mean score of attractiveness across all the remaining face stimuli was 2.85 (*SD* = 1.02). The means and standard deviations for roundness scores were calculated for each face. Any face that had a standard deviation greater than 1.25 for the roundness score was not used in subsequent conditions that required a roundness judgement due to a high degree of variation in scores among subjects in the pre-rating task. The mean score of roundness across all remaining face stimuli was 3.03 (*SD* = 1.11).

The face stimuli were then paired for attractiveness with a score no greater than 0.25 between the means of faces within a pair, based on the pre-rated scores. The faces stimuli were then re-paired respectively for roundness, again with a score no greater than 0.25 between the means of faces within a pair, based on the pre-rated scores. All pairs were respectively consisting of faces from the same sex, with the same hair colour and presence of facial hair (e.g., men with beards were only paired with other men with beards that were close in their attractiveness rating). As a result of pairing based on the pre-rating analysis, there were 16 face pairs constructed from the AR face database (6 male and 10 female) and 28 face pairs constructed from the KDEF face database (10 male and 18 female).

Design and procedure

Experiment 1 consisted of 3 independent experimental conditions; *lateral attractiveness* condition, *central attractiveness* condition and the *lateral roundness* condition. There were 16 participants in the *lateral attractiveness* condition (2 males), 16 participants in the *central attractiveness* condition (4 males) and 15 participants in the *lateral roundness* condition (4 males). Subjects were tested in a quiet room. The experiment consisted of 44 trials split into 3 blocks. The first block consisted of 16 trials using face stimuli from the AR face database, the last two blocks each consisted of 14 trials using face stimuli from the KDEF face database.

During a trial in the *lateral attractiveness* condition, participants were required to fixate on a centrally present “x”. Once the participants had fixated on the “x” for 800ms, the “x” would disappear and the first face (Face A) of the pair would appear either to the left or right of the point of fixation. The face would be present on the screen for either 300ms or 900ms, after which point it would disappear and the second face (Face B) would appear on the opposite side for the alternative duration from the duration of Face A (e.g. if face appeared on the right for 900ms, Face B would then appear on the left for 300ms). The presentation of the faces alternated in this fashion for a further 6 repetitions (7 in all) as depicted in Figure 3.

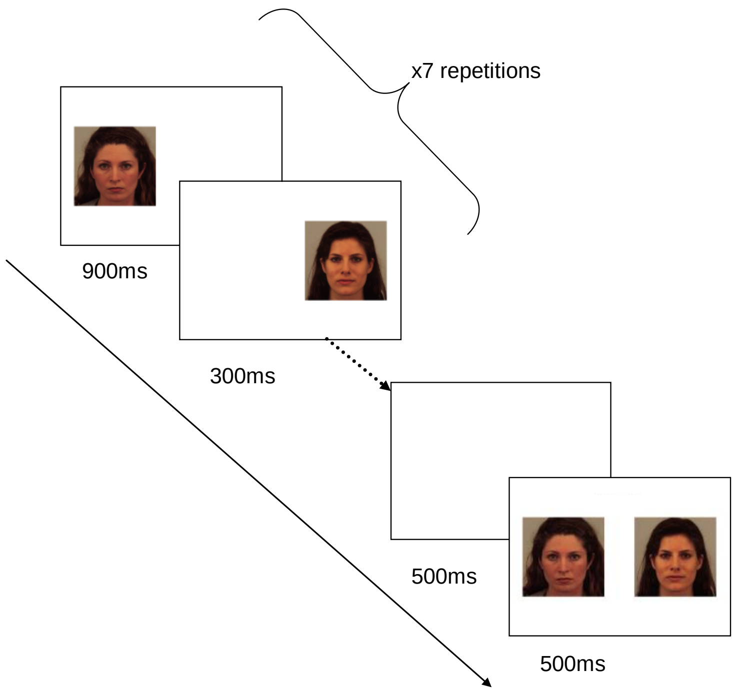

Figure 3. A flow chart representation of a trial during the *lateral attractiveness* condition in experiment 1a. Responses could be made as soon as both faces were simultaneously displayed (and could still be made once the faces had disappeared after 500ms).

The order of face pair presentation, side of first presentation and duration of first presentation was counterbalanced so that the respective faces in each pair would appear either first or second, on the left or right or for a longer or shorter duration an equal number of times across the 16 subjects within the *lateral attractiveness* condition. This was to ensure that any duration-related differences in preference for particular faces were not due to favouring the first presented face, a general bias to one side over the other, or due to one face being generally preferred over the other irrespective of presentation duration. The face pairs were based on the attractiveness pre-rated pairing. After the seven repetitions of alternative presentations of the faces, there was a blank screen for 500ms, followed by the faces being simultaneously presented in their respective locations for a further 500ms (target screen), followed again by a blank screen which was presented for 8 seconds or until the subject made a response.

The participants were instructed to look at the faces as they appeared on the screen and to judge which face was most attractive. Responses were to be made as soon as both faces were simultaneously presented on the target screen (and could still be made during the subsequent blank screen). Responses were made by pressing either a left-trigger button or right-trigger button on a control pad, corresponding to the faces on the left or the right. The subjects performed 4 practice trials before the experimental trials began and were encouraged to take breaks in between the blocks of trials. The order of trials was pseudo-randomised. The trial order was firstly randomised within each block of trials. The trial order was then arranged so that the first presented face was not presented on the same side (left or right respectively) for more than 4 consecutive trials. Further to this, the duration of the first presented face was not the same for more than 4 consecutive trials. These manipulations were to ensure that the subject would not form any kind of response bias based on location-based or duration-based information of the first presented face.

The *central attractiveness* condition was identical to the *lateral attractiveness* condition with two exceptions. Firstly, the faces were centrally presented (whilst still being simultaneously laterally presented during the target screen). Secondly, there was a central 15°x15° visual angle squared mask (random visual noise dots) presented for 50ms before each of the 14 presentations of the faces during a trial.

The *lateral roundness* condition was identical to the *lateral attractiveness* condition with two exceptions. Firstly, the subjects were instructed to judge which face was most round. Secondly, the face pairs were based on the roundness pre-rated pairings.

Data Analysis

Any trials in which the subject did not fixate on any one respective face for at least 6 out of the 7 presentations during the trial were removed from analysis. 156 of such trials (22.2%) were removed from the *lateral attractiveness* condition. The data from 2 subjects were completely removed from analysis for the *lateral attractiveness* condition as they had more than 40% of their trials removed via the aforementioned fixation criteria. None of the remaining had more than 40% of trials removed. Further to this, on 3 occasions there was no response made by the subject. Therefore, there were a total of 175 trials removed in the *lateral attractiveness* condition (24.9%).

In the *central attractiveness* condition, there were two occasions in which no response was made (0.3% of all trials). Finally, in the *lateral roundness* condition, 108 trials (16.4%) were removed due to not meeting the required 6 fixations for each face. The data from one subject was completely removed from analysis in the *lateral roundness* condition as they had more than 40% of their trials removed. There were a total of 119 trials removed for the *lateral roundness* condition (18%).

Reaction time was not considered during initial data analysis for two reasons. Firstly, it is possible that the decision could have been made before the opportunity to select the response, thus enabling the possibility of very quick responses upon the presentation of the “target screen”. Secondly, the deliberation process may still be active even at the target screen (particularly if the faces are closely matched for attractiveness) and even after the stimulus disappears. In order to convincingly propose that eye movements can influence decisions, the quickest and longest decisions will also need to be considered.

Results

Lateral attractiveness condition

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. As indicated in Table 1, the mean probability of choosing the face that was presented for the longer duration was 56.43% (*SD* = 11.29, *SE* = 1.70). Across all 44 face pairs, the probability of choosing the face that was presented for the longer duration was greater than chance ($t(43) = 3.776$, $p<0.001$, $d = 0.57$).

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 56.62% (*SD* = 11.11, *SE* = 2.97). Across all 14 subjects, the probability of choosing the face that was presented for the longer duration was greater than chance ($t(13) = 2.232$, $p<0.05$, $d = 0.60$).

Additional Statistics

As subjects in a binary forced choice paradigm are more likely to have a bias for choosing the right item irrespective of any other manipulation (Nisbett & Wilson, 1977), an item analysis was performed to assess any left/right bias. There was a bias towards the probability of selecting the face presented on the right hand side (*M* = 54.8%, *SD* = 10.92, *SE* = 1.65), which was significantly greater than chance ($t(43) = 2.89$, $p<0.01$). Upon removing trials in which the face to the right was selected, the probability of choosing the face that was presented for the longer duration was still greater than chance ($t(43) = 2.204$, $p<0.05$, $d = 0.33$).

The probability of choosing one face over the other within a face-pair irrespective of any other manipulation was calculated across all 44 face-pairs. This probability was considered to represent how closely matched the respective face-pairs were in attractiveness (in which faces-pairs that were evenly selected being considered closely matched for attractiveness, whilst face-pairs in which one face was consistently chosen over the other being considered not so closely matched for attractiveness). This matching of attractiveness was inferred to represent the difficulty of the task (with closely matched faces yielding a more difficult decision). A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen ($\beta = -.19$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced by fixation durations to guide the decision.

Central attractiveness condition

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. As indicated in Table 1, the mean probability of choosing the face that was presented for the longer duration was 55.26% ($SD = 11.67$, $SE = 1.76$). Across all 44 face pairs, the probability of choosing the face that was presented for the longer duration was greater than chance ($t(43) = 2.988$, $p<0.01$, $d = 0.45$).

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 55.26% (SD = 9.57, SE = 2.40). Across all 16 subjects, the probability of choosing the face that was presented for the longer duration was greater than chance ($t(15) = 2.191$, $p<0.05$, $d = 0.55$).

Additional Analysis

There was no significant bias towards selecting the face presented on the left or right hand side. A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen ($\beta = .11$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced by exposure durations to guide the decision.

Lateral roundness condition

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. As indicated in Table 1, the mean probability of choosing the face that was presented for the longer duration was 52.17% (SD = 13.87, SE = 2.09). Item analysis revealed the probability of choosing the face that was presented for the longer duration was no different to chance ($t(43) = 1.04$, p=0.31).

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 51.77% (SD = 7.73, SE = 2.06).

Across all 15 subjects, the probability of choosing the face that was presented for the longer duration was no different to chance ($t(14) = 0.86$, $p=0.41$).

Additional Analysis

There was a bias towards the probability of selecting the face presented on the right hand side (M = 59.54%, SE =2.25), which was significantly greater than chance ($t(43) = 4.25$, $p<0.001$). Upon removing trials in which the face to the right was selected, the probability of choosing the face that was presented for the longer duration was still no different to chance.

A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen ($\beta = .16$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced by fixation durations to guide the decision.

Table 1
Probability of choosing the longer presented face (as per item analysis) across conditions in Experiment 1a

	Condition		
	Lateral attractiveness	Central attractiveness	Lateral roundness
Percentage preference for longer shown face	56.43*	55.26*	52.17
SD	11.29	11.67	13.87

Note. * denotes a probability significantly greater than chance (50%).

Discussion

As per the findings of Shimojo et al. (2003), faces presented for a longer duration in the *lateral attractiveness* condition were expected to be more likely to be preferred. The results indicate that this was the case with the probability of choosing the longer presented face being significantly greater than chance (56.43%). It was also expected that *exposure duration* in the *central attractiveness* condition would have no effect on preference; however, the results indicate that the probability of choosing the longer presented face in the *central attractiveness* condition was also significantly greater than chance (55.26%). Lastly, as expected, the probability of choosing the longer presented face in the *lateral roundness* condition was not different than chance (52.17%). The lack of the *gaze duration effect* in the *roundness* condition would dispute the prospect that the increased exposure during attractiveness judgements is simply biasing the choice irrespective of perceived attractiveness.

It is important to consider the possibility that the roundness judgement task is simply an easier task, thus not relying on *gaze duration* to influence the decision. Task difficulty within conditions was inferred by an index calculated from the probability of choosing one face over the other within face pairs irrespective of any other manipulation (with face pairs that were equally chosen being considered a *difficult choice* and face pairs that had one face favoured over the other being considered an *easier choice*). The results indicated that task difficulty was not predictive of whether the decisions were influenced by *gaze/exposure duration* in all of the respective conditions. That is, *gaze/exposure duration* (irrespective of task difficulty) can influence attractiveness judgements, but does not influence the perceptually driven process of roundness judgements.

As per the results in the *central attractiveness* condition, the findings of experiment 1a are not in line with the gaze cascade hypothesis and suggest that exposure alone, in the absence of eye movements, can also influence preference formation. The results are similar to Nittono and Wada (2009), who found an *exposure effect* for centrally presented novel graphic patterns and suggest that with real faces, a simple increase in exposure can influence preference formation. A further condition is required to explore the nature of the *exposure effect* in the *central attractiveness* condition.

Experiment 1b

In Experiment 1a, the *exposure effect* in the *central attractiveness* condition was of a similar magnitude to the *gaze duration effect* in the *lateral attractiveness* condition. This finding was in contrast to Shimojo et al. (2003) who found a *gaze duration effect* only. There are 2 methodological differences between the present study and Shimojo et al.'s study. Firstly, the present study used real faces, whereas Shimojo et al. (2003) used CGFs. Secondly, the present study used inter-stimuli noise-masks in the *central attractiveness* condition, whereas Shimojo et al. (2003) did not use inter-stimuli masking. It is possible that either factor may have contributed to the different outcome.

It is possible that Shimojo et al. (2003) would have found an *exposure effect* in their version of the *central attractiveness* condition if they had used inter-stimuli noise-masking. On the other hand, it is possible that the preference formation of real faces is fundamentally different to the preference formation of CGFs. Either way, a logical progression would be to re-run the *central attractiveness* condition in the absence of inter-stimuli masking. This would expose which factor was responsible for the differing results between Experiment 1a and Shimojo et al. (2003). If, in the absence of masking, real faces that are centrally presented for a longer duration are more likely to be preferred, then it would indicate that the nature of the stimuli is responsible for the differing results between experiment 1a and Shimojo et al. (2003). However, if the duration of presentation has no effect on preference for centrally presented real faces, in the absence of a mask, then it is likely that the degree of interference is responsible for the differing results between experiment 1a and Shimojo et al. (2003).

Method

Participants

There were 16 undergraduate psychology students from Victoria University of Wellington, New Zealand, participated in return for course credit. All participants had normal or corrected-to-normal vision. There were 2 males and 14 females.

Apparatus and stimuli

The apparatus and stimuli were the same as the *central attractiveness* condition in Experiment 1a.

Design and Procedure

The design and procedure were same as the *central attractiveness* condition in Experiment 1a with the exception of no inter-stimuli masking.

Data Analysis

There were no trials removed from analysis. Every subject made a response on every trial. Reaction time was not considered as per the explanation from Experiment 1a.

Results

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. The mean probability of choosing the face that was presented for the longer duration was 61.36% (SD = 13.09, SE = 1.97). An item analysis revealed the probability of choosing the face that was presented for the longer duration was greater than chance

($t(43) = 5.76$, $p<0.01$, $d = 0.87$). There was no significant bias towards selecting the face presented on the left or right hand side.

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 61.36% ($SD = 9.46$, $SE = 2.37$). Across all 16 subjects, the probability of choosing the face that was presented for the longer duration was greater than chance ($t(15) = 4.80$, $p<0.001$, $d = 1.20$).

Additional Analysis

A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen ($\beta = .08$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced by exposure durations to guide the decision.

Discussion

The results of Experiment 1b showed an *exposure effect* in the *central attractiveness* condition even with the absence of inter-stimuli (noise) masking. In line with the *central attractiveness* condition in Experiment 1a, faces that were centrally presented for a longer duration were more likely to be judged as the most attractive even in the absence of an eye movement. This finding is contrary to the gaze cascade hypothesis (Shimojo et al. 2003) which proposes that an eye movement is necessary for the *gaze duration effect* to occur in the current paradigm.

Both the *central attractiveness masked* condition in experiment 1a and the *central attractiveness non-masked* condition in experiment 1b elicited an *exposure effect*. This finding indicates that the *exposure effect* in the centrally presented conditions is not reliant on an inter-stimuli noise mask when using real faces. As the only difference between experiment 1b and Shimojo et al. (2003) was the face stimuli, it can be proposed that the nature of the stimuli is an important factor when examining *gaze duration/exposure effects* during preference formation.

Shimojo et al.'s (2003) paper is the only one to date that has found a *gaze duration effect* in a *lateral attractiveness* condition, with no effect in an accompanying *central attractiveness* condition. It would therefore be advantageous to verify Shimojo et al's. (2003) findings with a direct replication using CGFs before a detailed attempt is made to account for the differing findings in the current study.

Experiment 2a

It is possible that there is a fundamental difference in processing CGFs compared to real faces. As previously mentioned, unique aspects of stimuli receive longer and more frequent fixations when preferential judgements are required (Sütterlin, Brunner & Opwis, 2008), thus the local-gaze patterns whilst examining stimuli may differ between real faces (that have more unique features) and CGFs. Further to this, CGFs may be considered more eerie due to there close resemblance of real faces (Macdorman, Green, Ho & Koch, 2009). Both factors could be possible reasons for the differing results between Shimojo et al. (2003) and the results from experiment 1a and 1b in the present study.

Experiment 2a of the present study aimed to directly replicate the *gaze duration* manipulation from experiment 2 in Shimojo et al. (2003). The results would be beneficial for two reasons. Firstly, they could lend additional support to the gaze cascade hypothesis showing that the act of an eye movement is necessary to produce the *gaze duration effect* for selective stimuli (CGFs). Secondly, the results could pave the way for a closer inspection of the differing perceptual attributes of real and CGFs, with a particular implication for further studies using CGFs.

The *exposure effect* in the *central attractiveness* (*masked* and *non-masked*) conditions in experiments 1a and 1b was not reliant on an inter-stimuli noise mask. However, due to the perceptual differences between real faces and CGFs, it is possible that inter-stimuli interference may still occur in a *non-masked* condition using CGFs. It is therefore necessary to include two *central attractiveness* conditions, one *masked* the other *non-masked*. This would further clarify whether the lack of effect in the *central attractiveness* condition in Shimojo et al.'s (2003) study was due to inter-stimuli interference or not.

As per the gaze cascade hypothesis and previous findings from Shimojo et al. (2003), it is expected that CGFs that are laterally presented for longer durations should be more likely to be judged as the more attractive. Duration of the lateral presentations of faces should not have an effect on judgements of roundness of CGF. Lastly, duration of the central presentations of CGFs (in respective *masked* and *non-masked* conditions) should not have an effect on judgements of attractiveness.

Method

Participants

There were 64 undergraduate psychology students from Victoria University of Wellington, New Zealand, participated in return for course credit. All participants had normal or corrected-to-normal vision. There were 15 males and 49 females[1].

Apparatus and stimuli

The apparatus was the same as used in Experiment 1. The face stimuli consisted of 140 randomly computer generated faces using the *Facegen Modeller 3.4* software (www.facegen.com). Parameters of the generator software were set to standardise age (20<30), Caricature (average<attractive), symmetry (absolute symmetric), race (European) and gender (female<very female; or male<very male)

during random generation of faces. Each face stimuli was standardised to fit into a 15°x15° visual angle square (whilst maintaining length-to-width proportions). Any differences in size were minimal. The faces (specifically the centre of the faces) were either presented centrally, 9° visual angle to the left of centre, or 9° visual angle to the right of centre; depending on the experimental condition.

Prior to the experiment, the 140 face stimuli were pre-rated independently by a further 20 undergraduate students for attractiveness and subsequently roundness (a score between 1-7; 1 being very unattractive or not-very-round respectively and 7 being very attractive or very round respectively). The means and standard deviations for attractiveness scores were calculated for each face. Any face that had a standard deviation greater than 1.25 for the attractiveness score was not used in subsequent conditions that required an attractiveness judgement due to a high degree of variation in scores among subjects in the pre-rating task. The mean score of attractiveness across all the remaining face stimuli was 3.63 (*SD* =1.04). The means and standard deviations for roundness scores were calculated for each face. Any face that had a standard deviation greater than 1.25 for the roundness score was not used in subsequent conditions that required a roundness judgement due to a high degree of variation in scores among subjects in the pre-rating task. The mean score of roundness across all remaining face stimuli was 3.73 (*SD* = 1.08).

The face stimuli were then paired for attractiveness and with a score no greater than 0.25 between the means of faces within a pair, based on the pre-rated scores. The faces stimuli were then re-paired respectively for roundness, again with a score no greater than 0.25 between the means of faces within a pair, based on the pre-rated scores. All pairs were respectively consisting of faces from the same sex. As a result of pairing based on the pre-rating analysis, there were 60 face pairs constructed (half male, half female).

Design and procedure

Experiment 2a consisted of 4 independent experimental conditions; *lateral attractiveness* condition, *central attractiveness masked* condition, *central attractiveness non-masked* condition and the *lateral roundness* condition. There were 16 participants in the *lateral attractiveness* condition (3 males), 16 participants in the *central attractiveness masked* condition (3 males), 16 participants in the *central attractiveness non-masked* condition (3 males) and 16 participants in the *lateral roundness* condition (7 males). Subjects were tested in a quiet room. The experiment consisted of 60 trials split into 3 blocks.

The procedure of a trial within the *lateral attractiveness*, *central attractiveness masked* and *lateral roundness* conditions was identical to their respective conditions in experiment 1a. The procedure of a trial within the *central attractiveness non-masked* condition was identical to experiment 1b.

Data Analysis

Any trial in which the subject did not fixate on any one respective face for at least 6 out of the 7 presentations during the trial was removed from analysis. There were 239 of such trials (24.9%) removed from the *lateral attractiveness* condition. The data from two subjects were completely removed from analysis for the *lateral attractiveness* condition as they had more than 40% of their trials removed via the aforementioned fixation criteria. Therefore, there were a total of 284 trials removed in the *lateral attractiveness* condition (29.6%).

In the *central attractiveness masked* condition, there were four occasions in which no response was made (0.4% of all trials). In the *central attractiveness non-*

masked condition, all responses were eligible for further analysis. Finally in the *lateral roundness* condition, 159 trials (16.6%) were removed due to not meeting the required 6 fixations for each face. As per Experiment 1, reaction time was also not considered during initial data analysis.

Results

Lateral attractiveness condition

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. As indicated in Table 2, the mean probability of choosing the face that was presented for the longer duration was 55.83% (*SD* = 12.73, *SE* = 1.64). Item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. Across all 60 face pairs, the probability of choosing the face that was presented for the longer duration was greater than chance ($t(59) = 3.55$, $p<0.001$, $d = 0.46$). There was no significant bias towards selecting the face presented on the left or right hand side.

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 55.26% (*SD* = 13.22, *SE* = 3.53). Across all 14 subjects, the probability of choosing the face that was presented for the longer duration was no different to chance ($t(15) = 1.49$, $p=0.16$).

Additional Analysis

A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen ($\beta = -.07$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced by exposure durations to guide the decision.

Central attractiveness masked condition

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. As indicated in Table 2, the mean probability of choosing the face that was presented for the longer duration was 53.94% (SD = 10.28, SE = 1.33). An item analysis revealed the probability of choosing the face that was presented for the longer duration was greater than chance ($t(59) = 2.97$, $p<0.01$, $d = 0.38$). There was no significant bias towards selecting the face presented on the left or right hand side.

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 53.97% (SD = 8.17, SE = 2.04). Across all 16 subjects, the probability of choosing the face that was presented for the longer duration was no different to chance ($t(15) = 1.95$, $p=0.07$).

Additional Analysis

A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) significantly predicted whether the face that was presented for the longer duration was more likely to be chosen ($\beta = -.33$, $t(59) = -2.70$, $p<0.01$). However, task difficulty only accounted for a small proportion of the variance in probability of choosing the face presented for a longer duration ($R^2 = .11$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were being slightly influenced by exposure durations to guide the decision.

Central attractiveness non-masked condition

Item Analysis

An Item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. As indicated in Table 2, the mean probability of choosing the face that was presented for the longer duration was 53.44% (*SD* = 13.64, *SE* = 1.76). An item analysis revealed the probability of choosing the face that was presented for the longer duration was close to being significantly greater than chance ($t(59) = 1.95$, $p = 0.056$, $d = 0.25$). There was no significant bias towards selecting the face presented on the left or right hand side.

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 53.44% (*SD* = 9.77, *SE* = 2.44). Across all 16 subjects, the probability of choosing the face that was presented for the longer duration was no different to chance ($t(15) = 1.41$, $p=0.18$).

Additional Analysis

A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen ($\beta = .08$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced by exposure durations to guide the decision.

Lateral roundness condition

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. As indicated in Table 2, the mean probability of choosing the face that was presented for the longer duration was 56.36% (*SD* = 10.77, *SE* = 10.77). Item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. Across all 60 face pairs, the probability of choosing the face that was presented for the longer duration was greater than chance ($t(59) = 4.57$, $p<0.001$, $d = 0.59$).

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 56.42% (*SD* = 10.19, *SE* = 2.55). Across all 16 subjects, the probability of choosing the face that was presented for the longer duration was greater than chance ($t(15) = 2.52$, $p<0.05$, $d = 0.63$).

Additional Analysis

There was a strong bias towards the probability of selecting the face presented on the right hand side ($M = 67.64\%$, $SE = 1.51$), which was significantly greater than chance ($t(59) = 11.67$, $p<0.001$). Upon removing trials in where the face to the right was selected, the probability of choosing the face that was presented for the longer duration was still greater than chance ($t(59) = 3.74$, $p<0.001$, $d = 0.49$) as per item analysis.

A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen ($\beta = -.08$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced on fixation durations to guide the decision.

Combining the findings from Experiment 1a, 1b and Experiment 2a (Figure 4), the lateral roundness condition using real faces is the only condition that does not appear to be influenced by the presentation duration of the stimulus (with the *central attractiveness non-masked* condition using CGFs being close to significance; p=0.56).

Table 2

Probability of choosing the longer presented face (as per item analysis) across conditions in Experiment 2a

	Condition			
	Lateral attractiveness	Central attractiveness masked	Central attractiveness non-masked	Lateral roundness
Percentage preference for longer shown face	55.83*	53.94*	53.44	56.36*
SD	12.73	10.28	13.64	10.77

Note. * denotes a probability significantly greater than chance (50%)

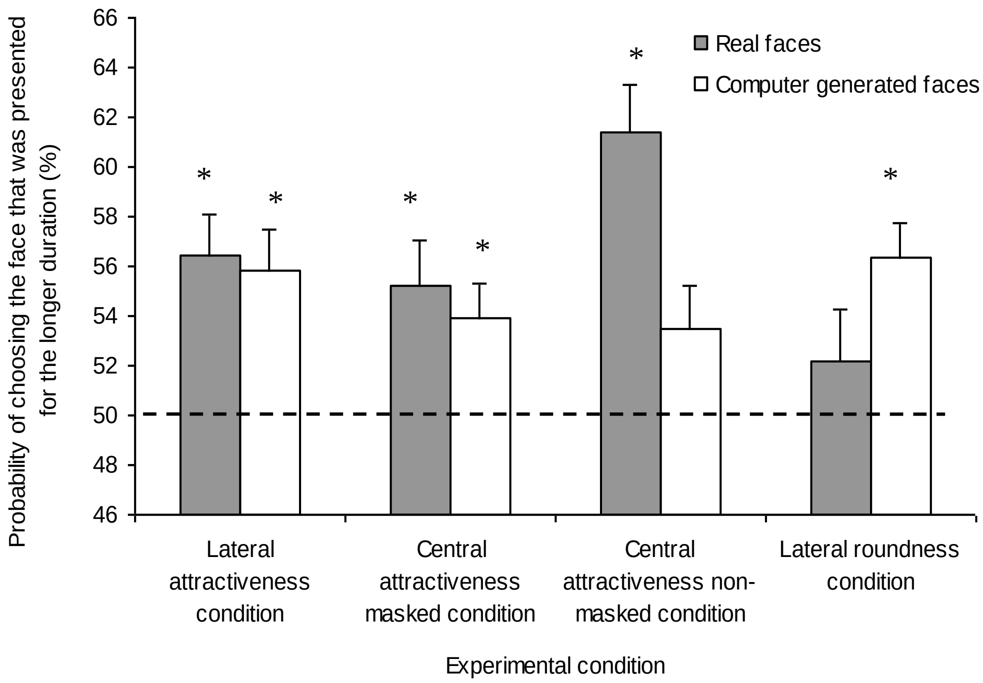

Figure 4. Mean probability of choosing the longer presented face (as per item analysis) across all experimental conditions in experiment 1a, 1b and experiment 2a. The dotted line represents chance levels (50%).

Note. * denotes a probability significantly greater than chance (50%)

Discussion

As per the findings of Shimojo et al. (2003), it was expected that faces presented for a longer duration in the *lateral attractiveness* condition would be more likely to be preferred. The results indicate that this was the case with the probability of choosing the longer presented face (as per item analysis) being significantly greater than chance (55.83%). It was also expected that exposure duration in the *central attractiveness masked* condition and the *central attractiveness non-masked* condition would have no effect on preference. However, the results indicate that the probability of choosing the longer presented face (as per item analysis) in the *central attractiveness masked* condition was significantly greater than chance (53.94), whereas the probability for choosing the longer presented face in the central attractiveness non-masked condition was on the border of being significantly greater than chance (53.44%). Lastly, the probability of choosing the longer presented face (as per item analysis and subject analysis) in the *lateral roundness* condition was significantly greater than chance (56.36%), which was contrary to the expected chance levels of probability.

When an *item analysis* was conducted for Experiment 2a, the results indicated that faces presented for the longer duration were more likely to be chosen in the *lateral attractiveness, central attractiveness masked* and *lateral roundness* conditions. However, when a *subject analysis* was conducted, the results indicated that faces presented for a longer duration were more likely to be chosen in the *lateral roundness* condition only. This difference between *item analysis* and *subject analysis* has an important implication for the interpretation of the results of Experiment 2a. The findings from the s*ubject analysis* would suggest that there was no effect in the *lateral attractiveness* and *central attractiveness masked* condition. However, it is possible that this lack of effect is due to a small number of subjects available for analysis (thus no significant effect is assumed when there actually is one; *type II error*). One the other hand, it is possible that the *item analysis* only revealed an effect in the *lateral attractiveness* and *central attractiveness masked* condition due to an *excessive* number of 60 face-pairs to analyse (thus a significant effect is assumed when there is actually no effect; *type I error*). In both cases, the results are different to the findings of Shimojo et al. (2003) who found a clear distinction between longer faces being preferred in their *lateral attractiveness* condition and longer presented faces being chosen at chance levels in their *central attractiveness* condition.

The results from *item analysis* are be deemed to be the most appropriate for interpreting the findings from Experiment 2a for two reasons. Firstly, in Experiment 1a and 1b both *item analysis* and *subject analysis* indicated that longer presented faces were preferred in the *lateral attractiveness, central attractiveness non-masked* and *central attractiveness masked* conditions. This finding would lend support to the argument that a *type II error* is likely to have occurred during *subject analysis* in the respective conditions of Experiment 2a. Furthermore, in all of the *lateral and central attractiveness* conditions across Experiment 1a, 1b and 2a, there is a trend showing that the probability of choosing the longer presented face is greater than 50%. This trend lends further support to the argument that a type II error is likely to have occurred in the respective conditions of Experiment 2a.

As per the *item analysis*, the results from experiment 2a have an important implication for the gaze cascade hypothesis and associated literature. Shimojo et al. (2003) have been the only researchers to date using the gaze manipulation paradigm that has found a *gaze duration effect* in a *lateral attractiveness* condition with no accompanying *exposure duration* effect in a *central attractiveness* condition. Shimojo et al.'s findings are referenced for support to the gaze cascade hypothesis (Simion & Shimojo, 2007), computational models of preference formation (Krajbich, Armel & Rangel, 2010; Armel, Beaurmel & Rangel, 2008), and self perception theories that propose emotional experience is interpreted from behavioural actions (Simion & Shimojo, 2006).

The direct replication in the current study produced results that are fundamentally different to the results from Shimojo et al.'s (2003) gaze manipulation experiment, thus questioning the validity of their well-referenced *gaze duration effect*. The results of the current study are more in line with the findings from Nittono and Wada (2009), who also found an *exposure effect* in a *central attractiveness* condition using novel graphic patterns. It is unclear as to why the present study differed from Shimojo et al. (2003), as it was a direct replication using the same paradigm and same type of stimuli (CGFs).

Why was there an *exposure effect* in the *central attractiveness* condition using CGFs in the present study? Faces that were presented for a longer duration were more likely to be preferred, thus a straight forward conclusion would be that this is evidence of an *exposure effect* irrespective of eye movements. Reber, Winkielman and Schwarz (1998) found that graphic patterns presented for longer durations were preferred in affective judgments, which is in line with the findings from the current study. This being the case, it is unclear why Shimojo et al. (2003) did not find the same results in their version of the *central attractiveness* condition. One possibility is the small sample size of 10 participants in the *central attractiveness* condition in Shimojo et al.'s (2003) study. *Exposure effects* can be sensitive to individual differences (e.g. levels of resting frontal-cortical activation; Harmon-Jones & Allen, 2001), as well as situational factors (e.g. current mood; de Vries, Holland, Chenier, Starr & Winkielmann, 2010) that can act to mediate the magnitude of the effect. Thus perhaps there was an over-representation of subjects that were not susceptible to the exposure manipulation in Shimojo et al.'s (2003) experiment. A speculative proposition nonetheless, one can only verify with replicating the *central attractiveness* condition with closer examinations of individuals differences (pre-measuring mediating factors such as baseline left-frontal cortical activation and mood).

A further intriguing finding in experiment 2a is the presence of a *gaze duration effect* in the *lateral roundness* condition. This finding cannot be explained by the gaze cascade hypothesis, which proposes that the *gaze duration effect* should only be present during *attractiveness* judgements, not *roundness* judgements. Further to this, it is unlikely that the effect is due to a general *exposure effect*, which is only present during affective judgements and not perceptual judgements (Seamon, McKenna & Binder, 1998). The effect cannot be explained by task difficulty, as task difficulty was not predictive of whether the subjects were influenced by gaze duration. To further examine the intriguing finding, it is necessary to further explore roundness judgments using CGFs.

Experiment 2b

It would be of interest to investigate whether eye movements are necessary for the *gaze duration effect* in the *lateral roundness* condition as this would assist in determining the cause of the effect. A *central roundness* condition would indicate whether a simple *exposure effect* irrespective of eye movements possibly influence the roundness judgement. Prior research has indicated that *exposure effects* irrespective of eye movements are present in affective judgements, but not for non-affective judgements (Seamon, McKenna & Binder, 1998). It was therefore expected that *exposure duration* of centrally presented faces with have no effect on roundness judgements.

Method

Participants

There were 16 undergraduate psychology students from Victoria University of Wellington, New Zealand, participating in return for course credit. All participants had normal or corrected-to-normal vision. There were 3 males and 13 females.

Apparatus and stimuli

The apparatus and stimuli was the same as the *lateral roundness* condition in Experiment 2a.

Design and Procedure

The design and procedure was the same as the *central attractiveness masked* condition in Experiment 2a.

Data Analysis

There were 3 trials removed from analysis due to no response being made (0.3% of trials altogether). Reaction time was not considered as per the explanation from Experiment 1a.

Results

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. The mean probability of choosing the face that was presented for the longer duration was 50.87% (SD = 12.85). An item analysis revealed the probability of choosing the face that was presented for the longer duration was no different to chance ($t(59) = 0.52$, $p=0.60$).

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 50.87% (*SD* = 7.37, *SE* = 1.84). Across all 16 subjects, the probability of choosing the face that was presented for the longer duration was no different to chance ($t(15) = 0.47$, p=0.65).

Additional Analysis

There was no significant bias towards selecting the face presented on the left or right hand side. A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen (β = .04). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced by exposure durations to guide the decision.

Discussion

As predicted, the *exposure duration* of the centrally presented CGFs had no influence on roundness judgements. This finding indicates that with CGFs, it is not a simple *exposure effect* irrespective of eye movements that is responsible for the *gaze duration effect* in the *lateral roundness* condition.

The findings from the *lateral roundness* and the *central roundness* conditions cannot be explained by the gaze cascade hypothesis (that proposes that such an effect is exclusive to preference formation). However, Krajbich, Armel and Rangel’s (2010) computational model of decision making and eye movements can still account for the findings in the *roundness* conditions. The act of fixating on the respective items, could still be adding to the decision value as postulated in the model, irrespective of the type of decision. Although feasible, there is still an important distinction to be made in the model, that is, the decoupling of eye movements and visual attention. To ensure that eye movements are necessary, and that the effect is not simple due to a shifting in visual attention, a further condition is necessary to investigate spatial shifts of attention irrespective of eye movements.

Experiment 2c

The act of making an eye movement is coupled with a shift in visual attention (Moore & Fallah, 2001). Eriksen and St. James (1986) refer to a single focusing of visual attention as a zoom lens in which a reduction of the size of the area results in a greater amount of processing resources within the field. For the majority of the time there is one spotlight of visual attention that is focused at the point of fixation (overt visual attention). It is possible that a shift in visual attention is influencing the value of the judgements during the *lateral roundness* condition irrespective of an eye movement.

To examine this prospect, a *peripheral roundness* condition can be used in where subjects are required to fixate on a central point whilst the stimuli are peripherally viewed (thus requiring a shift of spatial attention irrespective of an eye movement). As per Krajbich, Armel and Rangel's (2010) computational model with eye movements being necessary to add to the decision value, it was expected that *exposure duration* of peripheral presented faces would have no effect on roundness judgements.

Method

Participants

There were 15 undergraduate psychology students from Victoria University of Wellington, New Zealand, participating in return for course credit. All participants had normal or corrected-to-normal vision. There were 2 males and 13 females.

Apparatus and stimuli

The apparatus and stimuli were the same as the *lateral roundness* condition in Experiment 2a.

Design and Procedure

The design and procedure were identical to the lateral roundness condition in Experiment 2a, with the exception that participants were required to fixate at a central cross during the whole duration of a trial (blinking was allowed). If the participant broke this fixation, the trial would abort and a message would appear informing the subject that they broke their fixation.

Data Analysis

There were 190 trials (21.11%) removed from further analysis due to the subject breaking fixation on the central fixation mark, thus aborting the trial. Reaction time was not considered as per the explanation from experiment 1a.

Results

Item Analysis

An item analysis was performed to examine the probability that the chosen face within a face-pair had been presented for the longer duration of 900ms. The mean probability of choosing the face that was presented for the longer duration was 48.27% (*SD* = 12.84). An item analysis revealed the probability of choosing the face that was presented for the longer duration was no different to chance ($t(59) = -1.04$, $p=0.30$).

Subject Analysis

A subject analysis revealed that the mean probability of subjects choosing the face that was presented for the longer duration was 48.38% (*SD* = 9.83, *SE* = 2.54).

Across all 15 subjects, the probability of choosing the face that was presented for the longer duration was no different to chance. ($t(14) = -0.64$, $p=0.53$).

Additional Analysis

There was a bias towards the probability of selecting the face presented on the left hand side (M= 54.16%, SE =1.87), which was significantly greater than chance ($t(59) = 2.22$, $p<0.05$). Upon removing trials in where the face to the left was selected, the probability of choosing the face that was presented for the longer duration was still no different than chance.

A regression analysis revealed that task difficulty (as per net probability of choosing one face over the other) did not predict whether the face that was presented for the longer duration would be more likely to be chosen ($\beta = .005$). That is, as task difficulty increased and faces became a more similar level of attractiveness, subjects were not being influenced by exposure durations to guide the decision.

Comparing the roundness conditions across all experiments in the current study, it can be seen that the judgements of roundness in the *lateral roundness* condition with CGF stimuli were influenced by *gaze duration*. The judgement of roundness with CGFs in the *central roundness* and *peripheral roundness* conditions, along with real faces in the *lateral roundness* conditions were not influenced by presentation duration of the stimulus (as per Figure 5).

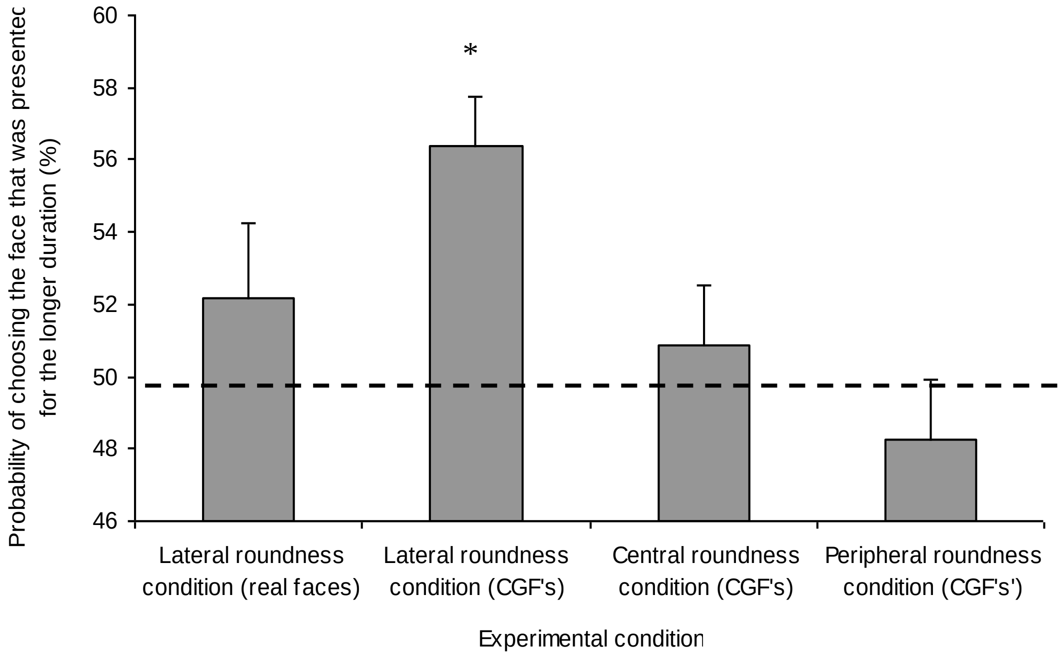

Figure 5. Mean probability of choosing the longer presented face (as per item analysis) across all experimental conditions involving a roundness judgement. The dotted line represents chance levels (50%).

Discussion

As predicted, the duration of the peripherally presented faces had no effect on roundness judgements. This finding, along with no effect in the *central roundness* condition of the prior experiment, indicates that the *gaze duration effect* in the *lateral roundness* condition was reliant on eye movements. Although it is not an affective judgement, such a finding is in line with Krajbich, Armel and Rangel's (2010) computational model of decision making, whereby the act of making an eye movement adds to the decision value. The finding cannot be explained by the gaze cascade hypothesis for two reasons. Firstly, the gaze cascade hypothesis suggests that eye movements influence preferential judgements exclusively. Secondly, in a free viewing paradigm, roundness judgements did not produce a cascading gaze pattern, thus indicating that roundness judgements are not utilising eye movements in the decision making process.

General Discussion

The gaze cascade hypothesis (Shimojo et al., 2003) postulates that during a binary decision task involving judging attractiveness of faces, the positive feedback loop of *preferential looking* and an *exposure effect* is acting implicitly to bias the gaze towards one item. The behavioural orientation of looking at one item for longer than the other is then emotionally interpreted as a positive affiliation (with the bias needing to reach a threshold before the ultimate decision is made). Shimojo et al. (2003) further supported the gaze cascade hypothesis with a *gaze duration* manipulation that found that faces presented for a longer duration were more likely to be judged as most attractive, but only when an eye movement was required to fixate on the items.

The findings from the present study are in contrary to what the gaze cascade hypothesis would predict. On the one hand, as predicted by the gaze cascade hypothesis, faces that were presented laterally for longer durations were more likely to be judged most attractive (for both real faces and CGFs). On the other hand, faces that were centrally presented (thus not requiring an eye movement) were also more likely to be judged as most attractive, a finding that is not what the gaze cascade hypothesis would predict in the current paradigm.

Analysing the Exposure Effect Irrespective of Eye Movements

The finding that centrally presented faces that were presented for longer durations were more likely to be chosen as most attractive indicates that an increase in *exposure duration* (duration of exposure in the absence of an eye movement) produces an increase in affiliation towards the face. This finding is in line with previous findings that have also indicated that an *exposure effect* in the absence of eye movements can occur when items are presented for longer durations.

Reber, Winkielman and Schwarz (1998) presented graphic patterns to subjects for varying durations (100, 200, 300 and 400ms respectively). Subjects were required to rate how much they liked the pattern. A longer duration of presentation resulted in a higher rating of liking. In line with this finding, Nittono and Wada (2009) used the same procedure as the *central attractiveness* condition in the present study, but requiring preference judgements for graphic patterns. The longer presented items were more likely to be preferred, thus further indicating the existence of an *exposure effect* from longer presented items in the absence of eye movements.

The *exposure effe*ct is a well established concept in cognitive psychology with many variations of manipulation (e.g. duration of exposure, amount of exposures, type of stimuli, see Bornstein, 1989 for review). However, the cause of such effects (including *exposure effects* with face stimuli) has been generalised to the same underlying mechanisms, with a distinction made between *attribution based* models (*familiarity* or *fluency)* and *hedonic marking* models.

The *familiarity attribution* model (Phaf & Rotteveel, 2005) postulates that a mechanism acts to elicit a positive affect when exposed to familiar stimuli. This positive affect has been conditioned from a strong likelihood of the object having non-threatening properties, i.e. the stimuli did not result in a negative consequence on previous encounters. Therefore, stimuli that are exposed for longer durations will become more familiar compared to stimuli exposed for shorter durations, and will elicit a greater positive affect. Decision making can utilise the familiarity/novelty dimension relying on a less critical and more heuristic-based positive affect for decisions towards familiar items, whilst novel items require careful consideration of their unknown quantities.

The *fluency attribution* model, on the other hand, postulates that facilitation of processing leads to the positive affect (Bornstein & D'Arostino, 1994). Importantly, the initial experience of perceptual fluency is affectively neutral. It is only when this fluency is cognitively attributed to liking the stimuli that the positive affect is subsequently experienced. Attribution based models assume a two-step process, the first being the cognitive experience (be it familiarity or fluency) and the second being a resulting interpretation of this cognitive process.

Alternatively, *hedonic marking* models, suggest that the resulting positive affect is a direct result from the fluency of processing and is not reliant on any cognitive attribution, thus a one-step process. Reber, Schwarz and Winkielman (2004) propose that the fluency of processing acts as a hedonic marker that inflicts a positive affect (in the same way as somatic states inflict positive states as proposed by the somatic marker hypothesis, Damasio, 1996). This account of the *exposure effect* is in line with some aspects of the gaze cascade hypothesis. Whereas the gaze cascade hypothesis suggests that making a saccade/fixation acts as a marker that elicits positive affect, the *hedonic marking of processing fluency* model proposes that it is simply the fluency of processing that acts as the marker that elicits a positive affect. Further to this, both the gaze cascade hypothesis and the hedonic marking model accept that evaluative judgements can consists of informational properties (e.g. memory constructs relating to attractive features), but can also rely on a more emotional evaluation in some situations (e.g. when the attractiveness of faces is equal).

The results from the *central attractiveness* condition do not provide any exclusive support for either attribution-based models or hedonic marking models of *exposure effects*. However, both models can account for the results in the *central attractiveness* conditions, as they both propose that a longer duration of exposure results in a greater positive affect. This proposal can explain the findings in the *central attractiveness* condition, with the longer presented faces eliciting a greater positive affect, which increases the probability of it being chosen as the most attractive. If an *exposure effect* can account for the findings in the *central attractiveness* conditions, it could also be possible that an *exposure effect* can account for the findings in the *lateral attractiveness* conditions.

Gaze Duration vs Exposure duration

There are two possible explanations for the relationship between similar results from the *lateral attractiveness* condition and the *central attractiveness* condition. Firstly, the *exposure effect* account could explain the results from both the *central attractiveness* conditions and the *lateral attractiveness* conditions with the eye movement not being a necessary component for the presence of the effect. Secondly, the *exposure effect* account can explain the findings from the *central attractiveness* condition, whereas the *lateral attractiveness* condition may be more influenced by the eye movements. If there was a difference in results between the *central attractiveness* and the *lateral attractiveness* conditions, it could be concluded that there is a difference in the influence of *gaze duration* and *exposure duration*. However, there is an association between the similar results of the two conditions, therefore *gaze duration* and *exposure duration* cannot be separated for attractiveness judgements in the current study.

If the effect in the *lateral attractiveness* condition was solely due to the eye movements being emotionally interpreted as a positive affect, then it would imply that there is no *exposure effect* occurring (as proposed by Shimojo et al., 2003). Intuitively, there does not seem to be a reason as to why an *exposure effect* would occur in the *central attractiveness* condition, but not in the *lateral attractiveness* condition. Thus, under this assumption, any influence of *gaze duration* would be expected to elicit an additive function to the existing influence of the *exposure effect*. This additive value should be seen by longer presented faces being even more likely to be chosen in the *lateral attractiveness* condition compared to the *central attractiveness* condition. However, the faces presented for longer durations were chosen to a similar probability across all conditions (sitting around the 55% mark). Thus, with the assumption that the *exposure effect* can occur in the *lateral attractiveness* condition, it would suggest that the eye movements (*gaze duration*) had no influence on the decision.

To remove the necessity of assuming an *exposure effect* in the *lateral attractiveness* conditions, it would be necessary to separate *gaze duration* and *exposure duration*. One possible way of attempting to tease apart the processes of *gaze duration* and *exposure duration* would be to examine the differences of the respective duration parameters and their effect on the respective *lateral attractiveness* and *central attractiveness* conditions. By systematically reducing the long durations in the faces pairs (i.e. 900ms/300ms vs 750ms/300ms vs 600ms/300ms), there could be a point at which the longer presented faces no longer exhibit a greater probability of being chosen (*duration threshold*). By reducing these times in the respective conditions, the relationship between *exposure duration* and *gaze duration* can be examined. If the same process is occurring in the *lateral attractiveness* and *central attractiveness* condition the *duration threshold* would be expected to be the same in the both conditions. If the *duration threshold* is different for the respective *lateral attractiveness* and *central attractiveness* condition, it would indicate that the *gaze duration effect* and *exposure duration effect* are likely to be different processes during preference formation. It would be vital to closely monitor fixation durations within the *lateral attractiveness* condition to ensure they represent an accurate *duration threshold*.

Gaze duration and *exposure duration* can be considered to be separate processes to a certain degree due to the results of the *roundness* conditions (albeit in a non-affective judgement). In fact, the results of the *roundness* conditions in experiment 1 and 2 are very intriguing in light of the role of eye movements and decision making on a whole. There was a *gaze duration effect* in the *lateral roundness* condition using CGFs, in the absence of an *exposure duration effect* in the *central roundness* and *peripheral roundness* conditions, thus suggesting that eye movements were a necessary component of the effect. Further to this, when the stimuli were real faces, the *gaze duration effect* did not occur, thus indicating that the result from the lateral roundness condition using CGFs was not simply due to a general bias to choose left or right based on the longer durations.

The Causal Role of Eye Movements in Roundness Judgements

The *gaze duration effect* in the *lateral roundness* condition using CGFs cannot be explained by the gaze cascade hypothesis, which stipulates that the prolonged fixation on an item is emotionally interpreted as an affiliation towards the object. The increase in positive affect would not be expected to influence roundness judgements. Krajbich, Armel and Rangel’s (2010) computational model of decision making however, can still account for *gaze duration effect* in the *lateral roundness* condition using CGFs. Their model proposes that the drive for fixations is task related (thus not exclusive to preference judgements), with a requirement to gain evidence for one response in comparison to the other. The *gaze duration* on one option adds to the decision value of that option until a threshold has been reached and the choice is made, thus accounting for the longer presented faces being judged as most round in the *lateral roundness* condition using CGFs.

Krajbich, Armel and Rangel's (2010) computational model of decision making can account for the findings in the *lateral roundness* condition using CGFs as the model predicts that faces that are fixated on for longer would be more likely to reach the decision threshold. However, this is not evident in the *lateral roundness* condition using real faces, where performance was at chance levels thus indicating no influence of *gaze duration*, a finding not predicted by the model. It is possible that the very similar roundness attributes of CGFs may elicit a fundamentally different type of decision process compared to the roundness attributes of real faces which may account for the difference between real and CGFs in the *lateral roundness* conditions. Figure 6 shows example face pairs from real faces and CGFs from the current study. It is evident that there is a greater similarity between the outline of the CGF face pair, also there are more unique faces within the real face pair (e.g. hair, wrinkles, skin tone etc.).

In the case of the CGFs, the features that would contribute to a perceptually driven objective roundness decision are very similar (with the outline of the head being almost identical), thus the decision may be relying on a more subjective process (e.g. a general *feeling*). The possibility of the roundness judgement with CGFs becoming a subjective choice has an important implication to Krajbich, Armel and Rangel's (2010) computational model of decision making, as the model may be exclusively valid for subjective judgements (e.g. subjective judgements of roundness when they are objectively equal).

Figure 6. Example face pairs from real faces and computer generated faces.

Subjective judgements tend to be more reliant on heuristic-based decision making (such as affect states) as opposed to concrete informational comparisons (Tversky & Kahneman, 1974), thus it is feasible that they would be influenced by mechanisms involving bottom-up processes that create a sense of subjective experience (as proposed by aforementioned embodiment theories such as the gaze cascade hypothesis, Shimojo et al., 2003; and self perception theory Bem, 1972). Therefore, if the roundness judgements are subjective, they could be more sensitive to the *gaze duration* manipulation.

Krajbich, Armel and Rangel’s (2010) computational model of decision making being exclusive to subjective decisions can still account for the predictive nature of the model during preference judgements for food items, as evident in their findings. The proposal that CGFs roundness judgments are subjective would allow Krajbich, Armel and Rangel’s (2010) computational model of decision making to also account for the *gaze duration effect* being present in the *lateral roundness* condition using CGFs (subjective decision) but not real faces (perceptually driven objective decision).

The proposal that roundness judgements of CGFs are a subjective decision also indicates that elements of the gaze cascade hypothesis may withstand the results of the present study. Glaholt and Reingold (2009) have shown a gaze cascade effect with judgements of preference *and* judgements of recency (e.g. judging which photograph has been taken most recently). They agreed with Shimojo et al’s. gaze cascade hypothesis in the sense that the eye movements are actively feeding into a cascading decision process up until a decision point, with the bias being interpreted as the preferred choice. However, they stipulate that this does not exclusively occur for preference judgements and can be utilised in other decision processes. Therefore they disagree with Shimojo et al.’s (2003) view that *preferential looking* and an *exposure effect* are driving the cascading gaze bias. They proposed that the level of processing was the most important factor for determining whether a gaze cascade will be utilised during the decision making process (with preference judgements and recency judgement requiring a deeper level of processing compared to roundness judgements). However, it is also important to note that both preference and recency judgements are also subjective decisions. Along with the results of the present study, it is possible that it may be a subjective nature of the decision (even during the shallow processing of roundness) that determines whether eye movements will be utilised during the decision process.

The findings from the roundness conditions ultimately provide evidence of a causal role of eye movements in roundness judgements. However, if CGFs *are* being subjectively judged for roundness and subjective judgements *are* a determinant on whether *gaze duration* will influence decision making, it is not clear why Shimojo et al. (2003) did not find a *gaze duration effect* in their *lateral roundness* condition. In the same way as the *central attractiveness* condition, the sample size in the *lateral roundness* condition of Shimojo et al's. (2003) study needs to be considered. A small sample size of 10 could result in the possibility of the *lateral roundness* condition being over-represented by individuals that are not susceptible to the *gaze duration effect*.

Individual Differences in the utilisation of Eye Movements

As per Krajbich, Armel and Rangel's (2010) computational model of decision making (under the assumption that roundness judgement using CGFs is a subjective decision) participants are assigning a decision value onto respective items during fixations after a saccades. The idea of cognitively interpreting a behavioural act as a subjective feeling is in line with bottom-up theories of emotion (e.g. Self perception theory, Bem; 1972). Schnall and Laird (2003) make a distinction between individuals that are more reliant on their behavioural acts to form a subjective emotion (*personal cuers*) and those that are more reliant on environmental situations to form the subjective emotion (*situational cuers*). In the same way, the subjective evaluation of roundness may be formed by the bottom-up process of a behavioural act that adds to a decision value from a fixation. On the other hand, the subjective evaluation of roundness may be formed by the top-down process cognitively evaluating the environmental cues (i.e. the face stimuli).

If individuals differ in their utilisation of bottom-up and top-down mechanisms, the *lateral roundness* condition in Shimojo et al.'s (2003) study may have been over-represented by *situational cuers*, thus explaining the lack of a *gaze duration effect* in their study. One way to test this would be to administer a pre-test that acts to categorise participants as either *situational cuers* or *personal cuers*. Duclos and Laird (2001) propose that this categorisation would need to consist of test that examined *bottom-up* influences vs *top-down* influences on emotional judgements. For example, whilst participants are required to hold a pen in their mouth to elicit the same muscle activations as a smile, they may also view a piece of abstract art that has been titled negatively (e.g. *betrayal*). The judgements could be compared to ratings that did not have the *bottom-up* or *top-down* manipulations. *Personal cuers* would be more influenced by the behavioural smile manipulation and rate the picture more positively. *Situational cuers* would be more influenced by the environmental evidence (i.e. the title) and rate the picture more negatively. Once categorised, it would be expected that *personal cuers* would be more likely to be influenced by *gaze duration* in the *lateral roundness* condition compared to *situational cuers*.

If *personal cuers* were more likely to be influenced by *gaze duration*, it would provide support for *bottom-up* theories of emotion. It would also support elements of the gaze cascade hypothesis that proposed a subjective evaluation is being driven by interpretation of the behavioural act of an eye movement. Lastly, if there was a clear distinction between *personal cuers* and *situational cuers* performance in the *lateral roundness* condition, it would indicate that a larger sample size than what Shimojo et al. (2003) used in their *lateral roundness* condition is needed (with a pre-test to control for individual differences)

An important consideration for the aforementioned proposed study is that *personal cuers* would be expected to be unaware of their utilisation of behavioural mechanisms in their decision formation. This assumption can be challenged in the current paradigm as the gaze manipulation is very explicit (i.e. the participants are fully aware that one face is being presented for longer than the other).

Explicit vs Implicit Manipulations

Although there was an absence of an *exposure effect* in any other roundness condition, it is still possible that the longer exposure and the spatial dominance of one side during a trial in the *lateral roundness* condition may jointly result in a bias to choosing that item if the participant had no other content information to draw upon (i.e. they are perceptually very similar). One way to thoroughly rule out the possibility that the decision was being based on knowledge that one face was presented for longer than the other would be to make the manipulation implicit.

An implicit manipulation of presentation durations could be achieved by carefully manipulating the spatial and temporal presentation parameters of two faces. The first factor would be to have the faces presented on screen at the same time during a trial. This would convince the participant that they are freely viewing the faces. The two faces (*Face A* and *Face B*) can then move either via a *salient move* or a *subtle move* into various positions within a visual array. A *salient move* would occur when *Face A* is fixated on and *Face B* moves into a new position. The abrupt onset of the move would exogenously capture visual attention and increase the likelihood of a saccade being made towards *Face B* (Lauwereyns, 1998). A *subtle move* could occur during the process of making a saccade. The move would not be easily detected due to *saccadic suppression* (the inhibition of visual processing during the actual saccade; Burr, 2004) that results in change blindness (an undetected change) to the environment (Henderson & Hollingworth, 2003). Further to this, during the *subtle move*, *Face A* could move into the position that was previously occupied by *Face B*. This would utilise the mechanism of *inhibition of return* (in where there is an inhibition of spatial attention in a previously attended location; Klein, 2000), thus resulting in move that does not easily capture attention thereby making it less likely for a saccade to be made to *Face A*.

Inhibition of return and *saccadic suppression* can be utilised to bias the gaze towards Face B, without the participant being aware of the bias. It would then be expected that *personal cuers* would be more likely to choose the face that was fixated on for the longer duration as being most round. Such a finding would indicate that *gaze duration* is adding to a decision value in individuals that are more reliant on interpreting behavioural actions to form subjective valuations, even when they are unaware of the behavioural act.

Computational Models of Decision Making and the Current Study

Computational models of decision making propose that a decision is a process that acts to assign decision related activity to respective options. There is an escalation of activity with a decision threshold for the activity to overcome in order for the choice to be made (Bogacz, 2007; Glimcher, 2003; Gold & Shadlen, 2007). The results from the current study have added valuable knowledge to developing models and paradigms that investigate computational models of subjective decision making.

Firstly, eye movements *can* have an active part in the process of choosing between one of two options as per the findings of the *roundness* conditions (which are concluded to be subjective judgements for CGFs). Therefore, eye movements (in particular *gaze duration*) can continue to be utilised as a tool for examining subjective decision making. It is important to note however, that whilst *gaze duration* can produce robust effects, it is vital to have an accompanying condition that centrally presents the stimuli. In addition to this, if there is no difference between *exposure effects* and *gaze duration effects,* there can be no inference made in regards to what is causing the *gaze duration effect*. It is possible it could either be *exposure duration* alone, *gaze duration* alone, or perhaps both factors. *Gaze duration* can only be inferred when there is no accompanying *exposure effect* (as in the *roundness* conditions of experiment 2).

Shimojo et al. (2003) suggested that the *gaze duration effect* in their study was strong evidence of the causal role of eye movements during preference formation, as they had no accompanying *exposure effect* in their *central attractiveness* condition. Due to the causal influence of the eye movement in the gaze manipulation paradigm of Shimojo et al.'s (2003) study, the cascading nature of the fixations during a free viewing paradigm was proposed as evidence of an escalating decision mechanism, thus supporting computational models of subjective decision making. However, the current study found similar results between the *lateral attractiveness* condition and the *central attractiveness* condition, therefore the causal role of eye movements in attractiveness judgements can be disputed (i.e. the *gaze duration effect* may not be reliant on the eye movement, but simply the *exposure duration* irrespective of the eye movement). It is therefore unclear whether the escalation of *gaze duration* in a free viewing task is an active functional component of the decision making process, that relies on a causal influence from eye movements.

On the one hand, *gaze duration* could be adding to a decision value, on the other hand, an increase in *exposure duration* could be resulting in an increase in affiliation (as per a simple *exposure effect*). To form a clearer picture of the role of eye movements and computational subjective decision making, it is necessary to tease apart *gaze duration* and *exposure duration* in a free viewing paradigm. This dissociation would allow a more convincing argument that the decision is being influenced by the escalation of *gaze duration*, with the eye movements having a causal role.

A simple way to tease *gaze duration* and *exposure duration* apart in a free viewing paradigm would be to centrally present one face at a time. The participant could select when to view the alternative face via a button press, thus having control over the *exposure durations*. If *exposure durations* showed the same escalating pattern as *gaze duration* during this free viewing, it would indicate that *exposure duration* escalates up until the decision point, thus the eye movement is not a necessary component of this escalatory decision process as stipulated by the gaze cascade hypothesis.

Although there is a possibility that eye movements may not be necessary in Shimojo et al's. (2003) free viewing paradigm, either way there is still a clear escalation in fixation durations during attractiveness judgments no matter what is influencing the choice (be it *gaze duration* or *exposure duration*). It could therefore be argued that both the *gaze duration* and *exposure duration* explanations of the gaze cascade still provide evidence of computational decision making, as there is still a fundamental cascade up until the point of decision. The importance of distinguishing *gaze duration* and *exposure duration* in a free viewing paradigm would therefore reside in determining whether a behavioural act is being interpreted as emotion (gaze cascade hypothesis, self perception theory) or whether an increase in exposure is causing an increase in positive affect that influences the decision (models of the *exposure effect*).

The prospect of a causal role of *exposure duration* would also have an implication for Krajbich, Armel and Rangel's (2010) computational model of decision making. Fixations times and decision latencies were found to match the predictions of the model across different attractiveness conditions. Closely matched faces elicited slower decisions with more and longer fixations across the two faces, whereas faces that were not matched for attractiveness elicited quicker decisions with shorter and less amount of fixation across the two faces. The researchers argued that the match between the predictive model and results suggest evidence of the casual role of eye movements in the decision process. However, it is possible that it’s simply the longer exposure of the stimuli that is eliciting a positive affiliation adding to a decision value, thus influencing the decision irrespective of an eye movement. Again, centrally presenting one face at a time, with a button press to alternate the faces presentations would allow the model to be tested using *exposure effect* irrespective of eye movements.

Lastly, to further examine the relationship between free viewing paradigms and gaze manipulation paradigms and their impact on computational models of decision making, it is important to consider roundness judgements. One problem with the idea that a gaze cascade is evidence of computational decision making is that roundness judgements in a free viewing paradigm do not produce a cascading pattern. Gaze manipulations can affect roundness judgements (with longer *gaze durations* being more likely to be chosen) however, the same roundness judgements in a free viewing task do not rely on *gaze durations* to influence the decision. If subjective decision making in a free viewing paradigm was characterised by an escalation of activity representing a decision value, with eye movements having a causal influence, then a gaze cascade would be likely in a free viewing task involving roundness judgements (assuming that the roundness judgements using CGFs are subjective). The lack of a gaze cascade in roundness judgements during a free viewing cannot be explained by computational models of subjective decision making, as there is no accumulation of fixations.

Summary

Future research in the area of eye movements and computational decision making needs to consider several important factors that have been made evident by the findings of the present study. Firstly, there should be no assumption as to which types of decisions are considered subjective and which are considered objective. There was a clear difference in the *lateral roundness* conditions using CGFs compared to real faces. This difference was not due to the difficulty of the decision (as task difficulty within the condition did not predict the influence of the gaze duration), thus it is concluded that roundness judgements with CGFs is a more subjective decision compared to real faces. Secondly, any experimental design that investigates *gaze duration* needs to account for *exposure duration*. The implication being that either factor could have a causal role during the gaze cascades in free viewing attractiveness judgements. It is vital to tease apart these processes as they have vital implications to the development of computational models of subjective decision making. Further to this, future research needs to examine the nature of the relationship between *gaze duration effects* and inferences made from gaze cascades in free viewing paradigms. This is particularly evident with roundness judgements, which elicit a lack of a gaze cascade in free viewing paradigms, but are influenced by *gaze durations* in the current gaze manipulation paradigm.

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Footnotes

[1] There was no interaction between the sex of the subject and the sex of the face pair in any condition.