The influence of reward on early information processing along the "visual perception-overt behaviour" continuum

Angela Vavassis

A Thesis

In the Department

of

Psychology

Presented in Partial Fulfillment of the Requirements
For the Degree of
Doctor of Philosophy (Psychology) at
Concordia University
Montreal, Quebec, Canada

February 2012

CONCORDIA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

This is to certify that the thesis prepared

By: Angela Vavassis

Entitled: The influence of reward on early information processing along the

"visual perception-overt behaviour" continuum

and submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy (Psychology)

complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the final examining committee:

Dr. Louis Cuccia (Chemistry & Biochemistry), Chair

Dr. Olga Overbury (École d'Optométrie, Université de Montreal), External Examiner

Dr. David Howes (Sociology & Anthropology), External to Program

Dr. Roberto de Almeida (Psychology), Examiner

Dr. Virginia Penhune (Psychology), Examiner

Dr. Aaron Johnson (Psychology), Administrative Thesis Supervisor

Approved by

____
Chair of Department or Graduate Program Director

__________ ___________________________________
Dean of Faculty

ABSTRACT

The influence of reward on early information processing along the "visual perception-overt behaviour" continuum

Angela Vavassis, Ph.D.
Concordia University, 2012

Past research has reliably established that rewards exert an influence on overt/observable behaviours (e.g., explicit choices, limb/body movements, eye-movements). Oftentimes, a reward may be acquired by performing a specific behaviour in response to a visual target. Under such circumstances, research has demonstrated that the reward covertly influences the late neural stages of information processing along the "visual perception-overt behaviour" continuum (e.g., the motor processing immediately preceding the performance of the overt behaviour needed to acquire the reward associated with the perceived visual target).

Only recently has research also begun to investigate whether reward covertly influences the earlier neural stages of information processing along the "visual perception-overt behaviour" continuum (i.e., the visual perception of the target stimulus). Such research has suggested that reward does indeed influence even the earliest form of visual perception (i.e., feature perception). This conclusion has been drawn form the handful of documented effects of reward on certain behavioural measures of performance during feature singleton visual search (e.g. the observation of slower key-press responses for targets associated with low than with high monetary reward). However, since the key-press response is a motor response, such results may entirely or partially reflect reward influences on the motor (i.e, late) as opposed to the perceptual (i.e, early) information processing stage. Other evidence, suggestive of the effects of reward on feature visual perception, stems from the documented effect of reward on attention (i.e., the N2pc, a reliable marker of attentional selection of visual targets, appears later and is weaker for low than for high reward targets), given attention's independently documented effects on feature visual perception.

The aim of the current study was to provide a more thorough behavioural assessment of reward influences on visual perception in feature singleton visual search (within the magnitude and probability dimensions). A measure of sensitivity (d'), reflective of perceptual rather than motor processing, was added to the behavioural measures used in past studies and was shown to be poorer for low than high reward targets. This finding suggested that low reward targets are visually perceived later than high reward targets are. Sensitivity was correlated with accuracy and inverse efficiency, suggesting that the observed variations in those measures as a function of target reward value reflected the same or similar underlying process as sensitivity did. Furthermore, shortening display duration across visual search trials was more detrimental to such behavioural performance for low than high reward targets, further suggesting that low reward targets are visually perceived later than high reward targets are (either via direct channels, via attention or both). In summary, this more thorough behavioural assessment of reward influences on visual feature perception corroborated the conclusions drawn in the existing literature.

ACKNOWLEGEMENTS

I would like to thank my late supervisor, Dr. Michael von Grünau, for his encouragement and feedback throughout the course of this research. I sincerely appreciated his flexibility in allowing me to explore some of my own research interests. I would also like to thank my administrative supervisor, Dr. Aaron Johnson, as well as the other members of my thesis committee who provided their individual input. Last, but not least, I would like to express gratitude to my 64 participants from the Concordia University Participant Pool, without whom these experiments would not have been possible. The Natural Sciences and Engineering Research Council of Canada (NSERC) supported this research.

Table of Contents

List of Figures

List of Tables

General Introduction

A significant portion of human and non-human animal behaviour is goal-directed. By definition, goal-directed behaviour is mediated by its outcome (e.g., Adams & Dickinson, 1981; Balleine & Dickinson, 1998; Colwill & Rescorla, 1985; de Wit, Kosaki, Balleine, & Dickinson, 2006). In other words, when the outcome of performing a given behaviour is a current goal, the thought of the outcome typically activates the behaviour needed to obtain it. Motivational outcomes known to shape behaviour include consumable rewards (e.g., food and drink for human and non-human animals) and non-consumable (e.g., money for humans) rewards (e.g., Estle, Green, Myerson, & Holt, 2007).

The strong influence of reward on overt/observable behaviour can most unambiguously be witnessed in simple human explicit choice experiments. When individuals are asked to make an explicit choice between two monetary rewards, their choice is relatively predictable when the reward alternatives differ in the magnitude dimension (e.g., Green & Myerson, 2004). For instance, if an individual is required to choose between a $10 monetary reward and a $1 monetary reward, he/she will almost certainly choose the $10 reward because of its higher subjective value. Similarly, given two monetary reward alternatives equal in magnitude (e.g., $10), but differing in the probability dimension, the individual will choose the reward with the higher (e.g., 100%) rather than the lower (e.g., 10%) probability. This occurs because the subjective value of the $10 reward is increasingly discounted as its likelihood progressively decreases (e.g., Green & Myerson, 2004). Also, given two monetary reward alternatives equal in magnitude (e.g., $10), but differing in the delay dimension, the individual will choose the reward with the shorter (e.g., 1 day from now) rather than the longer (e.g., 10 days from now) delay. This occurs because the subjective value of the $10 reward is increasingly discounted as its delay progressively increases (e.g., Green & Myerson, 2004). Probability and delay discounting have both been empirically demonstrated (e.g., Myerson & Green, 1995).

A rewarding outcome may also be acquired by performing a specific behaviour in response to a visual target. Under such circumstances, researchers have predominantly investigated and found that reward covertly influences the late neural stages of information processing along the "visual perception-overt behaviour" continuum (e.g., Behrens, Woolrich, Walton, & Rushworth, 2007; Glimcher & Rustichini, 2004; Hampton & O'doherty, 2007; Schultz, Tremblay, & Hollerman, 2000). Among others, these late stages include the motor processing immediately preceding the performance of the overt/observable behaviour needed to acquire the reward associated with the perceived visual target.

Only recently have researchers also begun to investigate whether reward covertly influences the earlier neural stages of information processing along the "visual perception-overt behaviour" continuum (i.e., the visual perception of the target stimulus). Such research, although very limited, has suggested that reward does indeed influence even the earliest form of visual perception (i.e., feature perception) (e.g., Kiss, Driver, & Eimer, 2009; Kristjansson, Sigurjonsdottir, & Driver, 2010). Therefore, the general goal of the current thesis was to investigate the influences of reward on the visual perception stage of information processing along the "visual perception-overt behaviour" continuum in feature visual search, in an attempt to corroborate, and supplement the conclusions drawn in the existing literature.

The late stage: Reward and motor processing

Reward and the motor system. Researchers have suggested that movement planning occurs via a neuronal network including the fronto-parietal cortex (e.g., Romo, Scarnati, & Schultz, 1992; Sugrue, Corrado, & Newsome, 2004), and basal ganglia, including the striatum (e.g., Romo, Scarnati, & Schultz, 1992). These areas are believed to be involved in the preparation and initiation of sensory-guided and self-initiated behaviour (e.g., Churchland, Santhanam, & Shenoy, 2006a; Gardiner & Nelson 1992; Lee & Assad 2003; Romo et al., 1992; Tsujimoto, Genovesio, & Wise, 2010; Turner & Anderson, 1997). Importantly, these areas have also been suggested to modulate the coordination of goal-directed motor behaviour as a function of reward. Specifically, the basal ganglia, together with motor areas of the brain, are believed to translate reward contingencies into the "vigor" of movement (e.g., Hayden, Nair, McCoy, & Platt, 2008; Turner & Desmurget, 2010). Movement "vigor" is overtly represented by the response time required to initiate a movement toward a stimulus and/or the speed with which the movement towards the stimulus is executed.

Reward and visual targets: Limb movements. A study conducted by Opris, Lebedev, and Nelson (2011) on monkeys and wrist movements provides an illustrative example of the influence of reward on the motor system. In their study, two monkeys were trained on a response time task requiring them to execute wrist movements for reward in response to vibro-tactile and visual stimuli. Behavioural findings from this study revealed that monkeys made earlier and faster wrist movements (i.e., more "vigourous" movements) in trials were they knew that they would be rewarded. Furthermore, single-unit recordings were consistent with the behavioural findings. More specifically, trials in which the monkeys knew that they would be rewarded resulted in earlier and greater neuronal firing rates in the dorsal striatum prior to the movement.

Reward and visual targets: Eye movements. Bottom-up factors known to influence eye-movements, such as the luminance and contrast of visual stimuli, can be measured with relative precision. As such, they are very simple to manipulate in a laboratory setting. Although top-down factors, such as reward contingencies, are more difficult to measure and manipulate, making their influence less well understood (e.g., Maunsell, 2004; Schall, 2004; Sparks, 1999), they have also been shown to influence eye-movements (e.g., Fecteau & Munoz, 2006; Thompson & Bichot, 2005). In addition, Campos, Breznen, Bernheim, and Andersen (2005) have demonstrated that supplementary motor area (SMA) neurons, neurons involved with body and limb movements, also carry a reward expectancy signal in the post-saccadic period of oculomotor tasks.

Several experiments have been conducted in which reward magnitude effects on saccadic behaviour have been reported while holding probability constant (e.g., Ding and Hikosaka, 2006; Lauwereyns, Watanabe, Coe, & Hikosaka, 2002; Leon & Shadlen, 1999; Platt & Glimcher, 1999; Takikawa, Kawagoe, Itoh, Nakahara, & Hikosaka, 2002). In addition, several experiments have been conducted in which probability effects on saccadic behaviour have been reported while keeping magnitude constant (e.g., Basso & Wurtz, 1998; Dorris & Munoz, 1998; Platt & Glimcher, 1999). These two independent sets of experiments have isolated the effects of reward magnitude and the effects of reward probability, respectively, on saccadic behaviour. Furthermore, Milstein and Dorris (2007) conducted a study in which both magnitude and probability were concurrently varied; resulting in a number of different expected reward values (magnitude x probability). In their study, the human subjects directed a saccadic eye-movement to a red dot presented to the left or right of fixation in a series of trials. Expected value was manipulated from one block to the next by adjusting the magnitude of the reward associated with the left versus the right target, and the probability of the target appearing in either location. The authors found that saccadic reaction times were negatively correlated with the expected value of the targets (i.e., longer saccadic reaction times with lower expected values). Thus, they determined that the advanced preparation of saccades reflected the expected value of the potential outcomes.

Takikawa, Kawagoe, Nakahara, and Hikosaka (2002) also assessed reward-oriented eye movements by devising a memory-guided saccade task in monkeys. In their study, the monkey was seated in a primate chair in a head-fixed position in front of a screen. Small red spots of light were back-projected onto the screen. One of the projectors was used for a fixation point and the other for an instructional cue. They began by training the monkey on a simple memory-guided saccade task referred to as the all-directions-rewarded task (Hikosaka & Wurtz, 1983). Each trial began with the onset of a central fixation point on which the monkey needed to fixate. This fixation point was followed by a cue stimulus that was 100 milliseconds (ms) in duration. The target was subsequently presented in the cued location for 150ms. The monkey needed to remember the location of the cue because it was required to make a rapid saccade to the target location for reward (i.e., drop of water). Since the target presentation itself was only

150ms in duration the eyes could not otherwise reach the target location. The monkey was then trained on a memory-guided saccade task referred to as a one-direction-rewarded task (Kawagoe, Takikawa, & Hikosaka, 1998). In this particular task, only one out of the four possible saccade directions was optimally rewarded. The three remaining saccade directions were either not rewarded or rewarded with a smaller amount (for one monkey). The rewarded direction was changed in each block. Importantly, the monkey needed to make a saccade even in the non-rewarded direction or less-rewarded direction, otherwise the same trial was continually repeated. The researchers found that several saccade parameters were changed depending upon whether or not the saccade was followed by reward. Among other differences, the mean saccade peak velocity was higher and the mean saccade latency was shorter in the rewarded condition than in the non-rewarded and less rewarded conditions. Also, the variability in saccade velocity, latency and amplitude was smaller in the rewarded condition than in the non-rewarded and less rewarded conditions.

Motor processing and reward: A possible explanation. Research by Shadmehr and colleagues (Shadmehr, 2010; Shadmehr, de Xivry, Xu-Wilson, & Shih, 2010) provides a possible account of why motor movements are influenced by reward. The researchers hypothesized that there is a connection between the delay discounting of reward and the control of movements. They focused on the control of saccades, given that this type of movement has been studied in numerous populations and conditions. As previously mentioned, delay discounting studies have demonstrated that reward loses value (i.e., is discounted) hyperbolically with increased delay (Myerson & Green, 1995). Through a series of computational analyses, Shadmehr et al. (2010) determined that the duration of a saccade is equivalent to the delay of reward, with longer saccade durations discounting the value of the reward more than shorter saccade durations. This is because the longer saccade durations delay the acquisition of reward to a greater extent than the shorter saccade durations. Additionally, they demonstrated that this relationship is adequately described by a hyperbolic function similar to the delay discounting function found in explicit choice studies.

As suggested by Shadmehr et al. (2010), the hyperbolic cost of delayed saccades on reward is also descriptive of the faster saccades found in children, who are known to discount reward more steeply. The computational account also explains why there is an increase in saccade velocity with higher rewards and why saccades are impaired in disorders that affect the encoding of reward (e.g., Parkinson's disease). Furthermore, the movement of the eyes is typically coordinated with the movement of the head (Guitton & Volle, 1987), and the hyperbolic function also accounts for the timing, velocity and task-dependent variability in these coordinated movements (Epelboim, Steinman, Kowler, Pizlo, Erkelens, & Collewijn, 1997). Such findings further support the theory put forth by Shadmehr et al. (2010), suggesting that the duration of a saccade represents the delay of reward acquisition, thus potentially accounting for the influence of reward on motor (i.e., late) processing.

The early stage: Reward and visual perception

Rewards have convincingly been shown to modulate overt/observable behaviour (e.g., limb movements and eye movements) towards visual targets, as summarized in the above-mentioned studies. The neural correlates of motor (i.e., late) processing as a function of reward have been suggested to exert an important influence on these overt behaviours. However, the effects of reward on visual perception (i.e., the early information processing stage along the "visual perception-overt behaviour" continuum) have yet to be well documented (Kristjansson, Sigurjonsdottir & Driver, 2010). Findings, form a handful of studies, have nonetheless suggested that reward does indeed influence even the earliest form of visual perception (i.e., feature perception). Such studies have used the feature singleton visual search task as a tool.

Visual search. On a daily basis, we visually scan our surroundings attempting to locate items of interest. The visual search task was developed as a laboratory paradigm to mimic the real-world phenomenon of locating an item of interest among a cluttered visual scene (e.g., Kristjansson, 2006; Kristjansson & Campana, 2010; Müller & Krummenacher, 2006; Wolfe & Horowitz, 2004).

Visual search can be broadly subdivided into 2 categories: feature and conjunction. Feature visual search consists of searching for a target that differs from its surrounding distractors by a unique feature, such as colour or shape. For instance, searching for a red square among green squares and green circles of the same size and luminance (Trick & Enns, 1998). In contrast, conjunction visual search consists of searching for a target that differs from its surrounding distractors by a combination of at least two features. For instance, searching for a red square among green squares and red circles.

Top-down knowledge and feature visual search: "Cold" cognition. Although top-down knowledge regarding the task-relevance of a target seems intuitively necessary to guide conjunction visual search, it is not as obvious whether it is also required to guide feature visual search. This is because the greater dissimilarity of the target relative to its surrounding distractors in the feature than in the conjunction visual search implies greater activation for the target relative to its surrounding distractors in the feature than in the conjunction visual search (e.g., Cave & Wolfe, 1990; Theeuwes, 1992, 1994; Wolfe, 1994). Thus, it is important to address whether top-down influences can further boost the already high bottom-up activity generated by the feature singleton target.

Subsequent studies have shown that bottom-up saliency in feature visual search can indeed be modulated by the behavioural importance of stimuli (e.g., Ivry & Cohen, 1990; Müller, Heller, & Ziegler, 1995; Wang, Cavanagh, & Green, 1994; Wang, Kristjánsson, & Nakayama, 2005; Wolfe, Cave, & Franzel, 1989). For instance, some early evidence was found showing that response time to locate a feature singleton target is faster when top-down knowledge is involved (i.e, knowing whether the target will be a unique shape versus a unique colour) (Treisman, 1988). More recent studies have corroborated these findings (e.g., Found & Müller, 1996; Müller, Heller, & Ziegler, 1995; Müller, Reimann & Krummenacher, 2003). Importantly, top-down effects have not only been demonstrated in regards to the task-relevance of stimuli (i.e., “cold” cognition”) but also in terms of the emotional significance and reward contingencies of stimuli (i.e., “hot” cognition) (Vuillermier & Driver, 2007).

Top-down knowledge and feature visual search: “Hot” cognition. Kristjansson et al. (2010) investigated whether the reward level associated with two different feature singleton targets affects visual search and repetition effects from trial-to-trial. Participants in this study were asked to search for a red target diamond among green distractor diamonds or vice versa. They were asked to report whether the target had a notch at its top or bottom by pressing a corresponding key on a computer keyboard.

Correct responses led to reward, and the reward varied according to the target colour. For half of the participants, the red target led to higher reward than the green target, and for the other half of the participants, the green target led to higher reward than the red target. Search performance was measured in inverse efficiency, calculated by dividing the response time by proportion correct. The researchers found better inverse efficiency (i.e., more efficient search) for the target associated with the higher reward than for the target associated with the lower reward. Furthermore they found increased trial-to-trial priming for the high reward colour target when the priming was repeated from trial-to-trial.

Della Libera and Chelazzi (2006) reported potentially related effects of reward on distractor rejection. In their study, variable monetary rewards were given to participants who performed a series of prime-probe sequences, based on their performance on the task. The results showed evidence that the distractor was ignored more effectively in highly rewarded selections.

Findings from such studies suggest that the reward value associated with a feature singleton target may affect the visual perception (i.e., early) stage of information processing along the "visual perception-overt behaviour" continuum. However, it is important to note that the key-press response used in all of these studies is a motor response (i.e., late stage processing). Consequently, the results obtained in such studies may entirely or partially reflect reward influences on the motor (i.e., late) as opposed to the perceptual (i.e., early) information processing stage, depending upon the ability of the employed behavioural measure (i.e., response time to make the key press response, accuracy in making the key-press response, efficiency in making the key-press response, etc.) to reflect one underlying process relative to the other.

Other evidence, suggestive of the effects of reward on feature visual perception, stems from the documented effect of reward on attention (Kiss et al., 2009), given attention's independently documented effects on feature visual perception (e.g., Fang, Boyaci, & Kersten, 2009; Ghose & Maunsell, 2008; Kamitani & Tong, 2006; McAdams & Maunsell, 1999; McAlonan, Cavanaugh, & Wurtz, 2008; McAlonan, Cavanaugh, & Wurtz, 2006; Reynolds, Chelazzi, & Desimone, 1999; Reynolds et al., 1999).

For instance, a study conducted by Kiss et al. (2009) assessed the effects of reward on feature visual perception using a paradigm similar to that used by Kristjansson et al. (2010). More specifically, participants in this study were asked to search for a red or green target diamond among grey distractor diamonds, all of which had a notch either at their top or their bottom. The participants reported the position of the notch on the target diamond on each trial by pressing the corresponding key on a computer keyboard. Reward was manipulated by informing participants that they could earn a bonus payment through the accumulation of sufficient bonus points from fast and correct responses. For half of the participants more bonus points were rewarded for fast and correct responses to the red target stimulus and for the other half of the participants, more bonus points were rewarded for fast and correct responses to the green target stimulus. As would be predicted by reward influences on feature visual perception, the researchers found faster response time and better inverse efficiency for high reward targets.

What sets this study apart from others is that the researchers acquired electroencephalography (EEG) data in addition to behavioural data (i.e., response time accuracy and inverse efficiency). This allowed them to assess whether event-related potential (ERP) signatures vary as a function of reward. ERP literature on feature singleton visual search already exists (e.g., Eimer & Kiss, 2008; Hickey, McDonald, & Theeuwes, 2006; Schubö, Schröger, Meinecke, & Müller, 2007). Such work has uncovered an important correlate of visual target selection, the N2pc component. The N2pc is an enhanced negativity at posterior electrodes contralateral to the target, emerging 180-220ms following display onset. It is believed that this N2pc signal reflects attentional selection of the target among the distractors in the display as a task-relevant item that needs to be judged and reported on (Eimer, 1996; Girelli & Luck, 1997; Woodman & Luck, 1999). Magnetoencephalography (MEG) recordings have implicated the extrastriate visual cortex and the posterior parietal cortex in the N2pc (Hopf et al., 2000). Importantly, however, it is considered a reliable marker of attentional selection in visual search.

Given that both the red and green targets were equally salient in terms of their physical characteristics and both needed to be selected, judged and responded to in the Kiss et al. (2009) study, both were expected to elicit an N2pc. Thus, they were perfectly equated in terms of "cold" cognition. They differed only in whether they were associated with higher versus lower reward (i.e., "hot" cognition). The researchers hypothesized that, if reward affects attentional selection, a later and weaker N2pc would be found for the low rather than the high reward targets. This was indeed their finding, suggesting that low reward targets are attended to later than are high reward targets. The researchers conducted correlation analyses to investigate whether the obtained differences between high and low reward targets in inverse efficiency were related to the obtained differences in N2pc between high and low reward targets. They found a positive correlation between the N2pc and inverse efficiency, suggesting that inverse efficiency reflects a related underlying process.

In turn, a substantial amount of research has investigated and found the neural correlates of attention in visual areas important for feature visual perception. For example, in a study by Somers and colleagues (1999), functional magnetic resonance imaging (fMRI) was used to study humans during attentionally demanding visual discriminations. The results indicated similar robust attentional modulations in both striate and extrastriate cortical areas. These data suggest that neural processing in V1 is not governed simply by sensory stimulation, but, like extrastriate regions, V1 can be strongly and specifically influenced by attention. For example, attention has been shown to affect spatial resolution within the primary visual cortex. In a study by Wörgötter et al. (1998), performed on anesthetized cats, the shape of receptive fields in V1 underwent significant modifications that were correlated with the general state of the brain as assessed by EEG. More specifically, receptive fields were wider during synchronized states (drowsiness) and smaller during non-synchronized states (attentive perception). This shrinking of the receptive field allows the cells in the visual cortex to become more highly sensitized to receiving detailed information regarding visual stimuli, improving performance. Therefore, the effect of target reward value on the N2pc in the Kiss et al. (2009) study may suggest an indirect effect of reward on visual perception (i.e., via attention).

Summary

In summary, numerous studies have reliably shown that overt/observable behaviour in response to visual targets can be modulated by reward. Most studies have investigated and implicated the behavioural differences between responses to low and high reward visual targets to reward-contingent neural modulations during the motor (i.e, late) stage of information processing along the "visual perception-overt behaviour" continuum. More recent studies have also begun to show evidence that these behavioural differences may reflect reward-contingent neural modulations during the visual perception (i.e., early) stage of information processing along the "visual perception-overt behaviour" continuum.

The study conducted by Kiss et al. (2009) showed that low-reward targets are not simply associated with poorer behavioural responses than are high-reward targets, which may reflect later visual perception (i.e., early processing stage) and/or later motor processing (i.e., late processing stage) for low-reward targets than for high-reward targets. The researchers also showed that low-reward targets are associated with a later and weaker N2pc than are high-reward targets, which reflects later attentional selection for low-reward targets than for high-reward targets. In turn, the effects of reward on the N2pc (i.e., attentional selection) suggest that reward influences the visual perception (i.e., early) stage of information processing along the "visual perception-overt behaviour" continuum. Kiss et al. (2009) also found that responses on the behavioural measure of inverse efficiency were correlated with N2pc recordings, suggesting that inverse efficiency reflects a similarly early underlying processing stage as does the N2pc. Thus, findings from the Kiss et al. (2009) study are noteworthy because they are one of the first kinds of evidence demonstrating that reward influences feature visual perception (indirectly, via attention) and that inverse efficiency is a behavioural measure that can alternatively be used to assess the influence exerted by reward on this early underlying process in the absence of EEG recordings.

Current thesis

The aim of the current thesis was to provide a more thorough behavioural assessment of reward influences on visual perception in feature singleton visual search and, thus, on the earliest stage of information processing along the "visual perception-overt behaviour" continuum. This assessment was conducted not only within the magnitude dimension, but also within the probability dimension of reward. The probability dimension of reward was integrated into this study as a preliminary attempt to determine whether the influence of reward on visual processing within the magnitude and probability dimensions follows the same overall principles.

In the current series of experiments, the paradigm used was similar to that used by Kiss et al. (2009). This paradigm was designed to assess only reward-related influences on feature visual perception (i.e., "hot" cognition), given that bottom-up influences and top-down influences that are not related to reward (i.e., "cold" cognition) are controlled for. Some minor adjustments were made to the original paradigm in terms of reward manipulation (discussed in detail later), in order to prevent or reduce the intentional use of go-fast and go-slow motor strategies that were a reported concern in the Kiss et al. (2009) study.

A measure of sensitivity (d') was added to the behavioural measures used in previous experiments of this nature (i.e., response time, accuracy and inverse efficiency). Sensitivity (d') is a statistic used in Signal Detection Theory (Green & Swets, 1966). It quantifies the degree of difficulty with which a target stimulus (i.e., a signal) can be detected amongst background stimuli and random activity generated by the brain (i.e., noise). As such, d' reflects perceptual processing (rather than motor processing). In addition, thresholds for detecting a target (i.e., a signal) are known to vary according to factors such as experience, expectations and psychological state. However, detection thresholds have yet to be assessed in terms of reward contingencies. Therefore, if in the current thesis sensitivity (d') were lower for low-reward targets than for high-reward targets, two important interrelated inferences could be drawn. First, that detection thresholds can vary according to reward contingencies. Second, that perceptual (i.e., early) processing is slower for low-reward targets than for high-reward targets.

Correlations were also performed between all behavioural measures in order to determine whether any observed differences in response time, accuracy and inverse efficiency between low-reward targets and high-reward targets reflected the same or similar underlying process as sensitivity did, namely feature visual perception (i.e., early processing).

Furthermore, in Experiment 3, the display duration across visual search trials was manipulated. It was expected that shortening the display duration would be more detrimental to behavioural measures reflecting early processing, such as sensitivity, for low-reward targets than for high-reward targets. This would further suggest that low-reward targets are visually perceived later than are high-reward targets (either via direct channels, via attention or a combination of both).

Experiment 1

Behavioural assessment of monetary reward magnitude and monetary reward probability influences on feature visual perception

Experiment 1 assessed the overt/observable effects of independently varying a target's reward magnitude (i.e., low reward magnitude versus high reward magnitude), and a target's reward probability (i.e., low reward probability versus high reward probability) on feature visual search. This assessment was conducted on 4 behavioural measures of performance, namely response time, accuracy, inverse efficiency and sensitivity (d'). The experiment concurrently investigated the extent to which each behavioural measure can reflect visual (i.e., early) processing of target features as opposed to motor (i.e., late) processing along the "visual perception-overt behaviour" continuum.

The feature visual search paradigm used was similar to that used by Kiss et al. (2009). However, it was modified in the current experiment in 5 ways. First, Kiss et al. (2009) varied target reward value only within the magnitude dimension. The current study also did so within the probability dimension, while keeping magnitude constant. The probability dimension of reward was integrated into this study as a preliminary attempt to determine whether the influence of reward on visual processing within the magnitude and probability dimensions follows the same principles. Second, the reward manipulation methodology was altered in the current study so as to reduce the possibility that participants employ a conscious go-slow motor strategy for targets low in reward value or go-fast motor strategy for targets high in reward value, which was one of the reported concerns in the Kiss et al. (2009) study. Third, a measure of sensitivity (d') was added to the data analysis in addition to the response time, accuracy and inverse efficiency measures reported in the Kiss et al. (2009) study. Sensitivity was added due to its known reflection of perceptual (i.e., early) rather than motor (i.e., late) processing. Fourth, the association between the four behavioural measures was assessed in an attempt to determine whether differences in measures of response time, accuracy and inverse efficiency reflected the same underlying process as did sensitivity, namely feature visual perception (i.e., early processing). Fifth, a static noise mask was presented immediately following each stimulus presentation so as to reduce afterimages.

Regardless of the reward dimension (i.e., magnitude/**m** or probability/**p**), it was expected that target identification response times would be slower, error rates would be higher, efficiency would be poorer and sensitivity would be lower for targets low in reward value (**LR)** than for targets high in reward value (**HR**). However, given the more stringent control placed on go-slow/go-fast motor strategies in the current experiment as compared to the Kiss et al. (2009) experiment, behavioural measures entirely or primarily reflecting visual (i.e., early) processing, such as sensitivity, were expected to be influenced by reward more than behavioural measures reflecting motor (i.e., late) processing. It was also expected that sensitivity - which reflects early processing - would be correlated with inverse efficiency. This correlation was expected given the Kiss et al. (2009) findings showing inverse efficiency to be positively correlated with the N2pc, suggesting that inverse efficiency is a behavioural measure that reflects a similarly early processing stage as does the N2pc. No expectations were formulated as to additional correlations.

Methodology

Participant sample

Two independent groups of participants were used in this experiment. Participants in the magnitude component of this experiment consisted of 5 female and 3 male (mean age = 25) Concordia University undergraduate psychology students. Participants in the probability component of this experiment consisted of 7 female and 1 male (mean age = 21) Concordia University undergraduate psychology students. All participants had self-reported normal vision. They were drawn from the Psychology Department's Participant Pool and treated in accordance with the guidelines set by the "Concordia University Human Research Ethics Committee".

Apparatus and laboratory space

Stimuli were created using VPixx software (v.2.32) running on a Mac Pro computer and presented on a 24-inch colour LCD Apple Cinema HD display at a 57cm viewing distance. The resolution of the screen was 1920 x 1200 pixels and its refresh rate was 60 Hz. A chin-rest was used so as to avoid head movements. Each participant was tested individually and was seated alone in a dimly lit and quiet room.

Stimuli

On each trial, a circular stimulus array of 12 diamonds was presented against a black background (see Figure 1). The stimulus array on each trial consisted of 11 gray distractor diamonds and 1 red or green target diamond. The gray, red and green diamonds were adjusted to be physically equiluminant (14.1 cd/m^2). Each diamond had a notch randomly positioned either at the top or bottom and subtended 1° x 1° of visual angle (disregarding the 0.35° notch). A central gray fixation dot (0.3° x 0.3° of visual angle) was presented throughout each trial. All diamonds were 4° of visual angle away from the fixation dot. At the end of each trial, the stimulus array region was masked by a static noise pattern so as to minimize afterimages.

Procedure

Testing for each participant consisted of 2 blocks of 240 trials, in which a covert visual search was performed to identify the position (top or bottom) of the notch on the red or green target diamond among the grey distractor diamonds. The total length of testing for each participant was approximately 60 minutes, with a short break between the two blocks. All participants gave informed consent prior to the onset of their first testing block (see Appendix A) and were debriefed as to the rationale of the study following completion of their last testing block.

To initiate each trial, the participant pressed the space bar (see Figure 1). Once the space bar was pressed, the fixation dot was presented for 1.5 seconds (s). When the 1.5s had elapsed, the stimulus array also appeared on the screen and remained there for 150ms (9 frames), which was too brief for the participant to make saccades. Prior to the onset of testing, the participant was explicitly instructed to maintain fixation on the central fixation dot at all times. The participant was also informed that there was an equal likelihood of either the red or green target appearing on each trial and that either target was equally likely to appear in any location within the stimulus array. This information was provided because the probability of a given target appearing in a given location has been suggested to influence the reward value of that target/location (Milstein & Dorris, 2007). The stimulus array was masked by the static noise pattern following its 150ms (9 frames) presentation.

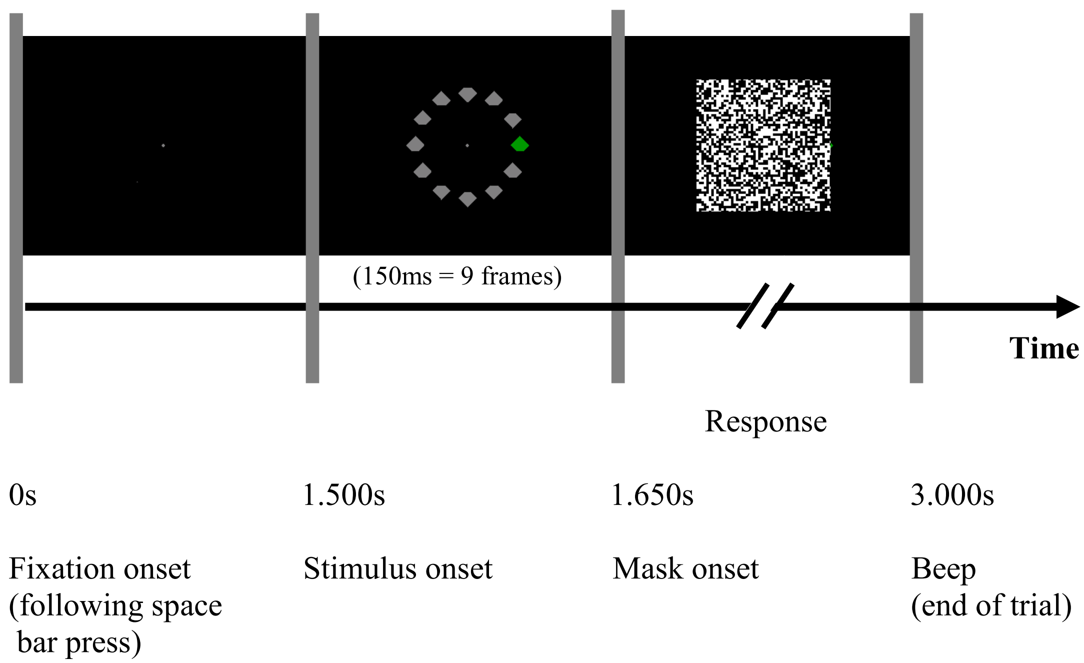

Figure 1. Sample stimulus and trial sequence used in Experiment 1.

The participant reported whether the target stimulus had a notch at the top or the bottom, using the up and down keys on the computer keyboard, as quickly and as accurately as possible. The participant was aware that the response had to be made before a beep sounded 3s following fixation onset, which indicated trial termination.

Reward manipulation

All participants received 2 course credits simply for participating in the study. In addition, at the end of each participant's testing session, a random-number generator was used to select one of the trials therein.

In the magnitude component of the experiment, if the randomly selected trial contained a Low-Reward-Magnitude target (**LRm**), a $1 monetary reward was given. If it contained a High-Reward-Magnitude target (**HRm**), a $10 monetary reward was given. However, if an incorrect or late response (after the 3s) was made in the trial that was randomly selected, no monetary reward was given. For half of the participants, the **LRm** target was red and the **HRm** target was green. For the other half of the participants, the **LRm** target was green and the **HRm** target was red. Participants were informed of these reward contingencies prior to the start of the experiment.

In the probability component of the experiment, if the randomly selected trial contained a Low-Reward-Probability target (**LRp**), a $10 monetary reward was given with 10% probability (A random number generator with numbers 1 through 10 was used. If the number 1 was drawn, the $10 reward was given; if any of the other numbers were drawn, it wasn't). If it contained a High-Reward-Probability target (**HRp**), a $10 monetary reward was given with 100% probability. However, if an incorrect or late response (after the 3s) was made in the trial that was randomly selected, no monetary reward was given. For half of the participants, the **LRp** target was red and the **HRp** target was green. For the other half of the participants, the **LRp** target was green and the **HRp** target was red. Participants were informed of these reward contingencies prior to the start of the experiment.

It was to the participant's benefit to get as many correct and on-time responses as possible regardless of reward value in order to get a monetary reward of some kind. Therefore, every trial was worth something if it was responded to accurately and on time, making both accuracy and speed relevant. In the Kiss et al. (2009) study, bonus points were awarded to any correct trial that exceeded the mean response time of all trials in the block, regardless of reward size. Thus, going slower on **LR** trials and faster on **HR** trials may have served as a conscious strategy to optimize reward. And, making errors on the **LR** trials did not lead to $0 monetary payment as it did in the current experiment.

Results

The raw data generated by each participant were automatically exported from VPixx (v.2.32) to Excel (v.12.3.0). Excel was used to summarize each participant's raw data into "**LRm** target" and "**HRm** target" means for participants in the magnitude group and into "**LRp** target" and "**HRp** target" means for participants in the probability group. This was dome for each of the 4 behavioural measures, namely, response time, accuracy, inverse efficiency, and sensitivity (d'), resulting in a total of 16 means.

Paired samples t-tests: Magnitude and probability dimensions

SPSS software (v.19) was used to conduct a separate paired samples *t*-test on each of the four behavioural measures in the magnitude (**m**) component of the experiment and a separate paired samples *t*-test on each of the four behavioural measures in the probability (**p**) component of the experiment. For each of the four analyses in the **m** dimension, the mean for the **LRm** target was compared to the mean for the **HRm** target. And, for each of the four analyses in the **p** dimension, the mean for the **LRp** target was compared to the mean for the **HRp** target (see Appendix B for complete proofs).

These paired samples *t*-tests were conducted to assess the overt/observable effects of independently varying a target's reward magnitude (i.e., low reward magnitude versus high reward magnitude), and a target's reward probability (i.e., low reward probability versus high reward probability) on feature visual search. Regardless of the reward dimension (i.e., magnitude/**m** or probability/**p**), it was expected that target identification response times would be slower, error rates would be higher, efficiency would be poorer and sensitivity would be lower for targets low in reward value **(LR)** than for targets high in reward value (**HR**).

These paired samples *t*-tests were also conducted to assess the extent to which different behavioural measures can reflect visual (i.e., early) processing of target features as opposed to motor (i.e., late) processing along the "visual perception-overt behaviour" continuum. Given the more stringent control placed on go-slow/go-fast motor strategies in the current experiment as compared to the Kiss et al. (2009) experiment, behavioural measures entirely or primarily reflecting visual (i.e., early) processing, such as sensitivity, were expected to be influenced by reward more than behavioural measures reflecting motor (i.e, late) processing.

Magnitude dimension. Contrary to expectations, the mean response time for the **LRm** target (M = 0.630s, SE = 0.030s) did not differ significantly from the mean response time for the **HRm** target (M = 0.627s, SE = 0.030s), $t(7) = 0.509$, $p = 0.63$, g = 0.03 (see Table B1).

Contrary to expectations, the mean accuracy for the **LRm** target (M = 92.5%, SE = 2.7%) did not differ significantly from the mean accuracy for the **HRm** target (M = 97.3%, SE = 1.1%), $t(7) = 2.190$, $p = 0.07$, $g = 0.77$ (see Table B1).

Contrary to expectations, the mean inverse efficiency for the **LRm** target (M = 0.661s, SE = 0.042s) did not differ significantly from the mean inverse efficiency for the **HRm** target (M = 0.643s, SE = 0.035s), $t(7) = 1.408$, $p = 0.20$, $g = 0.15$ (see Table B1).

As expected, the mean sensitivity for the **LRm** target ($M = 2.812$, SE = 0.258) was significantly lower than the mean sensitivity for the **HRm** target ($M = 3.212$, $SE = 0.223$), $t(7) = 2.309$, $p = 0.05$, $g = 0.55$ (see Figure 2 and Table B1).

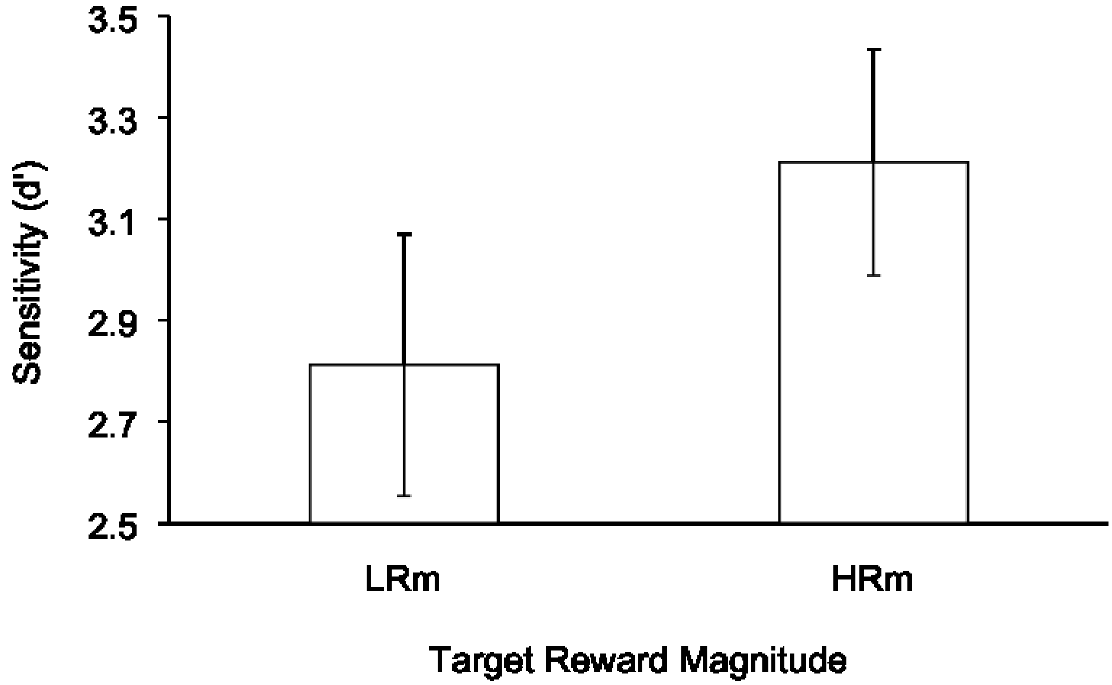

Figure 2. Mean sensitivity (d') (+*SE*) for the Low-Reward-Magnitude target (**LRm**) and High-Reward-Magnitude target (**HRm**) in Experiment 1, $p = 0.05$.

Probability dimension. Contrary to expectations, the mean response time for the **LRp** target (*M* = 0.627s, *SE* = 0.016s) did not differ significantly from the mean response time for the **HRp** target (*M* = 0.622s, *SE* = 0.016s), $t(7) = 0.791$, $p = 0.46$, $g = 0.11$ (see Table B2).

As expected, the mean accuracy for the **LRp** target (*M* = 96.5%, *SE* = 1.3%) was significantly lower than the mean accuracy for the **HRp** target (*M* = 97.5%, *SE* = 1.3%), $t(7) = 2.506$, $p = 0.04$, $g = 0.24$ (see Figure 3 and Table B2).

Contrary to expectations, the mean inverse efficiency for the **LRp** target (*M* = 0.650s, *SE* = 0.016s) did not differ significantly from the mean inverse efficiency for the **HRp** target (*M* = 0.638s, *SE* = 0.015s), $t(7) = 1.448$, $p = 0.19$, $g = 0.25$ (see Table B2).

As expected, the paired samples *t*-test conducted on the sensitivity (d') data in the **p** dimension of reward revealed that the mean sensitivity for the **LRp** target (*M* = 2.882, *SE* = 0.154) was significantly lower than the mean sensitivity for the **HRp** target (*M* = 3.154, *SE* = 0.148), $t(7) = 3.761$, $p = 0.01$, $g = 0.60$ (see Figure 4 and Table B2).

Paired samples *t*-tests summary. As expected, sensitivity (d') was significantly lower for **LR** targets than for **HR** targets in both the **m** and **p** dimensions. Thus, two important interrelated inferences could be drawn for both dimensions of reward. First, detection thresholds can vary according to reward contingencies. Second, perceptual (i.e., early) processing is slower for low-reward targets than for high-reward targets.

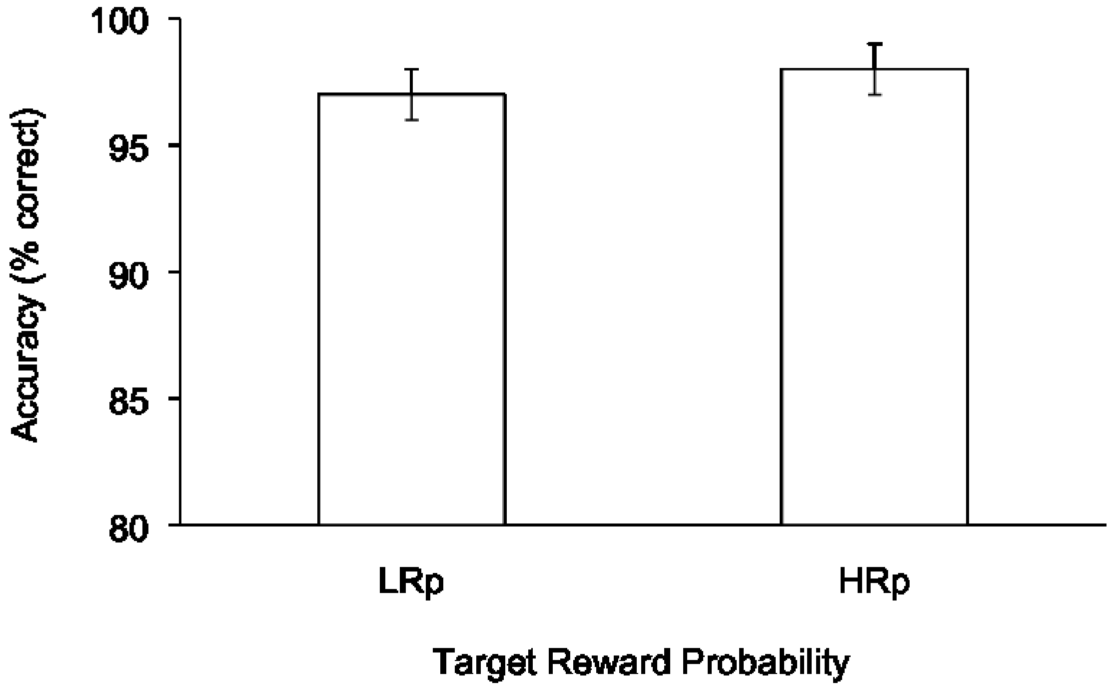

Figure 3. Mean accuracy (+*SE*) for the Low-Reward-Probability target (**LRp**) and High-Reward-Probability target (**HRp**) in Experiment 1, $p = 0.04$.

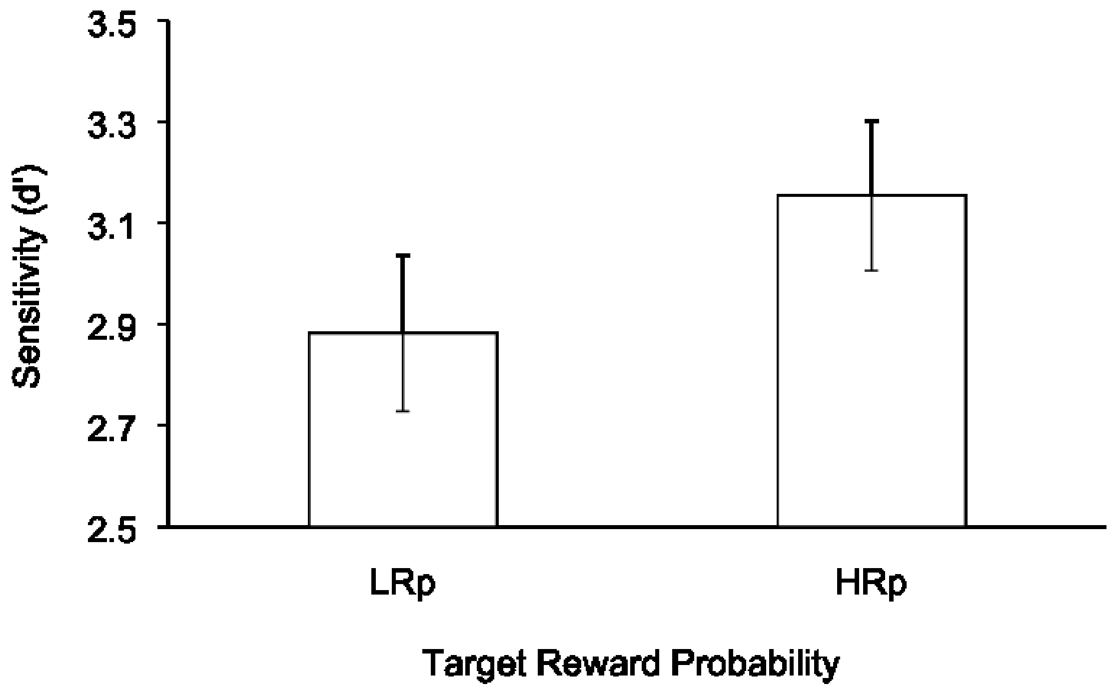

Figure 4. Mean sensitivity (d') (+*SE*) for the Low-Reward-Probability target (**LRp**) and High-Reward-Probability target (**HRp**) in Experiment 1, $p = 0.01$.

Also, as expected, accuracy was significantly lower for **LR** targets than for **HR** targets in the **p** dimension. A trend in the same direction was obtained in the **m** dimension. This finding on its own did not allow for a disambiguation between accuracy being a reflection of early and/or late processing. Therefore, accuracy's relationship with sensitivity (i.e., reflection of early processing) was subsequently investigated in the "**Intercorrelations between measures**" results section (p. 43). A significant positive accuracy-sensitivity correlation would suggest that, accuracy, like sensitivity, is a likely reflection of perceptual (i.e., early) processing.

Contrary to expectations, response time was not significantly slower and inverse efficiency was not significantly poorer for **LR** targets than for **HR** targets in both the **m** and **p** dimensions. Nonetheless, the direction of findings was in the expected direction. The non-significant findings for response time were somewhat expected given the more stringent control placed on go-slow/go-fast motor strategies (i.e., late processing stage) in the current experiment as compared to the Kiss et al. (2009) experiment. In contrast, the non-significant inverse efficiency findings were surprising given inverse efficiency's correlation with the N2pc (i.e., early processing stage) in the Kiss et al. (2009) study. The non-significant inverse efficiency findings may therefore be due to the response time component involved in the calculation of inverse efficiency (inverse efficiency = response time/proportion correct). Furthermore, the possibility that the use of a training block in the Kiss et al. (2009) study but not in the current study lead to the statistical discrepancies for response time and inverse efficiency between their study and the current study was reliably ruled out. This was accomplished by re-analyzing the data within Experiment 1. More specifically, the 480 trials were divided into 4 blocks of 120 trials. Differences in response time and inverse efficiency between **LR** targets and **HR** targets did not differ significantly across blocks in either dimension (see Table B3). In other words, a significant perceptual learning effect was not observed for response time (**m** dimension: $F(3, 21) = 0.399$, $p = 0.76$; $\eta 2 = 0.05$; **p** dimension: $F(3, 21) = 0.257$, $p = 0.86$, $\eta 2 = 0.04$) or inverse efficiency (**m** dimension: $F(3, 21) = 2.099$, $p = 0.13$, $\eta 2 = 0.23$; **p** dimension: $F(3, 21) = 2.560$, $p = 0.08$, $\eta 2 = 0.27$) between bocks, possibly due to the inherent simplicity of the task.

Independent samples *t*-tests: Magnitude versus probability dimensions

Findings from the paired samples *t*-tests reported in the previous section were similar within the magnitude (**m**) and probability (**p**) dimensions of reward. This observation suggested that reward manipulations in both dimensions had similar effects on behavioural performance. However, it was considered noteworthy that the paired samples *t*-tests in the **m** component of the experiment showed somewhat weaker statistical results than those in the **p** component of the experiment. More specifically, for all 4 measures of performance, the *p*-values were larger and *t*-scores were smaller in the **m** dimension as compared to the **p** dimension. Furthermore, statistical significance was obtained only for the sensitivity (d') measure of performance in the **m** dimension, whereas statistical significance was obtained for both the accuracy and sensitivity (d') measures of performance in the **p** dimension.

The larger *p*-values and smaller *t*-scores in the **m** dimension as compared to the **p** dimension were somewhat contradictory to the observation that the mean difference between the **LRm** and **HRm** targets seemed larger than the mean difference between the **LRp** and **HRp** targets, for the accuracy, inverse efficiency and sensitivity measures of performance (opposite, but negligible for response time). Similarly contradictory to the *p*-value and *t*-score observations, but in line with the mean differences observations, was the larger effect size for accuracy in the **m** dimension as compared to the **p** dimension.

It must be emphasized that these observed inconsistencies would normally not be investigated further. However, given that Experiments 3 and 4 address **m** and **p** dimensions of reward, such subtleties were important to understand in order to allow an informed interpretation of the findings in each dimension. Therefore, SPSS software (v.19) was used to conduct a separate independent samples *t*-test on each of the 4 behavioural measures of performance. For each of the 4 analyses, the mean difference between the **LRm** and **HRm** targets was compared to the mean difference between the **LRp** and **HRp** targets (see Appendix B for complete proofs).

Response time. The mean difference in response time between the **LR** target and **HR** target in the **m** dimension ($M = 0.003$s, $SE = 0.005$s) did not differ significantly from the mean difference in response time between the **LR** target and **HR** target in the **p** dimension ($M = 0.005$s, $SE = 0.007$s), $t(7) = -0.512$, $p = 0.62$ (see Table B4).

Accuracy (% correct). The mean difference in accuracy between the **LR** target and **HR** target in the **m** dimension ($M = -4.8\%$, $SE = 2.2\%$) did not differ significantly from the mean difference in accuracy between the **LR** target and **HR** target in the **p** dimension ($M = -1.0\%$, $SE = 0.4\%$), $t(7) = -1.719$, $p = 0.13$ (see Table B4).

Inverse efficiency. The mean difference between in inverse efficiency between the **LR** target and **HR** target in the **m** dimension ($M = 0.018$s, $SE = 0.013$s) did not differ significantly from the mean difference in inverse efficiency between the **LR** target and **HR** target in the **p** dimension (*M* = 0.012s, *SE* = 0.008s), *t*(7) = 0.648, *p* = 0.54 (see Table B4).

Sensitivity (d'). The mean difference in sensitivity between the **LR** target and **HR** target in the **m** dimension (*M* = -0.400, *SE* = 0.173) did not differ significantly from the mean difference in sensitivity between the **LR** target and **HR** target in the **p** dimension (*M* = -0.272, *SE* = 0.072) , *t*(7) = -0.831, *p* = 0.43 (see Table B4).

Range and Variance

In the independent samples *t*-tests section above, the mean difference between the **LRm** and **HRm** targets was not shown to be significantly larger than the mean difference between the **LRp** and **HRp** targets for any behavioural measure of performance. This finding solidified the earlier conclusion that reward manipulations in both dimensions had similar effects on behavioural performance.

However, even the non-significant larger mean differences in the **m** dimension for the accuracy, inverse efficiency and sensitivity measures, combined with larger effect size for accuracy in the **m** dimension, remained contradictory with the larger *p*-values and smaller *t*-scores in the **m** dimension. Thus, the standard errors of means were compared in each dimension. This comparison revealed that they were larger in the **m** dimension than in the **p** dimension for the accuracy, inverse efficiency and sensitivity measures. Thus, it was hypothesized that the surprisingly weaker *p*-value and *t*-score findings in the **m** dimension were simply due to a greater range and variance between participant responses in that dimension (see Table B5 for complete proofs).

Range. As expected, for all behavioural measures of performance, the range of responses was larger in the **m** dimension than in the **p** dimension (averaged over Target Reward Value). More specifically, for the response time measure, the **m** dimension had a 0.263s range and the **p** dimension had a 0.135s range. For the accuracy measure, the **m** dimension had a 13.5% range and the **p** dimension had an 11.5% range. For the inverse efficiency measure, the **m** dimension had a 0.298s range and the **p** dimension had a 0.146s range. For the sensitivity measure, the **m** dimension had a 2.172 range and the **p** dimension had a 1.344 range.

Also, the larger range found in the **m** dimension as compared to the **p** dimension applied to both the **LR** and **HR** targets for the response time, inverse efficiency and sensitivity measures of performance (but only for the **LR** target for the accuracy measure of performance). More specifically, for the response time measure, the **LRm** target had a range of 0.255s and the **LRp** target had a range of 0.141s; the **HRm** target had a range of 0.270s and the **HRp** target had a range of 0.128s (see Figure 5). For the accuracy measure, the **LRm** target had a range of 16.8% and the **LRp** target had a range of 11.3%; the **HRm** target had a range of 10.1% and the **HRp** target had a range of 11.6% (see Figure 6). For the inverse efficiency measure, the **LRm** target had a range of 0.314s and the **LRp** target had a range of 0.156s; the **HRm** target had a range of 0.282s and the **HRp** target had a range of 0.136s (see Figure 7). For the sensitivity measure, the **LRm** target had a range of 2.407 and the **LRp** target had a range of 1.254; the **HRm** target had a range of 1.936 and the **HRp** target had a range of 1.433 (see Figure 8).

Also potentially noteworthy is that the difference in range between the **LRm** and **HRm** targets was larger than the **LRp** and **HRp** targets for the response time

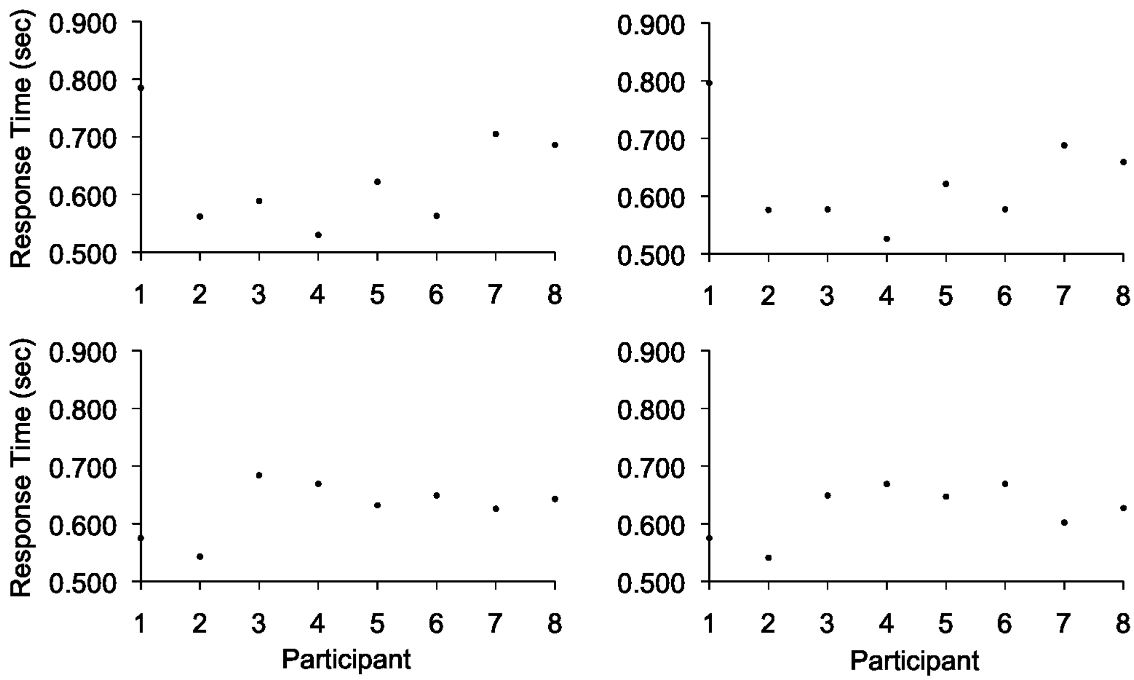

Figure 5. Response time scatter plots for the **LRm** (top left), **HRm** (top right), **LRp** (bottom left) and **HRp** (bottom right) targets in Experiment 1. Each point represents the data of one participant.

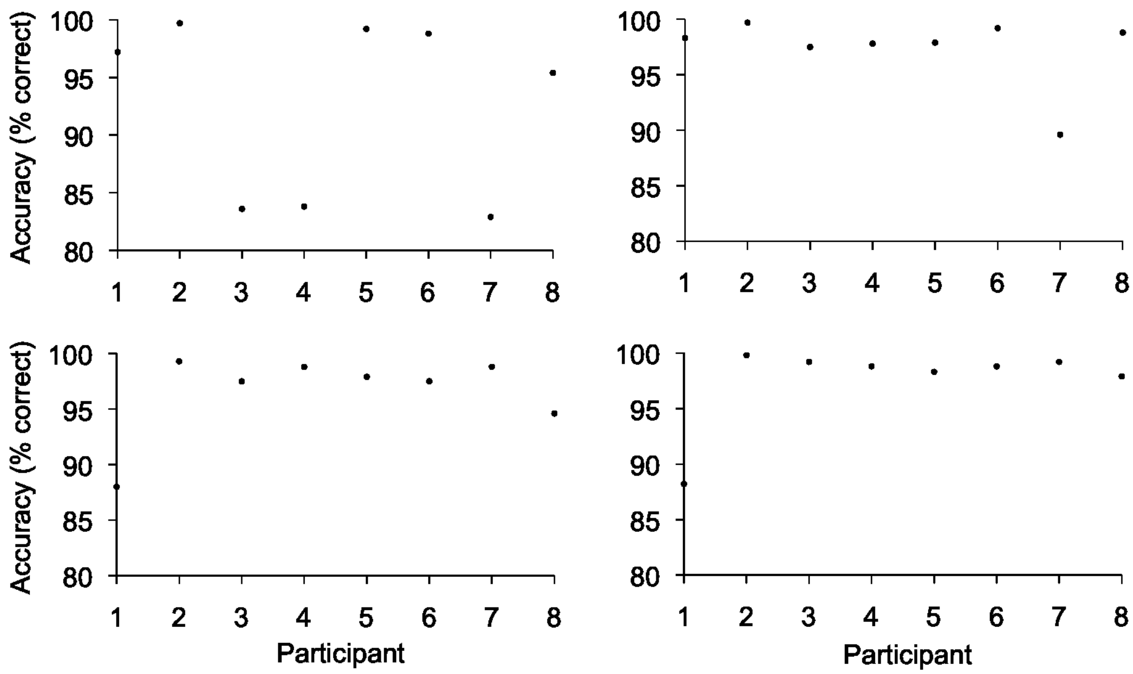

Figure 6. Accuracy scatter plots for the **LRm** (top left), **HRm** (top right), **LRp** (bottom left) and **HRp** (bottom right) targets in Experiment 1. Each point represents the data of one participant.

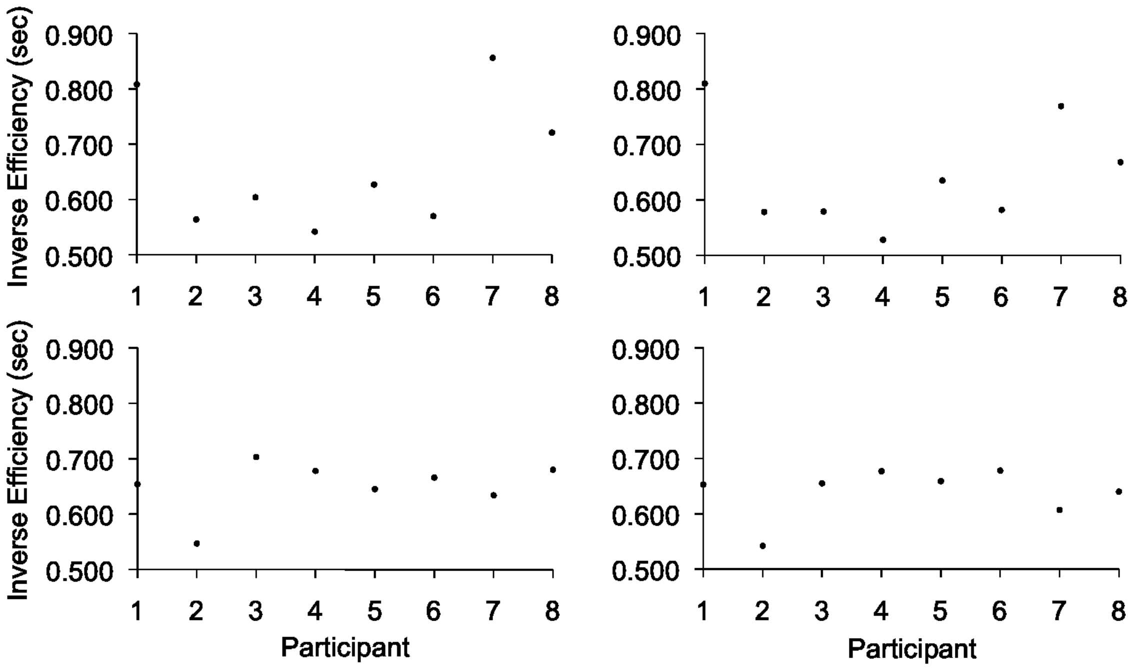

Figure 7. Inverse efficiency scatter plots for the **LRm** (top left), **HRm** (top right), **LRp** (bottom left) and **HRp** (bottom right) targets in Experiment 1. Each point represents the data of one participant.

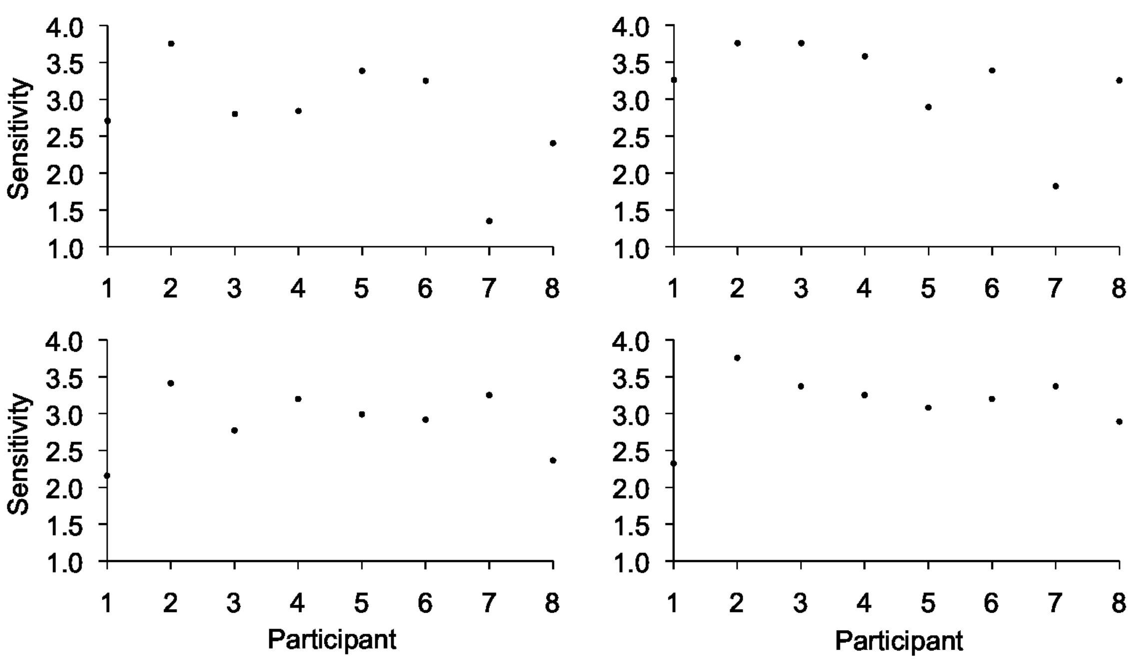

Figure 8. Sensitivity scatter plots for the **LRm** (top left), **HRm** (top right), **LRp** (bottom left) and **HRp** (bottom right) targets in Experiment 1. Each point represents the data of one participant.

measure (**LRm** - **HRm** = -0.015s; **LRp** - **HRp** = 0.013s), accuracy measure (**LRm** - **HRm** = 6.7%; **LRp** - **HRp** = -0.3%), inverse efficiency measure (**LRm** - **HRm** = 0.032s;

LRp - **HRp** = 0.020s) and sensitivity measure (**LRm** - **HRm** = 0.471; **LRp** - **HRp** = -0.179).

Variance. Also, as expected, for all behavioural measures of performance, the variance was larger in the **m** dimension than in the **p** dimension (averaged over Target Reward Value). More specifically, for the response time measure, the **m** dimension had a 0.008s variance and the **p** dimension had a 0.002s variance. For the accuracy measure, the **m** dimension had a 0.4% variance and the **p** dimension had a 0.1% variance. For the inverse efficiency measure, the **m** dimension had a 0.012s variance and the **p** dimension had a 0.002s variance. For the sensitivity measure, the **m** dimension had a 0.467

Also, the larger variance found in the **m** dimension as compared to the **p** dimension applied to both the **LR** and **HR** targets for the response time, inverse efficiency and sensitivity measures of performance, but only for the **LR** target for the accuracy measure of performance. More specifically, for the response time measure, the **LRm** target had a variance of 0.008s and the **LRp** target had a variance of 0.002s; the **HRm** target had a variance of 0.007s and the **HRp** target had a variance of 0.002s (see Figure 5). For the accuracy measure, the **LRm** target had a variance of 0.6% and the **LRp** target had a variance of 0.1%; the **HRm** target had a variance of 0.1% and the **HRp** target had a variance of 0.1% (see Figure 6). For the inverse efficiency measure, the **LRm** target had a variance of 0.014s and the **LRp** target had a variance of 0.002s; the **HRm** target had a variance of 0.010s and the **HRp** target had a variance of 0.002s (see Figure 7). For the sensitivity measure, the **LRm** target had a variance of 0.533 and the

LRp target had a variance of 0.191; the **HRm** target had a variance of 0.400 and the **HRp** target had a variance of 0.176 (see Figure 8).

Also potentially noteworthy is that there is a difference in variance between the **LRm** and **HRm** targets but not between the **LRp** and **HRp** targets for the response time measure (**LRm** - **HRm** = 0.001s; **LRp** - **HRp** = 0.000s), accuracy measure (**LRm** - **HRm** = 0.5%; **LRp** - **HRp** = 0.0%) and inverse efficiency measure (**LRm** - **HRm** = 0.004s; **LRp** - **HRp** = 0.000s). And, that the difference in variance between the **LRm** and **HRm** targets is larger than the difference in range between the **LRp** and **HRp** targets for the sensitivity measure (**LRm** - **HRm** = 0.133; **LRp** - **HRp** = 0.015).

Intercorrelations between measures

Finally, it was clearly noticeable that the paired samples *t*-test results from the 4 different behavioural measures are were not identical. More specifically, the response time measure seemed not to be greatly affected by target reward manipulation in either dimension of reward (**m** or **p**), as evidenced by it having the lowest effect sizes of all measures in the paired samples *t*-tests. In contrast, the accuracy and sensitivity measures seemed to respond to target reward manipulation the most (measures with the highest effect sizes). Inverse efficiency was somewhere in between (moderate effect sizes). Thus, it was deemed important to investigate the relationships among the 4 behavioural measures of performance, as they may reflect somewhat different underlying processes.

SPSS software was used to compute Pearson product-moment correlation coefficients among the 4 measures, separately for the **m** dimension of reward (see Table B6) and the **p** dimension of reward (see Table B7) (see Appendix B for complete proofs).

As outlined bellow, similar results were obtained for both dimensions of reward, again suggesting that reward magnitude and reward probability manipulations affected visual search similarly.

Magnitude dimension. For the **m** dimension, there was a positive correlation between the response time and inverse efficiency measures ($r(8) = 0 .943$, $p = 0.00$) and between the accuracy and sensitivity measures ($r(8) = 0.712$, $p = 0.00$). Therefore, increases in response time were correlated with increases in inverse efficiency (see Figure 9) and increases in accuracy were correlated with increases in sensitivity (see Figure 10). There was a negative correlation between the inverse efficiency and sensitivity measures ($r(8) = -0.719$, $p = 0.00$). Therefore, increases in inverse efficiency were correlated with decreases in sensitivity (see Figure 11). No significant correlations were found between the response time and accuracy measures ($r(8) = -0.019$, $p = 0.95$), between the response time and sensitivity measures ($r(8) = -0.494$, $p = 0.06$), or between the accuracy and inverse efficiency measures ($r(8) = -0.244$, $p = 0.36$).

Probability dimension. For the **p** dimension, there was a positive correlation between the response time and inverse efficiency measures ($r(8) = 0.855$, $p = 0.00$) and between the accuracy and sensitivity measures ($r(8) = 0.878$, $p = 0.00$). Therefore, increases in response time were correlated with increases in inverse efficiency (see Figure 12) and increases in accuracy were correlated with increases in sensitivity (see Figure 13). Also, there was a negative correlation between the inverse efficiency and sensitivity measures ($r(8) = -0.538$, $p = 0.03$). Therefore, increases in inverse efficiency were correlated with decreases in sensitivity (see Figure 14). No significant correlations

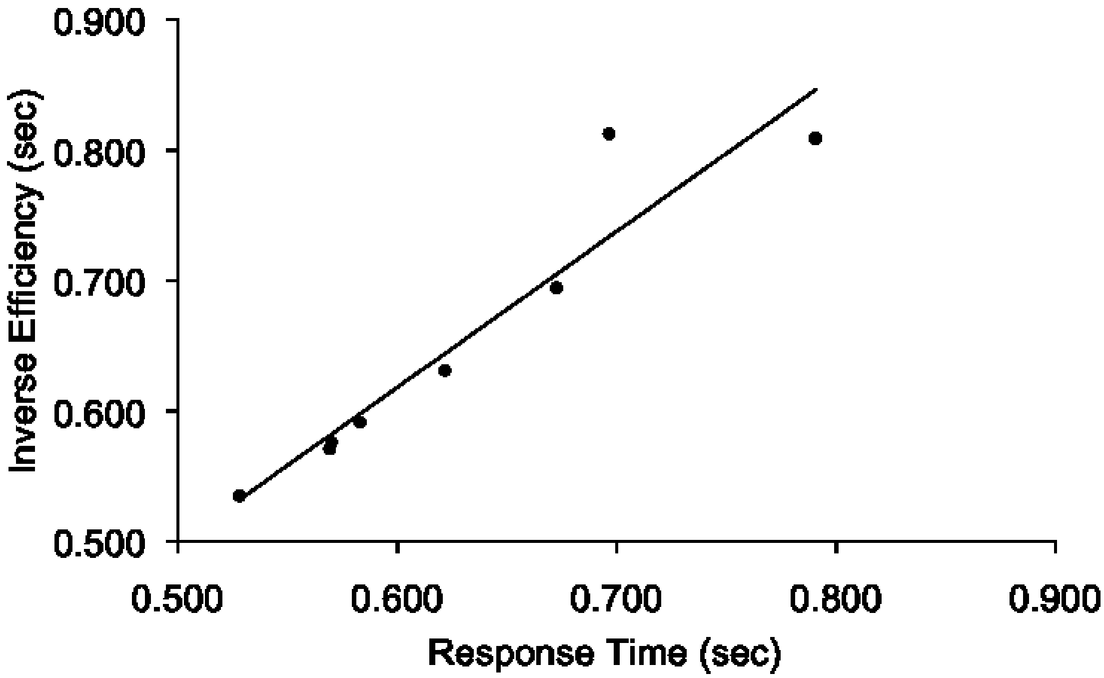

Figure 9. Significant positive correlation between the response time and inverse efficiency measures in the magnitude component of Experiment 1, ($r(8) = 0.943$, p = 0.00). Each point represents the data of one participant.

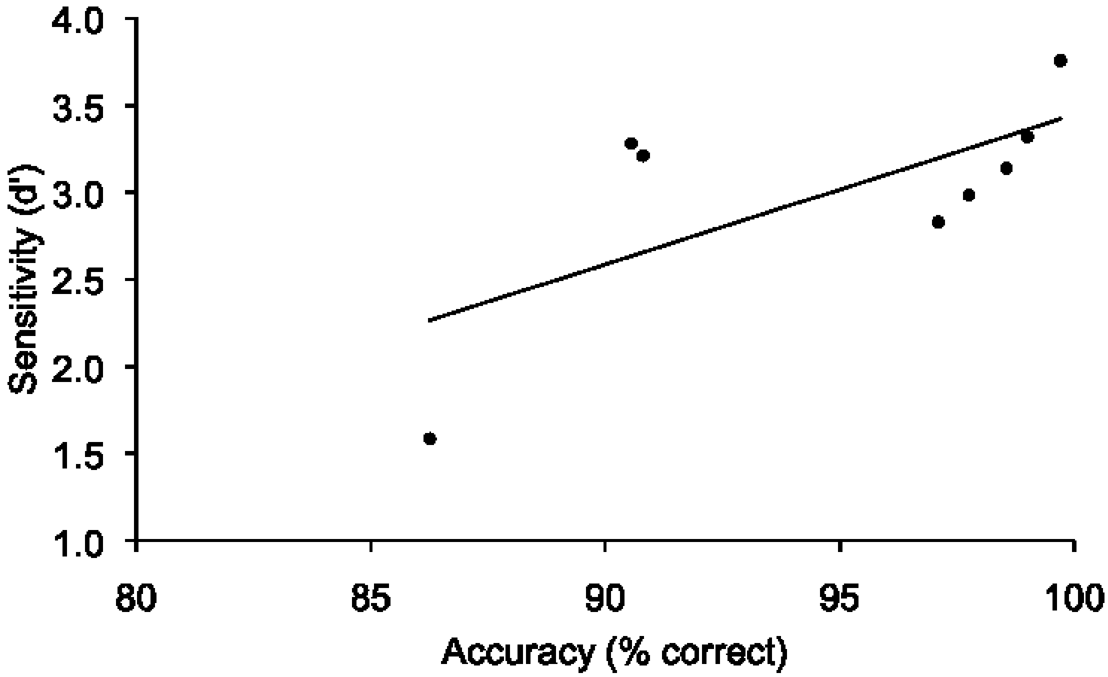

Figure 10. Significant positive correlation between the accuracy and sensitivity measures in the magnitude component of Experiment 1, ($r(8) = 0.712$, $p = 0.00$). Each point represents the data of one participant.

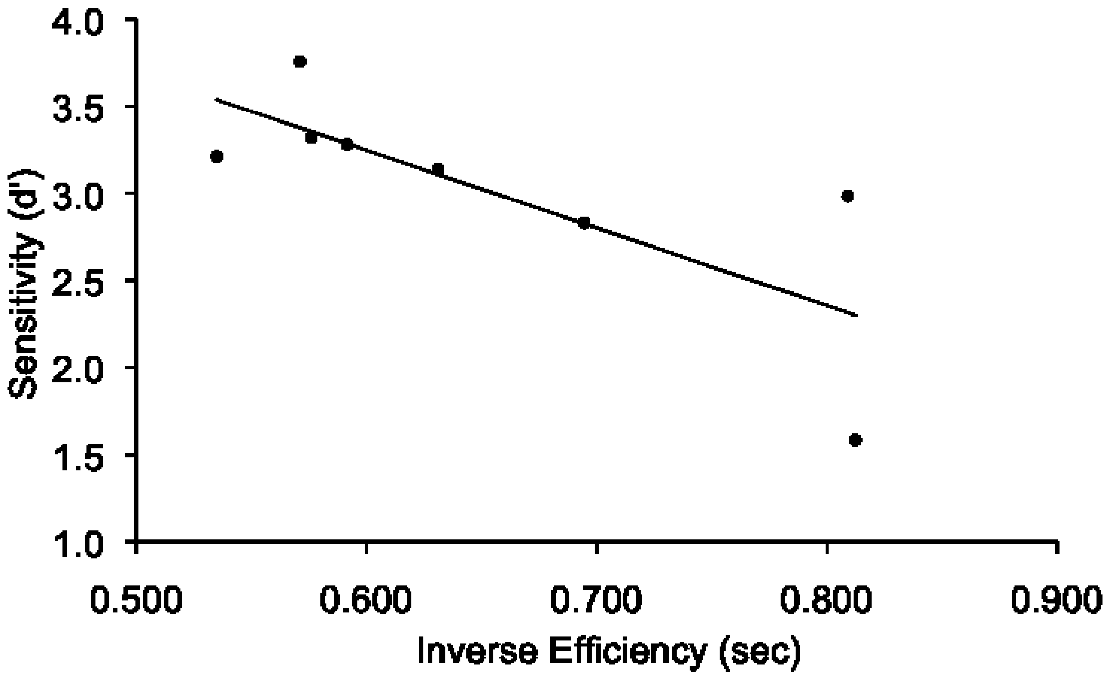

Figure 11. Significant negative correlation between the inverse efficiency and sensitivity measures in the magnitude component of Experiment 1, ($r(8) = -0.719$, $p = 0.00$). Each point represents the data of one participant.

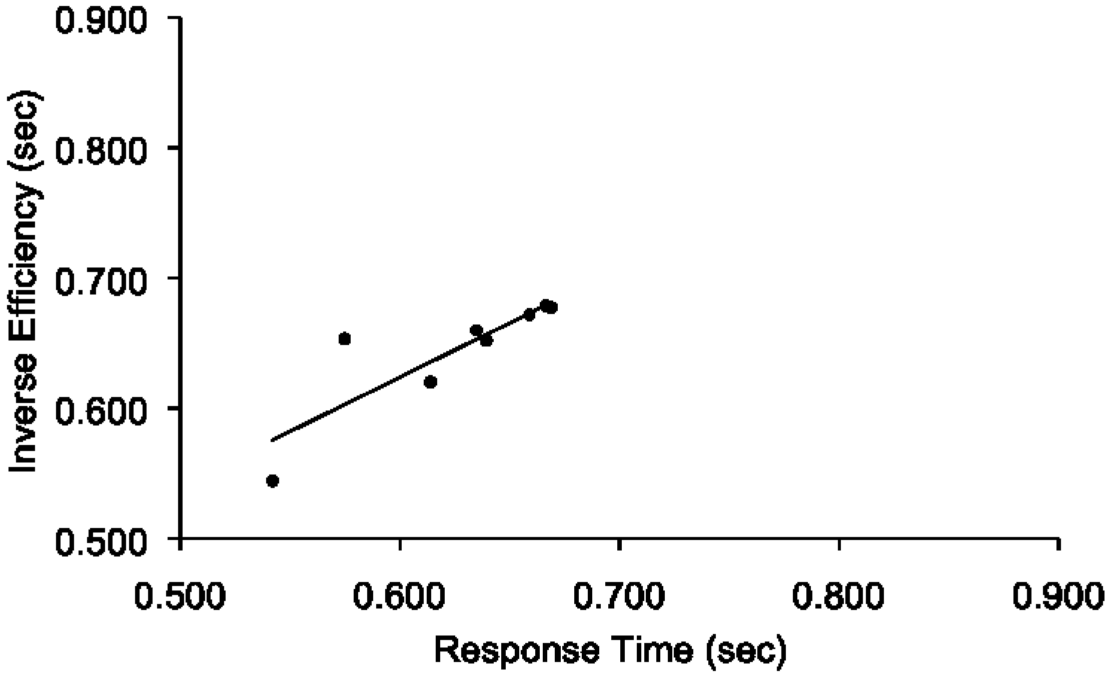

Figure 12. Significant positive correlation between the response time and inverse efficiency measures in the probability component of Experiment 1, ($r(8) = 0.855$, $p = 0.00$). Each point represents the data of one participant.

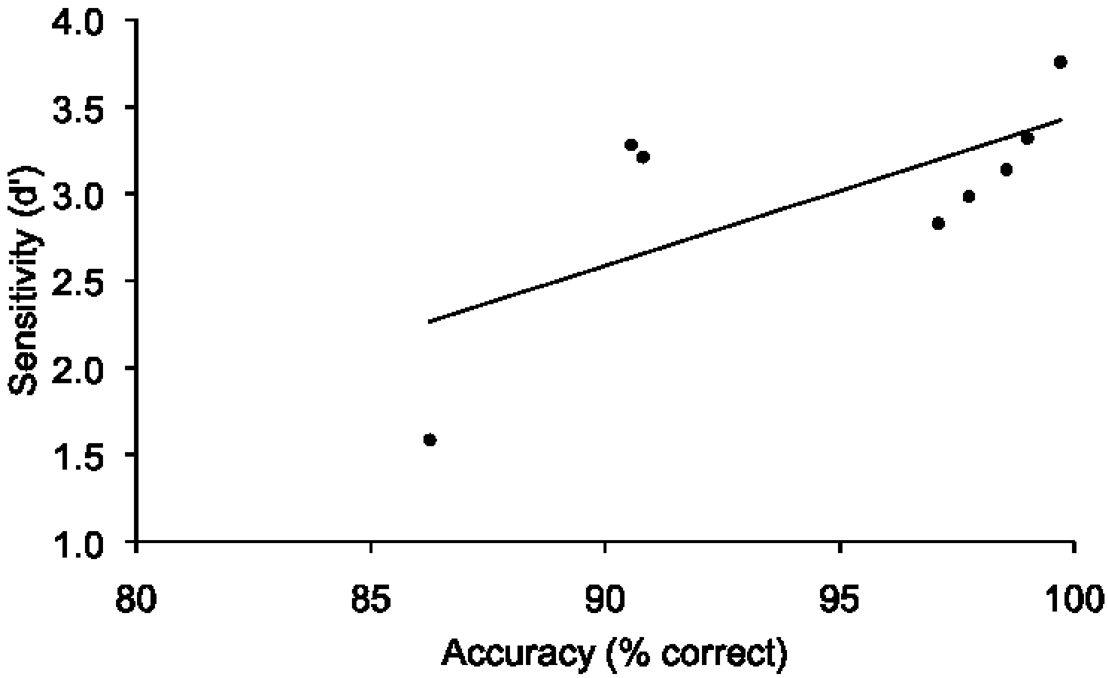

Figure 13. Significant positive correlation between the accuracy and sensitivity measures in the probability component of Experiment 1, ($r(8) = 0.878$, $p = 0.00$). Each point represents the data of one participant.

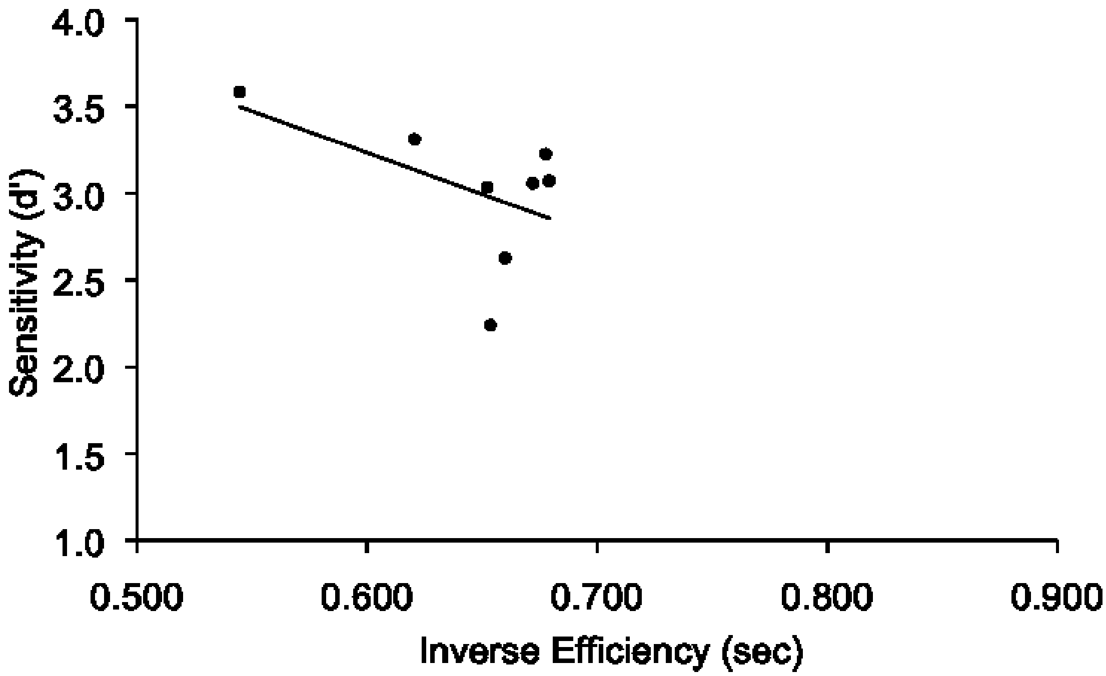

Figure 14. Significant negative correlation between the inverse efficiency and sensitivity measures in the probability component of Experiment 1, ($r(8) = -0.538$, $p = 0.03$). Each point represents the data of one participant.

were found between the response time and accuracy measures ($r(8) = 0.297$, $p = 0.26$), between the response time and sensitivity measures ($r(8) = -0.060$, $p = 0.83$), or between the accuracy and inverse efficiency measures ($r(8) = -0.241$, $p = 0.37$).

Discussion

Summary of Findings

Paired samples *t*-tests: Magnitude and probability dimensions. The paired samples *t*-tests conducted on the sensitivity (d') measure resulted in statistical significance for the **m** and **p** dimensions of reward. As expected, the **LRm** target was responded to with significantly less sensitivity than the **HRm** target and the **LRp** target was responded to with significantly less sensitivity than the **HRp** target. Thus, two important interrelated inferences could be drawn for both dimensions of reward. First, detection thresholds can vary according to reward contingencies. Second, perceptual (i.e., early) processing is slower for low-reward targets than for high-reward targets.

The paired samples *t*-tests conducted on the accuracy measure resulted in statistical significance for the **p** dimension of reward. As expected, the **LRp** target was responded to with significantly less accuracy than the **HRp** target. A strong trend in the same direction was observed for the **m** dimension of reward. Accuracy's close relationship with sensitivity was demonstarted by a significant accuracy-sensitivity correlation (discussed further in the "**Intercorrelations between measures"** discussion section). Thus, accuracy, like sensitivity, is a likely reflection of perceptual (i.e., early) processing.

In contrast, contrary to expectations and to the Kiss et al. (2009) findings, response time was not significantly slower and inverse efficiency was not significantly poorer for **LR** targets than for **HR** targets in both the **m** and **p** dimensions. Nonetheless, the direction of findings was in the expected direction.

The discrepancy in the statistical significance of response time findings between the Kiss et al. (2009) study and the current study may be due to the differences in reward manipulation between the two studies. More specifically, research has shown less movement “vigor” (i.e., slower response time) towards **LR** than **HR** targets (e.g., Opris et al., 2011). This effect of reward on motor (i.e., late) processing may be part of the cause for the statistically significant slower response time for **LR** targets in the Kiss et al. (2009) study (aside from the potential of slower visual perception consequently affecting motor processing). However, the current study placed more stringent control over conscious go-slow/go-fast motor response strategies by having every response associated with the potential of leading to some level of reward and by making the time limit to respond more lenient than in the Kiss et al. (2009) study. Therefore, the current study may not have entirely masked the effect of reward on motor (i.e., late) processing, but may have diminished it, leading to the non-significant response time results.

The discrepancy in the statistical significance of inverse efficiency findings between the Kiss et al. (2009) study and the current study were somewhat surprising given inverse efficiency’s correlation with the N2pc (i.e., early processing stage) in the Kiss et al. (2009) study. The non-significant inverse efficiency findings were also surprising given inverse efficiency’s significant correlation with sensitivity (i.e., early processing stage) in the current experiment (discussed further in the “**Intercorrelations between measures”** discussion section). Therefore, this discrepancy, like the discrepancy observed for response time, may be due to the differences in reward manipulation between the two studies. This is believed to be the case because of the response time component involved in the calculation of inverse efficiency (inverse efficiency = response time/proportion correct). This conclusion was further supported by a significant response time-inverse efficiency correlation (discussed further in the "**Intercorrelations between measures"** discussion section).

Independent samples *t*-tests: Magnitude versus probability dimensions. The similarity in findings between the **m** and **p** dimensions suggested that the reward manipulations in both dimensions affected behaviour similarly. However, because there have been no direct comparisons of reward magnitude and reward probability manipulations on the same visual search task in the past, the data in each dimension were more closely examined in order to determine if there were any patterns that would merit further analysis.

Larger mean differences were observed between the **LRm** and **HRm** targets than between the **LRp** and **HRp** targets for all behavioural measures of performance apart from response time, where the direction of findings was opposite yet negligible. (And, a larger effect size was obtained for accuracy in the **m** dimension as compared to the **p** dimension.) Therefore, independent samples *t*-tests were conducted to statistically compare these mean differences. However, statistical significance was not reached, further confirming that the reward manipulations in both dimensions affected behaviour similarly.

Range and Variance. Even though the mean differences between the **LRm** and **HRm** targets were not significantly larger than the mean differences between the **LRp** and **HRp** targets for accuracy, inverse efficiency and sensitivity, the larger *p*-values and smaller *t*-scores in the **m** dimension remained contradictory. Thus, the standard errors of means between the **m** and **p** dimensions were compared. Apart from the response time measure, the standard errors of means were larger in the **m** than in the

p dimension. Therefore, a closer look at the range and variability between participant responses was deemed necessary. This closer examination led to the conclusion that the surprisingly larger *p*-values and smaller *t*-scores in the **m** dimension were due to a greater range and variability in participant responses.

Intercorrelations between measures. Relationships among the 4 measures of performance were also assessed, independently for the **m** and **p** dimensions and similar findings were obtained in both dimensions. Once again, this finding confirmed that the reward manipulations in both dimensions affected behaviour similarly.

More specifically, the response time measure was positively correlated with the inverse efficiency measure and the accuracy measure was positively correlated with the sensitivity measure. The positive nature of both correlations was expected. More specifically, a longer response time should be associated with a higher inverse efficiency score because both indicate poorer performance than a faster response time and lower inverse efficiency score. Similarly, a lower accuracy should be associated with a lower sensitivity because both indicate poorer performance than a higher accuracy and a higher sensitivity. Also, in general, these correlations are not surprising given that response time and inverse efficiency led to the smallest effect sizes whereas accuracy and sensitivity led to the largest effect sizes.

Combined with the smaller effect sizes for response time and inverse efficiency, the correlation between these two measures may suggest that the response time measure (an established reflection of movement vigor) and response time component of the inverse efficiency measure are more closely, though not necessarily exclusively, tied to the motor (i.e., late) processing stage rather than to the visual perception (i.e., early) stage of information processing along the "visual perception-overt behaviour" continuum. As previously mentioned, the current study placed even more stringent control over conscious go-slow/go-fast motor strategies than the Kiss et al. (2009) study, perhaps somewhat masking the effect of reward on the late stage of processing.

Although slower visual perception (i.e., early stage of information processing) of a target may also be reflected by a slower response time and worse inverse efficiency, the difference in the associated covert visual processing speed between **LR** and **HR** targets may not be large enough to be detected by the response time measure and response time component of the inverse efficiency measure. This hypothesis is consistent with the Kiss et al. (2009) N2pc findings. More specifically, although the Npc (attentional selection) for **LR** targets appeared significantly later than the N2pc for **HR** targets, the difference was a subtle one.

In contrast, combined with the larger effect sizes for accuracy and sensitivity, the correlation between these two measures may suggest that the sensitivity measure (an established reflection of perceptual rather than motor processing) and accuracy measure are more closely, though not necessarily exclusively, tied to the visual perception (i.e., early) stage rather than to the motor (i.e., late) stage of information processing along the "visual perception-overt behaviour" continuum.

Furthermore, the anticipated negative correlation between inverse efficiency and sensitivity was obtained. This correlation was expected given that both inverse efficiency (shown to be correlated with the N2pc by Kiss et al., 2009) and sensitivity are likely similar reflections of the visual perception (i.e., early) stage of information processing. Also, in all other statistical analyses conducted, inverse efficiency effect sizes were not as low as response time effect sizes (which were moderate). Additionally, given that the calculation of both inverse efficiency and sensitivity includes accuracy data and that accuracy was positively correlated with sensitivity, the inverse efficiency-sensitivity correlation becomes further intuitive. The negative nature of the inverse efficiency-sensitivity relationship was also predictable. More specifically, a higher inverse efficiency score should be associated with a lower sensitivity because both indicate poorer performance than a lower inverse efficiency score and higher sensitivity.

Finally, the potential for a speed-accuracy tradeoff (i.e., sacrificing response speed for accuracy) was reliably ruled out given that no positive correlation was found between response time and accuracy. Furthermore, the fact that a negative correlation between response time and accuracy was also not found corroborated the speculation discussed earlier that the two measures might, at least in part, reflect two different underlying stages of processing along the "visual perception-overt behaviour" continuum (motor processing versus visual perception, respectively).

Conclusion

In summary, it was concluded that low-reward targets are visually perceived later than are high-reward targets. Furthermore, certain behavioural measures have a greater ability to reflect covert reward influences on the visual perception (i.e., early) stage of information processing as opposed to the motor (i.e., late) stage of information processing along the "visual perception-overt behaviour" continuum. More specifically, for both dimensions of reward (**m** and **p**), differences in feature visual perception between **LR** and **HR** targets in the current experiments seem to be mostly reflected by sensitivity and accuracy, moderately reflected by inverse efficiency (perhaps because inverse efficiency is composed of both an early/accuracy and late/response time component) and least reflected by response time.

Given the Kiss et al. (2009) findings showing a later N2pc and, thus, potentially later attentional selection of **LR** than **HR** targets, the 150ms display duration in their study and in the current study may not have provided a sufficiently large window of time for the participant to attend to, and consequently visually perceive, the **LR** targets as well as they did the **HR** targets. For example, this would intuitively lead to the significantly poorer sensitivity obtained for **LR** than **HR** targets in the current study. In order to further investigate this possibility, display duration was manipulated across visual search trials in Experiment 3. The rationale behind this manipulation was that shortening the display duration would be more detrimental to behavioural measures of feature visual perception (i.e., early processing) for low-reward targets than for high-reward targets, further suggesting that low-reward targets are visually perceived later than are high-reward targets. More specifically, behavioural measures of accuracy, inverse efficiency and sensitivity (and, perhaps to a lesser extent, response time) were expected to reflect poorer performance for **LR** targets than for **HR** targets.

However, prior to further investigating this early stage of visual processing, it was deemed important to assess the cause of the non-significant subtle differences between the **m** and **p** dimensions in order to allow an informed comparison of results between dimensions in the subsequent experiments. The non-significant larger differences between **LRm** and **HRm** targets than between **LRp** and **HRp** targets (opposite but negligible for response time) may imply that the subjective difference in reward value between the former was larger than between the latter. Research has shown that decreasing the probability of a reward of a given magnitude also decreases its subjective value (e.g., Myerson & Green, 1995). The **HR** targets in the **m** ($10) and **p** (100% for $10) dimensions had an equivalent subjective value ($10) because their magnitude was identical and neither was probabilistic. In contrast, although the subjective value of the **LRm** target was known ($1) because it was not probabilistic, it was not possible to conclude that it was or wasn't equivalent to the probabilistic subjective value of the **LRp** target (10% chance for $10). In light of the non-significant trend for larger differences between **LRm** and **HRm** means than between **LRp** and **HRp** means, it was assumed that the subjective value of the **LRm** target was somewhat lower than that of the **LRp** target. Although not significant, the lower accuracy, inverse efficiency and sensitivity in the **m** dimension was also consistent with the combined subjective value of the **HR** and **LR** targets in the **m** dimension being less than that in the **p** dimension. In order to address this speculation empirically, a simple discounting procedure was conducted in Experiment 2.

Experiment 2

Empirically determining the subjective reward value of the LRp target

The purpose of Experiment 2 was to empirically determine the subjective reward value of the **LRp** target in Experiment 1. Although not significant, there were larger mean differences in most behavioural measures of performance between the **LR** and **HR** targets in the **m** dimension than in the **p** dimension. Therefore, the subjective difference in reward value between **LR** and **HR** targets in the **m** dimension may have been larger than the subjective difference in reward value between **LR** and **HR** targets in the **p** dimension. More specifically, it was expected that the **LRm** target ($1) had a lower subjective value than the **LRp** target ($10 with a 10% chance). Although not significant, the overall worse behavioural performance in the **m** dimension was also consistent with the combined subjective value of the **LR** and **HR** targets being less in the **m** dimension (LRm + HRm = $1 + $10 = $11) than in the **p** dimension (LRp + HRp = >$1 + $10 = >$11).

Methodology

Participant sample

The 12 female and 4 male (mean age = 23) participants from Experiment 1 were contacted approximately 3 months after having completed the visual experiment. They were treated in accordance with the guidelines set by the "Concordia University Human Research Ethics Committee".

Task and procedure

All participants gave informed consent prior to the onset of testing (see Appendix A) and were debriefed as to the rationale of the study following completion of testing. The total length of the lab visit for each participant was approximately 15 minutes.

Testing for each participant consisted of completing a simple paper-based probability-discounting questionnaire, adapted from the procedures of Myerson & Green (1995; see Appendix C). The questionnaire was divided into 2 parts, each composed of a series of 10 questions. On each question, the participants were asked to circle their choice between a low-magnitude certain reward and a high-magnitude probabilistic reward. The first question in PART 1 of the questionnaire contained a choice between "$1 for sure" and "$10 with a 10% chance" (note: the second option corresponds to the value of the **LRp** target in Experiment 1). Assuming that the participant chose the probabilistic reward (e.g., "$10 with a 10% chance"), he/she moved on to the second question, where the magnitude of the certain reward was raised to $2, and was asked to choose again. The procedure continued until the point at which the participant switched over to the certain reward (e.g., Question 5: selecting "$5 for sure" when asked to chose between "$5 for sure" or "$10 with a 10% chance").

The procedure was repeated in reverse order in PART 2 of the questionnaire, in an attempt to control for order effects. This time, the first question contained a choice between a certain reward equal in magnitude to the probabilistic one (e.g., “$10 for sure” or “$10 with a 10% chance”). Assuming the participant chose the certain reward, he/she moved on to the second question, where the magnitude of the certain reward was decreased to $9, and was asked to choose again. The procedure continued until the point at which the participant switched over to the probabilistic reward (e.g., Question 7: selecting “$10 with a 10% chance” when asked to chose between “$4 for sure” or “$10 with a 10% chance”).

Reward manipulation

The participant was told that one of the questions responded-to in PART 1 or PART 2 of the questionnaire would be randomly chosen at the end of the experiment, using a random number generator. And, that he/she would receive the associated certain reward or have a 10% chance of receiving the associated probabilistic reward, depending on the choice he/she had made on that question. The reason for employing this particular reward strategy, as compared to a strategy where reward outcomes were determined following each individual question, was three-fold. First, it kept the budget of the experiment within a reasonable limit. Second, it prevented the participant from purposefully choosing the certain reward throughout the questionnaire without it being a true reflection of preference, because doing so would earn him/her $110. Third, since there was no reward outcome for each individual choice, reward outcome did not influence the subsequent choice(s). This was important to control for because it was also controlled for in the visual experiment.

Results

For each participant, the magnitude of the certain reward was noted at the points when the switch in PART 1 (e.g., $5) and the switch in PART 2 (e.g., $4) of the questionnaire occurred. The average of these two points was computed (e.g., ($4+ $5)/2 = $4.50) in order to determine each participant's point of indifference (Myerson & Green, 1995). The point of indifference is considered to reflect the subjective value of the probabilistic reward (i.e., the subjective value of the **LRp** target in Experiment 1). SPSS software (v.19) was then used to conduct a 1-way ANOVA, comparing the subjective values of the **LRm**, **LRp**, and **HRm/HRp** targets (see Appendix B for complete proofs).

As seen in Figure 15, a significant main effect of Target was obtained, $F(2, 45) = 3171.712$, $p < 0.001$ (see Table B8). Bonferroni pairwise comparisons were also conducted (see Table B9). As expected, the subjective value of the **LRm** target (M = $1.00, SE = $0.00) was significantly lower than the subjective value of the **LRp** target (M = $5.09, SE = $0.14), $p < 0.001$. Also, the subjective value of both the **LRm** ($p < 0.001$) and **LRp** ($p < 0.001$) targets was significantly lower than the subjective value of the **HRm/HRp** targets (M = $10.00, SE = $0.00).

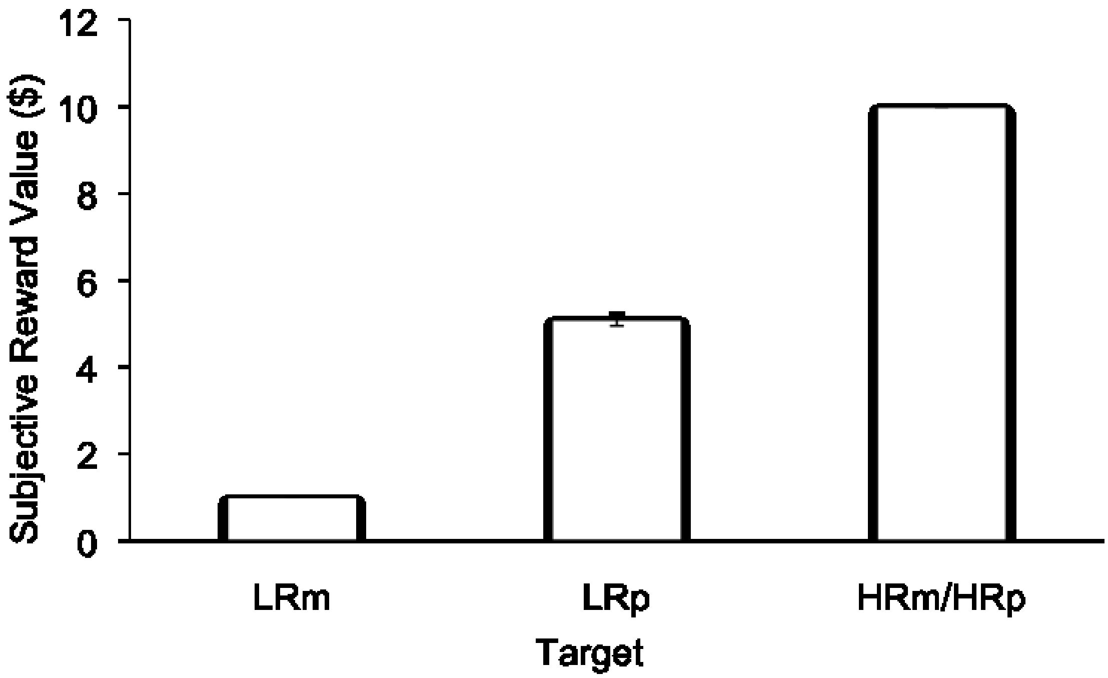

Figure 15. Mean subjective reward value for the **LRm** ($1.00), **LRp** ($5.09) and **HRm/HRp** ($10.00) targets in Experiment 1.

Discussion

Summary of findings

The results from this experiment empirically confirmed that, in Experiment 1, the subjective reward value of the **LRp** target ($5.09) was indeed higher than the subjective reward value of the **LRm** ($1.00) target. Therefore, the difference in subjective reward value between the **LRm** and **HRm** targets ($1.00 - $10.00 = -$9.00) was larger than the difference in subjective reward value between the **LRp** and **HRp** targets ($5.09 - $10.00 = -$4.91). This finding is in accord with the subtly larger, yet non-significant, differences in accuracy, inverse efficiency and sensitivity detected in Experiment 1 between the **LRm** and **HRm** targets than between the **LRp** and **HRp** targets. Importantly, however, the discounting procedure showed a significant difference in subjective reward value between the **LR** and **HR** targets in both the **m** and **p** dimensions. This occurred despite the fact that the subjective reward value of the **LRp** target was considerably closer to that of the **HRp** target than was the subjective reward value of the **LRm** target to that of the **HRm** target. This explains the fact that a similar pattern of findings was observed between both dimensions in Experiment 1. In addition, the lower combined subjective reward value of the **LR** and **HR** targets in the **m** dimension ($1.00 + $10.00 = $11.00) as compared to the **p** dimension ($5.09 + $10.00 = $15.09) is consistent with the subtle, yet non-significant, generally worse behavioural performance in the **m** dimension than in the **p** dimension reported in Experiment 1.

More specifically, the **p** dimension component of this finding is in accord with the significant paired samples *t*-test differences in accuracy and sensitivity measures found between **LRp** and **HRp** targets in Experiment 1 (i.e., lower accuracy and lower sensitivity for **LRp** targets than **HRp** targets). It is also in accord with the non-significant trend for inverse efficiency to be worse for **LRp** than **HRp** targets.

Similarly, the **m** dimension component of this finding is in accord with the significant paired samples *t*-test differences in the sensitivity measure found between **LRm** and **HRm** targets in Experiment 1 (i.e., lower sensitivity for **LRm** targets than **HRm** targets). It is also in accord with the non-significant trend for accuracy and inverse efficiency to be worse for **LRm** than **HRm** targets. The later is further in accord with the subtle, yet non-significant, larger differences in accuracy and inverse efficiency found between **LR** and **HR** targets in the **m** dimension having simply been masked by higher variability between participant responses, given the contradictory weaker statistical findings in the **m** dimension than in the **p** dimension. This higher variability between participant responses in the **m** dimension is assumed to be the result of the larger differences in subjective value. However, this conclusion remains speculative.

Conclusion

In summary, the subjective reward value of the **LRm** target in Experiment 1 was shown to be higher than that of the **LRp** target. And, thus, the difference in subjective reward value between the **LRm** and **HRm** targets was larger than that between the **LRp** and **HRp** targets. In turn, this may have led to the somewhat discrepant findings between the **m** and **p** dimensions. By the same token, this discrepancy suggested that some caution must be exercised when comparing results between the **m** and **p** dimensions in Experiment 3 as well. Nonetheless, because a significant difference in subjective reward value between the **LR** and **HR** targets was found in both the **m** and **p** dimensions, the target reward values used in Experiment 1 were maintained in Experiment 3.

An important cautionary note must nonetheless be made in terms of determining the subjective reward value of visual targets. To date, discounting procedures have been used to determine the subjective value of probabilistic monetary rewards using explicit choices only (e.g. Myerson & Green, 1995). For instance, “Do you prefer $1 for sure or $10 with a 10% chance?”. No attempt has been made to subsequently determine the subjective reward value of visual targets using these explicit discounting results. Determining how reliable the translation from explicit choice to visual perception is would require a much longer and more elaborate procedure than that encompassed by the current experimental protocol. This procedure would include several different magnitudes of the probabilistic reward to allow the plotting of a discounting curve that would afterward be compared to the hyperbolic discounting curve in an explicit choice experiment. Given this would exceed the scope of the current thesis, the goal of the current experiment was simply to provide an estimate of a visual target’s subjective reward value in order to aid in the interpretation of findings.

Experiment 3

Further behavioural assessment of monetary reward magnitude and monetary reward probability influences on feature visual perception

The purpose of Experiment 3 was to provide a further behavioural assessment than Experiment 1 of reward influences on the visual perception (i.e, early) stage of information processing along the "visual perception-overt behaviour" continuum. The Kiss et al. (2009) N2pc findings demonstrated that **LR** targets are selected for attention later than are **HR** targets. Coupled with the independently documented effects of attention on feature visual perception, these findings suggest that **LR** targets are visually perceived later than **HR** targets. In line with this reasoning, the 150ms display duration in the Kiss et al. (2009) study and in Experiment 1 of the current study may not have provided a sufficiently large window of time for the participant to visually perceive the **LR** targets as well as the **HR** targets. This possibly led to the significantly poorer sensitivity and tendency for poorer accuracy and inverse efficiency for **LR** than **HR** targets in the **m** dimension and to the significantly poorer accuracy and sensitivity and tendency for poorer inverse efficiency for **LR** than **HR** targets in the **p** dimension, obtained in Experiment 1.

The same paradigm used in Experiment 1 was used in the current experiment, except that display duration was manipulated in the current experiment. The rationale behind this manipulation was that shortening the display duration from 150ms (9 frames) to 33.33ms (2 frames) would be more detrimental to accuracy, inverse efficiency and sensitivity (and, perhaps to a lesser extent, to response time) for **LR** targets than for **HR** targets if, in fact, **LR** targets are visually perceived later than are **HR** targets.

If, in contrast, **LR** and **HR** targets differ only in terms of their associated motor processing speed (i.e., movement vigor), no differences should be observed between **LR** and **HR** targets on these 3 behavioural measures of performance. This alternative would, however, produce more pronounced differences in response time.

Importantly, since Experiment 1 showed somewhat discrepant findings between the **m** and **p** dimensions, and since Experiment 2 demonstrated that these discrepancies may be due to larger differences in subjective reward value between the **LR** and **HR** targets in the **m** dimension than in the **p** dimension, Experiment 3 was divided into 2 subcategories: Experiment 3A (Magnitude Dimension) and Experiment 3B (Probability Dimension). For both reward dimensions, the same pattern of findings was expected. However, assuming equal variances in the **m** and **p** dimensions, the possibility that the findings in the **m** dimension would be more pronounced than those in the **p** dimension was acknowledged, due to the larger difference in subjective reward value between the **LR** and **HR** targets in the **m** dimension than in the **p** dimension.

Experiment 3A: Reward Magnitude Dimension

In the magnitude component of Experiment 3, it was expected that target identification response times would be slower, error rates would be higher, inverse efficiency would be poorer and sensitivity would be lower for Low-Reward-Magnitude targets (**LRm**) than for High-Reward-Magnitude targets (**HRm**) and for 33.33ms display durations than for 150ms display durations. It was also expected that the effect of decreasing display duration would be more detrimental to target identification performance for the **LRm** target than for the **HRm** target, suggesting that the **LRm** target requires a longer processing time to be visually perceived than the **HRm** target. Based on the findings in Experiment 1, the accuracy, inverse efficiency and sensitivity measures were expected to show stronger statistical findings than the response time measure. Significant findings for accuracy, inverse efficiency and sensitivity in the presence or absence of significant findings in response time would suggest reward influences on the visual perception (i.e., early) stage of information processing along the "visual perception-overt behaviour" continuum. However, significant differences in response time in the absence of differences in accuracy, inverse efficiency and sensitivity would suggest a lack of reward influences on the visual perception (i.e., early) stage and evidence for differences in the motor (i.e., late) stage of information processing along the "visual perception-overt behaviour" continuum.

Methodology

Participant sample

Participants in this experiment consisted of 5 female and 3 male (mean age = 23) Concordia University undergraduate psychology students with self-reported normal vision, drawn from the Psychology Department's Participant Pool. They were treated in accordance with the guidelines set by the "Concordia University Human Research Ethics Committee".

Apparatus and laboratory space

The apparatus and laboratory space used in this experiment were the same as those used in Experiment 1.

Stimuli

The stimuli used in this experiment were the same as those used in Experiment 1.

Procedure

Testing for each participant consisted of 2 blocks of 360 trials, in which a covert visual search was performed to identify the position (top or bottom) of the notch on the red or green target diamond among the grey distractor diamonds. The total length of testing for each participant was approximately 90 minutes, with a short break between the two sessions. All participants gave informed consent prior to the onset of their first testing block (see Appendix A) and were debriefed as to the rationale of study following completion of their last testing block.

To initiate each trial, the participant pressed the space bar (see Figure 16). Once the space bar was pressed, the fixation dot was presented for 1.5s. When

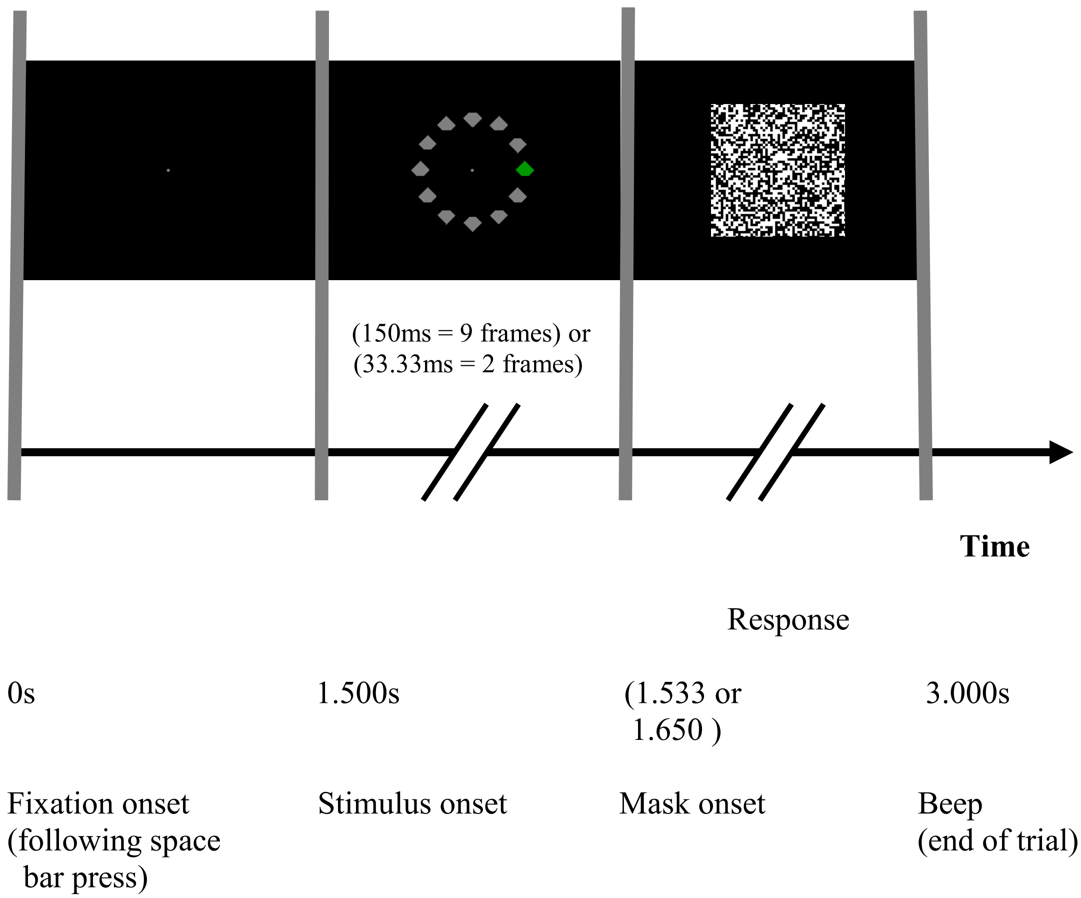

Figure 16. Sample stimulus and trial sequence used in Experiment 3 and 4.

the 1.5s had elapsed, the stimulus array also appeared on the screen and remained there for 150ms or 33.33ms, both of which were too brief for the participant to make saccades. Prior to the onset of testing, the participant was explicitly instructed to maintain fixation on the central fixation dot at all times. The participant was also informed that there was an equal likelihood of either the red or green target appearing in any position within the stimulus array on each trial. The stimulus array was masked by the static noise pattern following its 150ms or 33.33ms presentation.

The participant reported whether the target stimulus had a notch at the top or bottom, using the up and down keys on the computer keyboard, as quickly and as accurately as possible. The participant was aware that the response had to be made before a beep sounded 3s following fixation onset, which indicated trial termination.

Reward manipulation

The target reward magnitude manipulation used was the same as that used in the magnitude component of Experiment 1.

Results

The raw data generated by each participant were automatically exported from VPixx (v.2.32) to Excel (v.12.3.0). Excel was used to summarize each participant's raw data into "**LRm** target in **150ms** display"**, "LRm** target in **33.33ms** display"**,** "**HRm** target in **150ms** display"and "**HRm** target in **33.33ms** display" means for the response time, accuracy, inverse efficiency and sensitivity (d') behavioural measures. This resulted in a total of 16 means.

Repeated Measures ANOVAs

SPSS software (v.19) was used to conduct a separate 2 x 2 repeated measures analysis of variance on the response time, accuracy, inverse efficiency and sensitivity (d') behavioural measures (see Appendix B for complete proofs). For each of the 4 analyses, Target Reward Value had 2 levels (**LRm**, **HRm**) and Display Duration had 2 levels (**150ms**, **33.33ms**).

Significant interactions between Target Reward Magnitude and Display Duration were expected for all behavioural measures predominantly reflecting early processing, as suggested by the findings from Experiment 1 (i.e., for accuracy, inverse efficiency and sensitivity; not for response time). These interactions were expected to show larger mean differences between display durations for the **LRm** target than for the **HRm** target, suggesting that the **LRm** target requires a longer processing time to be visually perceived than the **HRm** target.

Response time. The 2 x 2 repeated measures ANOVA conducted on the response time data resulted in a non-significant main effect of Target Reward Magnitude, $F(1, 7) = 5.123$, $p = 0.06$, $\eta^2 = 0.42$, a significant main effect of Display Duration, $F(1, 7)$

= 14.619, p = 0.01, η^2 = 0.68, and a non-significant interaction between Target Reward Magnitude and Display Duration, $F(1, 7)$ = 0.001, p = 0.97, η^2 = 0.00 (see Table B10).

The non-significant main effect of Target Reward Magnitude showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean response time for the **LRm** target (M = 0.439s, SE = 0.010s) did not differ significantly from the mean response time for the **HRm** target (M = 0.422s, SE = 0.006s).

The significant main effect of Display Duration showed that, regardless of the target reward magnitude manipulation (**LRm** versus **HRm**), the mean response time for the **150ms** display duration (M = 0.407s, SE = 0.005s) was significantly faster than the mean response time for the **33.33ms** display duration (M = 0.455s, SE = 0.013s) (see Figure 17).

As expected, the non-significant interaction between Target Reward Magnitude and Display Duration showed that the mean difference in response time between the **150ms** display duration and **33.33ms** display duration for the **LRm** target (M = 0.225s, SE = 0.030s) was not larger than the mean difference in response time between the **150ms** and **33.33ms** display duration for the **HRm** target (M = 0.096s, SE = 0.030s).

Accuracy (% correct). The 2 x 2 repeated measures ANOVA conducted on the accuracy data resulted in a significant main effect of Target Reward Magnitude, $F(1, 7)$ = 11.092, p = 0.01, η^2 = 0.61, a significant main effect of Display Duration, $F(1, 7)$ = 64.582, p = 0.00, η^2 = 0.90, and a significant interaction between Target Reward Magnitude and Display Duration, $F(1, 7)$ = 8.052, p = 0.03, η^2 = 0.54 (see Table B11).

The significant main effect of Target Reward Magnitude showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean

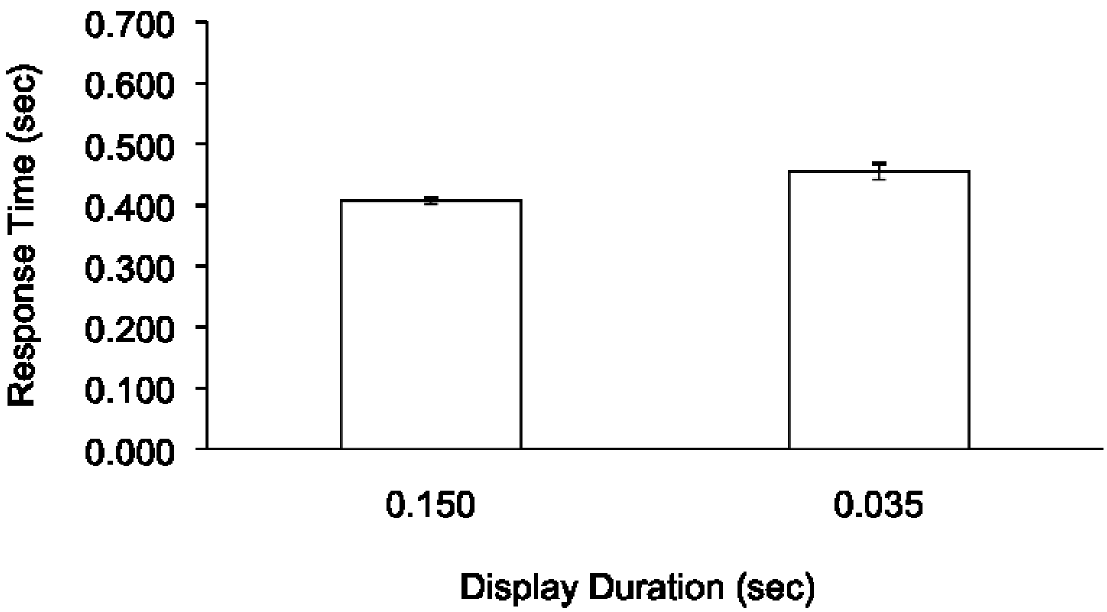

Figure 17. Mean response time (+*SE*) for the significant main effect of Display Duration in Experiment 3A, $p = 0.01$.

accuracy for the **LRm** target (*M* = 83.6%, *SE* = 0.9%) was significantly lower than the mean accuracy for the **HRm** target (*M* = 90.1%, *SE* = 1.5%).

The significant main effect of Display Duration showed that, regardless of the target reward magnitude manipulation (**LRm** versus **HRm**), the mean accuracy for the **150ms** display duration (*M* = 94.9%, *SE* = 0.8%) was significantly higher than the mean accuracy for the **33.33ms** display duration (*M* = 78.8%, *SE* = 1.6%).

As expected, the significant interaction between Target Reward Magnitude and Display Duration showed that the mean difference in accuracy between the **150ms** display duration and **33.33ms** display duration for the **LRm** target (*M* = 0.225%, *SE* = 0.030%) was larger than the mean difference in accuracy between the **150ms** and **33.33ms** display duration for the **HRm** target (*M* = 0.096%, *SE* = 0.030%) (see Figure 18 and Table B12).

Inverse efficiency. The 2 x 2 repeated measures ANOVA conducted on the inverse efficiency data resulted in a significant main effect of Target Reward Magnitude, $F(1, 7) = 13.970$, $p = 0.01$, $\eta^2 = 0.67$, a significant main effect of Display Duration, $F(1, 7) = 59.023$, $p = 0.00$, $\eta^2 = 0.89$, and a significant interaction between Target Reward Magnitude and Display Duration, $F(1, 7) = 5.417$, $p = 0.05$, $\eta^2 = 0.44$ (see Table B13).

The significant main effect of Target Reward Magnitude showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean inverse efficiency for the **LRm** target (*M* = 0.541s, *SE* = 0.016s) was significantly worse than the mean inverse efficiency for the **HRm** target (*M* = 0.474s, *SE* = 0.007s).

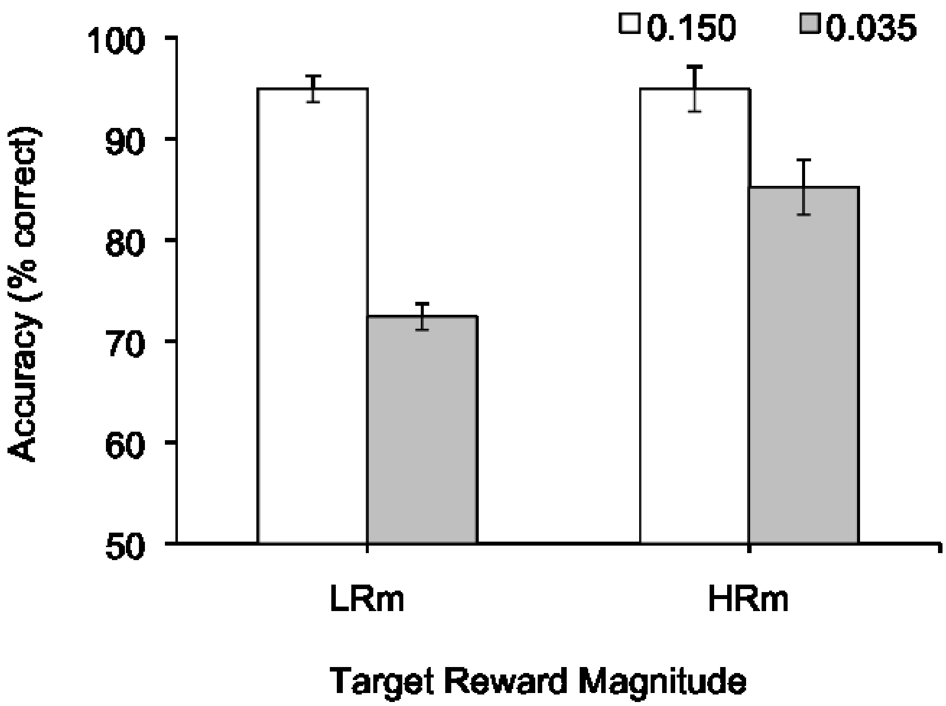

Figure 18. Mean accuracy (+*SE*) for the significant Target Reward Magnitude x Display Duration interaction in Experiment 3A, $p = 0.03$.

The significant main effect of Display Duration showed that, regardless of the target reward magnitude manipulation (**LRm** versus **HRm**), the mean inverse efficiency for the **150ms** display duration (*M* = 0.429s, *SE* = 0.007s) was significantly better than the mean inverse efficiency for the **33.33ms** display duration (*M* = 0.585s, *SE* = 0.017s).

As expected, the significant interaction between Target Reward Magnitude and Display Duration showed that the mean difference in inverse efficiency between the **150ms** and **33.33ms** display durations for the **LRm** target (*M* = -0.205s, *SE* = 0.034s) was larger than the mean difference in inverse efficiency between the **150ms** and **33.33ms** display durations for the **HRm** target (*M* = -0.107s, *SE* = 0.024s) (see Figure 19 and Table B14).

Sensitivity (d'). The 2 x 2 repeated measures ANOVA conducted on the sensitivity data resulted in a significant main effect of Target Reward Magnitude, $F(1, 7) = 5.424$, $p = 0.05$, $\eta^2 = 0.44$, a significant main effect of Display Duration, $F(1, 7) = 8.836$, $p = 0.02$, $\eta^2 = 0.56$, and a significant interaction between Target Reward Magnitude and Display Duration, $F(1, 7) = 8.732$, $p = 0.02$, $\eta^2 = 0.56$ (see Table B15).

The significant main effect of Target Reward Magnitude showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean sensitivity for the **LRm** target (*M* = 1.733, *SE* = 0.054) was significantly lower than the mean sensitivity for the **HRm** target (*M* = 2.298, *SE* = 0.217).

The significant main effect of Display Duration showed that, regardless of the target reward magnitude manipulation (**LRm** versus **HRm**), the mean sensitivity for

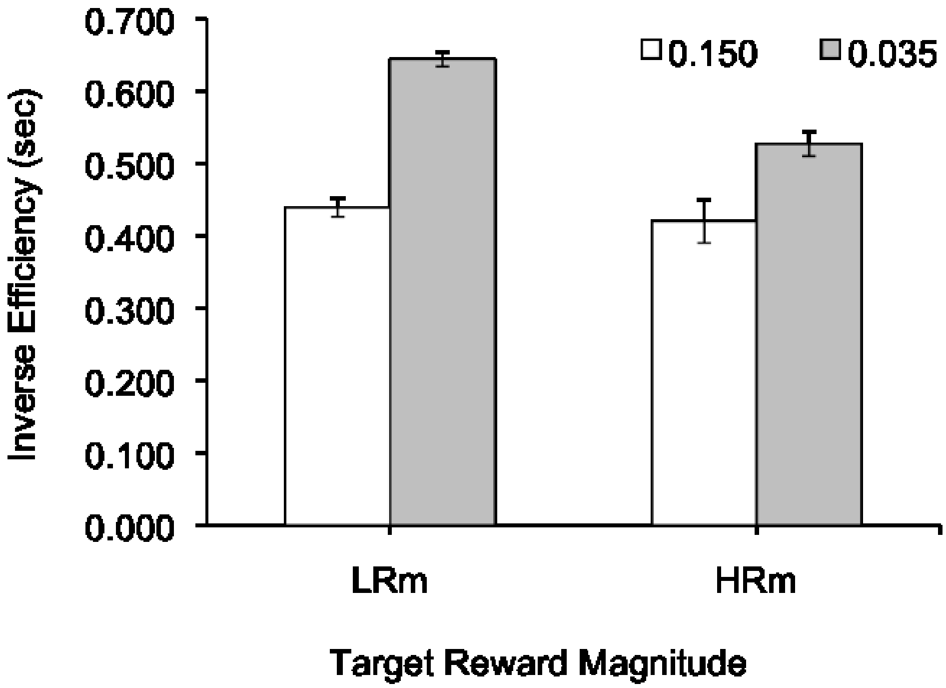

Figure 19. Mean inverse efficiency (+*SE*) for the significant Target Reward Magnitude x Display Duration interaction in Experiment 3A, $p = 0.05$.

the **150ms** display duration (*M* = 2.451, *SE* = 0.117) was significantly higher than the mean sensitivity for the **33.33ms** display duration (*M* = 1.579, *SE* = 0.223).

As expected, the significant interaction between Target Reward Magnitude and Display Duration showed that the mean difference in sensitivity between the **150ms** and **33.33ms** display duration for the **LRm** target (*M* = 0.992, *SE* = 0.291) was larger than the mean difference in sensitivity between the **150ms** and **33.33ms** display duration for the **HRm** target (*M* = 0.750, *SE* = 0.301) (see Figure 20 and Table B16).

ANOVA summary. As reported in the repeated measures ANOVAs section above, significant interactions between Target Reward Magnitude and Display Duration were obtained for all behavioural measures predominantly reflecting early processing, as suggested by the findings from Experiment 1 (i.e., for accuracy, inverse efficiency and sensitivity; not for response time). As expected, these interactions showed larger mean differences between display durations for the **LRm** target than for the **HRm** target, suggesting that the **LRm** target requires a longer processing time to be visually perceived than the **HRm** target.

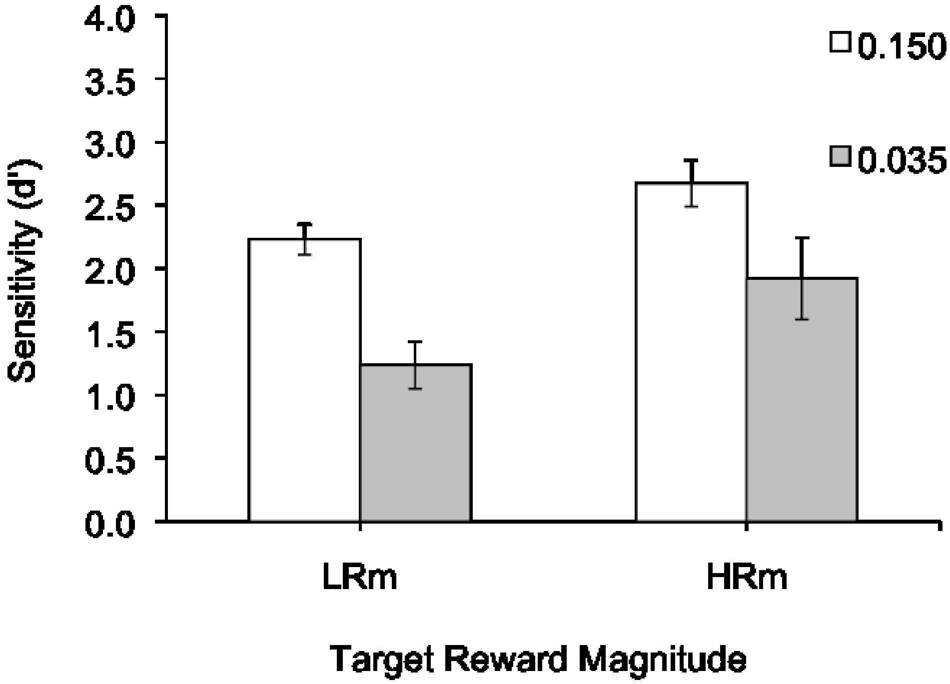

Figure 20. Mean sensitivity (+*SE*) for the significant Target Reward Magnitude x Display Duration interaction in Experiment 3A, $p = 0.02$.

Experiment 3B: Reward Probability Dimension

In the probability component of Experiment 3, as in the magnitude component of Experiment 3, it was expected that target identification response times would be slower, error rates would be higher, inverse efficiency would be poorer and sensitivity would be lower for Low-Reward-Probability targets (**LRp**) than for High-Reward-Probability targets (**HRp**) and for 33.33ms display durations than for 150ms display durations. It was also expected that the effect of decreasing display duration would be more detrimental to target identification performance for the **LRp** target than for the **HRp** target, suggesting that the **LRp** target requires a longer processing time to be visually perceived than the **HRp** target. Based on the findings in Experiment 1 and 3A, the accuracy, inverse efficiency and sensitivity measures were expected to show stronger statistical findings than the response time measure. Significant findings for accuracy, inverse efficiency and sensitivity in the presence or absence of significant findings in response time would suggest reward influences on the visual perception (i.e., early) stage of information processing along the “visual perception-overt behaviour” continuum. However, significant differences in response time in the absence of differences in accuracy, inverse efficiency and sensitivity would suggest a lack of reward influences on the visual perception (i.e., early) stage and evidence for differences in the motor (i.e., late) stage of information processing along the “visual perception-overt behaviour” continuum. Given the smaller subjective difference between the **LR** and **HR** targets in the **p** dimension than in the **m** dimension, as reported in Experiment 2, the strength of statistical findings was expected to be weaker in Experiment 3B (**p** dimension) than in Experiment 3A (**m** dimension).

Methodology

Participant sample

Participants in this experiment consisted of 6 female and 2 male (mean age = 26) Concordia University undergraduate psychology students with self-reported normal vision, drawn from the Psychology Department's Participant Pool. They were treated in accordance with the guidelines set by the "Concordia University Human Research Ethics Committee".

Apparatus and laboratory space

The apparatus and laboratory space used in this experiment were the same as those used in Experiment 1 and 3A.

Stimuli

The stimuli used in this experiment were the same as those used in Experiment 1 and 3A.

Procedure

The procedure used in this experiment was the same as that used in Experiment 3A.

Reward manipulation

The target reward probability manipulation used was the same as that used in the probability component of Experiment 1.

Results

The raw data generated by each participant were automatically exported from VPixx (v.2.32) to Excel (v.12.3.0). Excel was used to summarize each participant's raw data into "**LRp** target in **150ms** display"**, "LRp** target in **33.33ms** display"**,** "**HRp** target in **150ms** display"and "**HRp** target in **33.33ms** display" means for the response time, accuracy, inverse efficiency and sensitivity (d') behavioural measures. This resulted in a total of 16 means.

Repeated Measures ANOVAs

SPSS software (v.19) was used to conduct a separate 2 x 2 repeated measures analysis of variance on the response time, accuracy, inverse efficiency and sensitivity (d') behavioural measures (see Appendix B for complete proofs). For each of the 4 analyses, Target Reward Value had 2 levels (**LRp**, **HRp**) and Display Duration had 2 levels (**150ms**, **33.33ms**).

As in Experiment 3A, significant interactions between Target Reward Magnitude and Display Duration were expected for all behavioural measures predominantly reflecting early processing, as suggested by the findings from Experiment 1 (i.e., for accuracy, inverse efficiency and sensitivity; not for response time). These interactions were expected to show larger mean differences between display durations for the **LRp** target than for the **HRp** target, suggesting that the **LRp** target requires a longer processing time to be visually perceived than the **HRp** target. However, given the smaller subjective difference between the **LR** and **HR** targets in the **p** dimension than in the **m** dimension, as reported in Experiment 2, the strength of statistical findings was expected to be weaker here (**p** dimension) than in Experiment 3A (**m** dimension).

Response time. The 2 x 2 repeated measures ANOVA conducted on the response time data resulted in a non-significant main effect of Target Reward Probability, $F(1, 7) = 2.620$, $p = 0.15$, $\eta^2 = 0.27$, a significant main effect of Display Duration, $F(1, 7) = 10.377$, $p = 0.02$, $\eta^2 = 0.60$, and a non-significant interaction between Target Reward Probability and Display Duration, $F(1, 7) = 0.065$, $p = 0.81$, $\eta^2 = 0.01$ (see Table B17).

The non-significant main effect of Target Reward Probability showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean response time for the **LRp** target ($M = 0.441$s, $SE = 0.009$s) did not differ significantly from the mean response time for the **HRp** target ($M = 0.428$s, $SE = 0.007$s).

The significant main effect of Display Duration showed that, regardless of the target reward probability manipulation (**LRp** versus **HRp**), the mean response time for the **150ms** display duration ($M = 0.413$s, $SE = 0.005$s) was significantly faster than the mean response time for the **33.33ms** display duration ($M = 0.456$s, $SE = 0.013$s) (see Figure 21).

As expected, the non-significant interaction between Target Reward Probability and Display Duration showed that the mean difference in response time between the **150ms** display duration and **33.33ms** display duration for the **LRp** target ($M = -0.046$s, $SE = 0.021$s) was not larger (or smaller) than the mean difference in response time between the **150ms** and **33.33ms** display duration for the **HRp** target ($M = -0.040$s, $SE = 0.013$s).

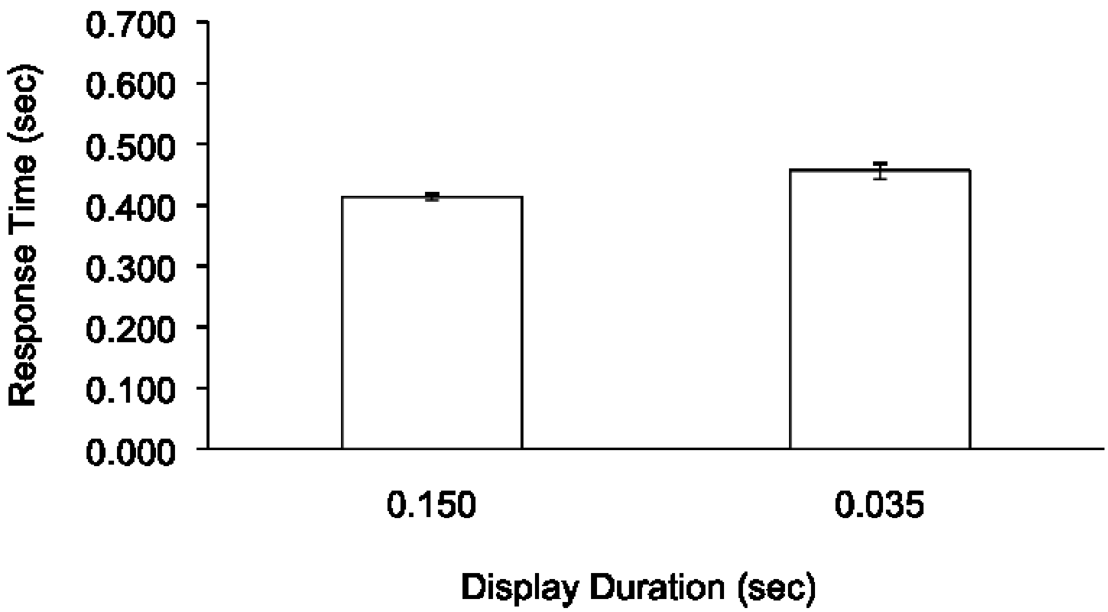

Figure 21. Mean response time (+*SE*) for the significant main effect of Display Duration in Experiment 3B, $p = 0.02$.

Accuracy (% correct). The 2 x 2 repeated measures ANOVA conducted on the accuracy data resulted in a non-significant main effect of Target Reward Probability, $F(1, 7) = 4.125$, $p = 0.08$, $\eta^2 = 0.37$, a significant main effect of Display Duration, $F(1, 7) = 82.867$, $p = 0.00$, $\eta^2 = 0.92$, and a non-significant interaction between Target Reward Probability and Display Duration, $F(1, 7) = 3.736$, $p = 0.10$, $\eta^2 = 0.35$ (see Table B18).

The non-significant main effect of Target Reward Probability showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean accuracy for the **LRp** target (M = 84.7%, SE = 1.2%) did not differ significantly from the mean accuracy for the **HRp** target (M = 89.1%, SE = 1.3%), although it was marginally worse for the **LRp** target.

The significant main effect of Display Duration showed that, regardless of the target reward probability manipulation (**LRp** versus **HRp**), the mean accuracy for the **150ms** display duration (M = 94.9%, SE = 0.8%) was significantly better than the mean accuracy for the **33.33ms** display duration (M = 78.9%, SE = 1.3%) (see Figure 22).

Contrary to expectations, the non-significant interaction between Target Reward Probability and Display Duration showed that the mean difference in accuracy between the **150ms** display duration and **33.33ms** display duration for the **LRp** target (M = 0.204%, SE = 0.030%) was not larger (or smaller) than the mean difference in accuracy between the **150ms** and **33.33ms** display duration for the **HRp** target (M = 0.116%, SE = 0.027%).

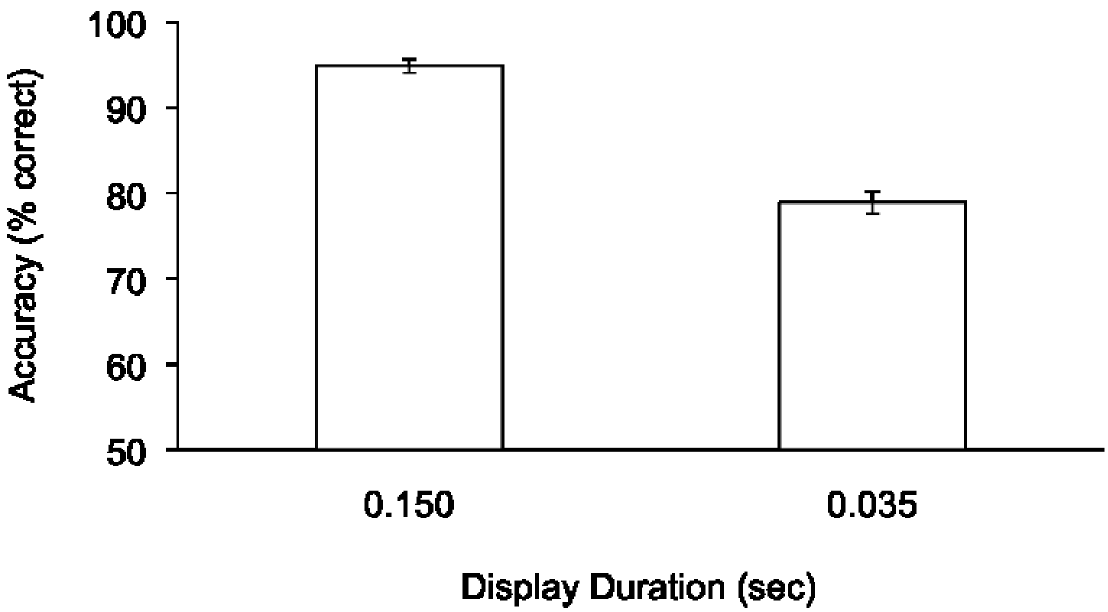

Figure 22. Mean accuracy (+*SE*) for the significant main effect of Display Duration in Experiment 3B, $p = 0.00$.

Inverse efficiency. The 2 x 2 repeated measures ANOVA conducted on the inverse efficiency data resulted in a significant main effect of Target Reward Probability, $F(1, 7) = 9.926$, $p = 0.02$, $\eta^2 = 0.59$, a significant main effect of Display Duration, $F(1, 7) = 40.459$, $p = 0.00$, $\eta^2 = 0.85$, and a non-significant interaction between Target Reward Probability and Display Duration, $F(1, 7) = 3.105$, $p = 0.12$, $\eta^2 = 0.31$ (see Table B19).

The significant main effect of Target Reward Probability showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean inverse efficiency for the **LRp** target (*M* = 0.534s, *SE* = 0.015s) was significantly worse than the mean inverse efficiency for the **HRp** target (*M* = 0.485s, *SE* = 0.008s) (see Figure 23).

The significant main effect of Display Duration showed that, regardless of the target reward probability manipulation (**LRp** versus **HRp**), the mean inverse efficiency for the **150ms** display duration (*M* = 0.436s, *SE* = 0.006s) was significantly better than the mean inverse efficiency for the **33.33ms** display duration (*M* = 0.584s, *SE* = 0.020s) (see Figure 24).

Contrary to expectations, the non-significant interaction between Target Reward Probability and Display Duration showed that the mean difference in inverse efficiency between the **150ms** and **33.33ms** display durations for the **LRp** target (*M* = -0.186s, *SE* = 0.039s) was not larger (or smaller) than the mean difference in inverse efficiency between the **150ms** and **33.33ms** display durations for the **HRp** target (*M* = -0.110s, *SE* = 0.022s).

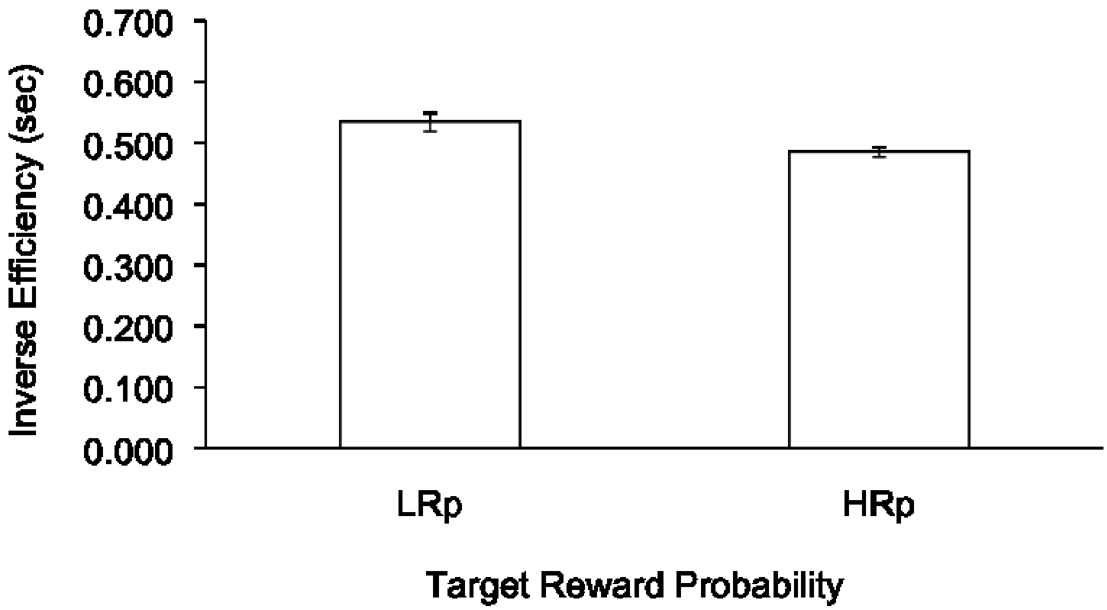

Figure 23. Mean inverse efficiency (+*SE*) for the significant main effect of Target Reward Probability in Experiment 3B, $p = 0.02$.

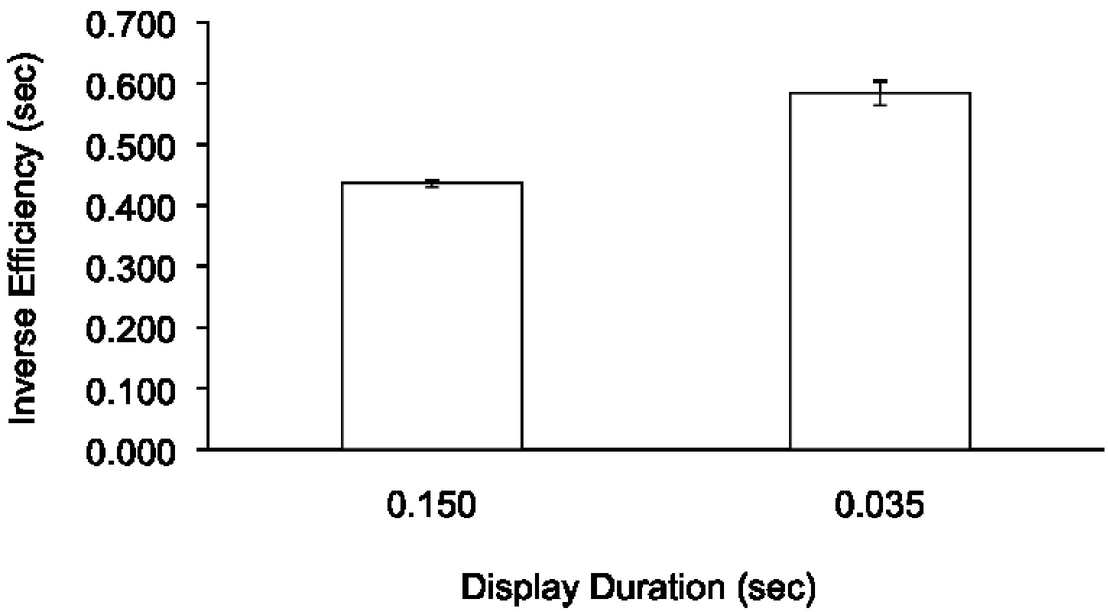

Figure 24. Mean inverse efficiency (+*SE*) for the significant main effect of Display Duration in Experiment 3B, $p = 0.00$.

Sensitivity (d'). The 2 x 2 repeated measures ANOVA conducted on the sensitivity data resulted in a non-significant main effect of Target Reward Probability, $F(1, 7) = 2.316$, $p = 0.17$, $\eta^2 = 0.25$, a significant main effect of Display Duration, $F(1, 7) = 6.725.$, $p = 0.04$, $\eta^2 = 0.49$, and a non-significant interaction between Target Reward Probability and Display Duration, $F(1, 7) = 0.023$, $p = 0.88$, $\eta^2 = 0.00$ (see Table B20).

The non-significant main effect of Target Reward Probability showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean sensitivity for the **LRp** target ($M = 1.956$, $SE = 0.096$) did not differ significantly from the mean sensitivity for the **HRp** target ($M = 2.313$, $SE = 0.211$), although it was marginally lower for the **LRp** target.

The significant main effect of Display Duration showed that, regardless of the target reward probability manipulation (**LRp** versus **HRp**), the mean sensitivity for the **150ms** display duration ($M = 2.501$, $SE = 0.117$) was significantly better than the mean sensitivity for the **33.33ms** display duration ($M = 1.768$, $SE = 0.229$) (see Figure 25).

Contrary to expectations, the non-significant interaction between Target Reward Probability and Display Duration showed that the mean difference in sensitivity between the **150ms** and **33.33ms** display duration for the **LRp** target ($M = 0.745$, $SE = 0.296$) was not larger (or smaller) than the mean difference in sensitivity between the **150ms** and **33.33ms** display duration for the **HRp** target ($M = 0.720$, $SE = 0.293$).

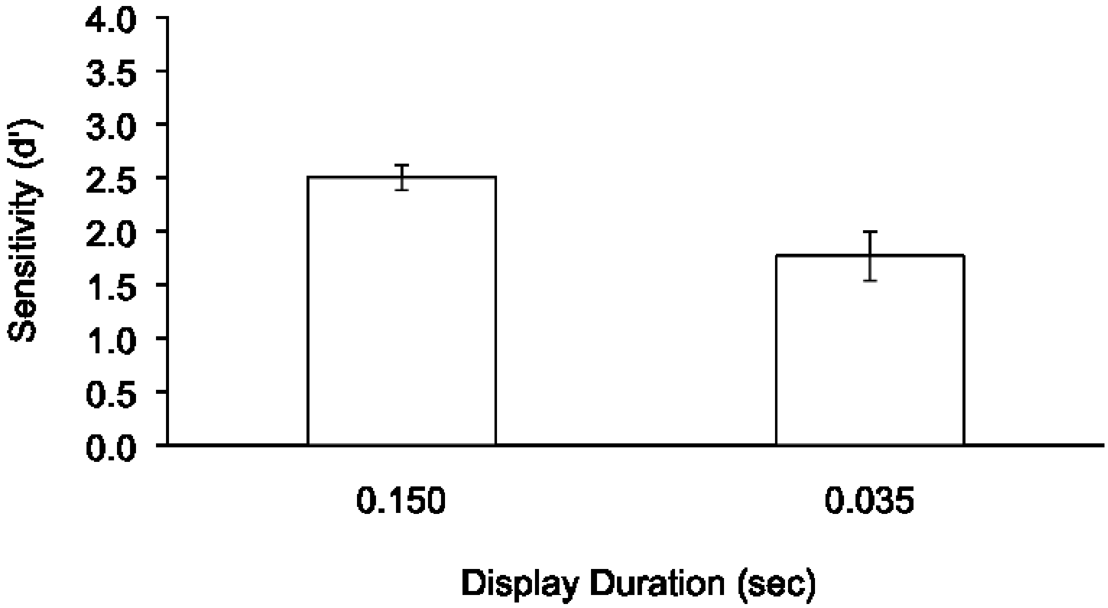

Figure 25. Mean sensitivity (+*SE*) for the significant main effect of Display Duration in Experiment 3B, $p = 0.04$.

ANOVA summary. As reported in the repeated measures ANOVAs section above, contrary to Experiment 3A (m dimension) significant interactions between Target Reward Magnitude and Display Duration were not obtained in this experiment (p dimension) for any of the behavioural measures predominantly reflecting early processing, as suggested by the findings from Experiment 1 (i.e., for accuracy, inverse efficiency and sensitivity; not for response time). However the non-significant findings were in the expected direction: non-significant larger mean differences between display durations for the **LRp** target than for the **HRp** target. Given the smaller subjective difference between the **LR** and **HR** targets in the **p** dimension than in the **m** dimension, as reported in Experiment 2, the strength of statistical findings was expected to be weaker here (**p** dimension) than in Experiment 3A (**m** dimension). Therefore, the non-significant findings may still suggest that the **LRp** target requires a longer processing time to be visually perceived than the **HRp** target.

Independent samples t-tests (Experiments 3A and 3B)

As evidenced by the repeated measures ANOVAs conducted in Experiments 3A (**m** dimension) and 3B (**p** dimension), there were some inconsistencies between the **m** and **p** dimensions of reward. More specifically, as expected, although a similar pattern of findings emerged in both dimensions, stronger statistical findings were found in the **m** dimension than in the **p** dimension. These observed inconsistencies were speculated to be due to a larger subjective difference between the **LR** and **HR** target in the **m** dimension than in the **p** dimension, as suggested by Experiment 2. Statistical comparisons were conducted to confirm the observation that the mean difference for all behavioural measures of performance was larger between the **LRm** and **HRm** targets than between the **LRp** and **HRp** targets.

SPSS software (v.19) was used to conduct a series of independent samples *t*-tests, comparing the **m** dimension mean difference between **LR** and **HR** targets to the **p** dimension mean difference between **LR** and **HR** targets. A separate *t*-test was conducted for each behavioural measure of performance (see Appendix B for complete proofs).

Response time. The mean difference in response time between **LR** and **HR** targets in the **m** dimension (M = 0.017s, SE = 0.007s) did not differ significantly from the mean difference in response time between **LR** and **HR** targets in the **p** dimension (M = 0.012, SE = 0.008), $t(14)$ = 0.579, p = 0.58, g = .20 (see Table B21).

Accuracy (% correct). As seen in Figure 26, the mean difference in accuracy between **LR** and **HR** targets in the **m** dimension (M = -6.4%, SE = 1.9%) was significantly larger than the mean difference in accuracy between **LR** and **HR** targets in the **p** dimension (M = -4.4%, SE = 2.2%), $t(14)$ = -3.433, p = 0.01, g = .34 (see Table B21).

Inverse efficiency. As seen in Figure 27, the mean difference in inverse efficiency between **LR** and **HR** targets in the **m** dimension (M = 0.068s, SE = 0.018s) was significantly larger than the mean difference in inverse efficiency between **LR** and **HR** targets in the **p** dimension (M = 0.049s, SE = 0.015s), $t(14)$ = 2.673, p = 0.03, g = .37 (see Table B21).

Sensitivity (d'). As seen in Figure 28, the mean difference in sensitivity between **LR** and **HR** targets in the **m** dimension (M = -0.565, SE = 0.243) was marginally significantly larger than the mean difference in sensitivity between **LR** and

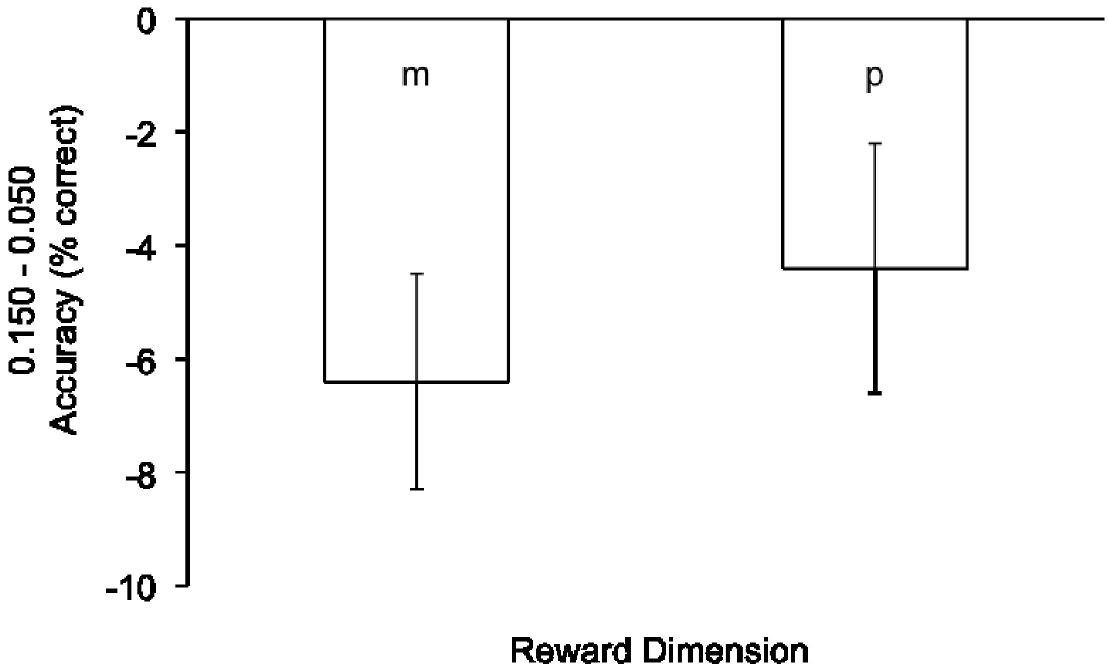

Figure 26. Mean difference (+*SE*) in accuracy between the **HR** and **LR** target in the **m** and **p** dimension, in Experiment 3, $p = 0.01$.

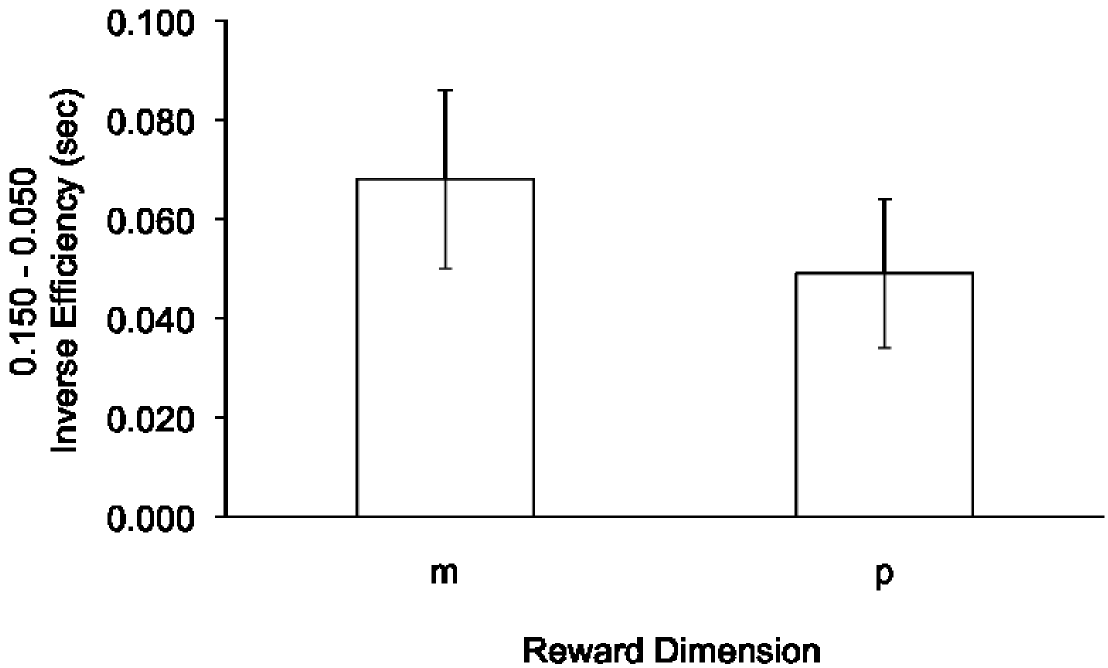

Figure 27. Mean difference (+*SE*) in inverse efficiency between the **HR** and **LR** target in the **m** and **p** dimension, in Experiment 3, $p = 0.03$.

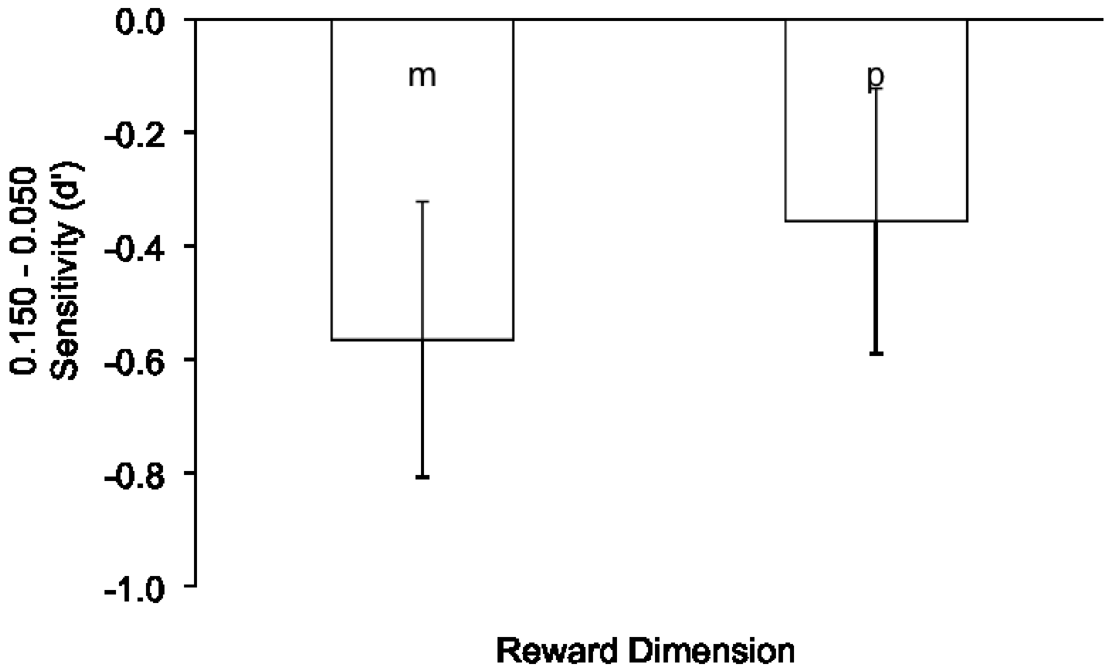

Figure 28. Mean difference (+*SE*) in sensitivity between the **HR** and **LR** target in the **m** and **p** dimension, in Experiment 3, $p = 0.05$.

HR targets in the **p** dimension (*M* = -0.356, *SE* = 0.234), $t(14) = -2.294$, $p = 0.05$, $g = .29$ (see Table B21).

Discussion (Experiments 3A and 3B)

Summary of findings

Repeated Measures ANOVAs. The repeated measures ANOVAs conducted on the **m** dimension of reward (Experiment 3A) and **p** dimension of reward (Experiment 3B) led to a somewhat comparable pattern of findings, as expected. This similarity between dimensions suggested that reward influences the **m** and **p** dimensions similarly. However, findings were notably stronger in the **m** dimension than in the **p** dimension, also as expected. This discrepancy was anticipated due to the possibly larger subjective difference in reward value between the **LR** and **HR** targets in the **m** than in the **p** dimension, as suggested by Experiment 2.

Furthermore, as expected, findings for the response time measure were weaker than those for the accuracy, inverse efficiency and sensitivity measures (similar findings in Experiment 1). This discrepancy between response time findings and findings from the other behavioural measures was anticipated because of the reward manipulation adjustments implemented in the current series of experiments. More specifically, the reward manipulation in the current series of experiments relative to the reward manipulation in the Kiss et al. (2009) study, was designed to reduce the conscious use of go-slow (for the **LR**) or go-fast (for the **HR** target) motor strategies. This was accomplished by making correct responses to both target types associated with some amount of reward and giving participants an equivalent and lenient amount of time (3s) in which to respond following display presentation for both **LR** and **HR** trials.

The specific findings as well as their potential reflection of reward influences on the visual perception (i.e., early) stage of information processing or motor (i.e., late) stage of information processing along the "visual perception-overt behaviour" continuum are outlined below.

A statistically significant main effect of Target Reward Value (**LR** versus **HR**) was not obtained in either dimension (**m** or **p**) for the response time measure. Nonetheless, the expected direction of findings was obtained: response time was non-significantly longer for the **LR** than **HR** target in both dimensions. As evidenced by the lower *p*-values and higher effect sizes, the non-significant direction of findings was stronger in the **m** than in the **p** dimension, also as expected.

The non-significantly longer response time for the **LR** than **HR** target is in line with the existing body of research suggesting an effect of reward value on the "vigor" of movement/motor processing (e.g., Opris et al., 2011). As mentioned above, the lack of statistically significant findings for response time in the current thesis is therefore likely due to the control implemented on go-fast/go-slow strategies. Furthermore, the non-significantly longer response time for the **LR** than **HR** target is in line with the theory put forth by Shadmehr and colleagues, which holds that reward value is progressively discounted as the time taken to make the response increases, thus accounting for the effect of reward on movement vigor (Shadmehr et al. 2010; Shadmehr, 2010). According to this theory, a faster response would inevitably be required for the **HR** than **LR** target in order to maintain the **HR** target's larger subjective value relative to the smaller subjective value of the **LR** target. Once again, however, the lack of statistically significant findings for response time in the current thesis is believed to be due to the control implemented on go-fast/go-slow strategies.

Nonetheless, the non-significantly longer response time for the **LR** than **HR** target is equally in line with more recent research suggesting an effect of reward on feature visual perception (e.g., Kiss et al. 2009). In other words, since motor processing and responding logically follow visual perception of the given visual target, the trend for a more delayed motor response for the **LR** than **HR** target may, in part, be due to the longer amount of time needed to visually perceive the **LR** than **HR** target.

However, given that the differences in response time between the **LR** and **HR** target were not significant and given that they may reflect either motor processing, visual perception or both, an examination of the response time data alone did not allow for reliable disambiguation between the effects of reward on the early and late stages of information processing along the "visual perception-overt behaviour" continuum. Therefore, accuracy, inverse efficiency and sensitivity measures were also examined.

As expected, a statistically significant main effect of Target Reward Value (**LR** versus **HR**) was obtained in the **m** dimension for the accuracy, inverse efficiency and sensitivity measures, indicating lower accuracy, worse inverse efficiency and lower sensitivity for the **LRm** than **HRm** target. A statistically significant main effect of Target Reward Value (**LR** versus **HR**) was also obtained in the **p** dimension for the inverse efficiency measure, indicating worse inverse efficiency for the **LRp** than **HRp** target. Although this main effect did not reach statistical significance in the **p** dimension for the accuracy and sensitivity measures, the expected direction of findings was obtained: non-significantly lower accuracy and sensitivity for the **LRp** than **HRp** target. As evidenced by the lower *p*-values and higher effect sizes, the statistically significant findings and trends were stronger in the **m** than in the **p** dimension, as expected.

The significantly worse inverse efficiency for the **LR** than **HR** target, found in both dimensions of reward (**m** and **p**), is also in line with the existing body of research suggesting an effect of reward on movement "vigor"/motor processing (i.e., late processing). This is the case because inverse efficiency is composed of a response time component (inverse efficieny = response time/accuracy) and response time is speculated to partly be a reflection of movement vigor/motor processing, as discussed previously. Furthermore, Experiment 1 showed that inverse efficiency was positively correlated with response time in both reward dimensions, suggesting that they both reflect the same (or part of the same) underlying process. Therefore, regardless of accuracy, the non-significantly slower response time (i.e., less movement vigor) for the **LR** than **HR** target could, at least in part, lead to the significantly higher (worse) inverse efficiency score observed for the **LR** than **HR** target. However, since the response time results did not reach statistical significance in either dimension of reward (**m** or **p**), perhaps due to the implemented control on go-fast/go-slow response strategies, it is unlikely to be the main or only cause of the significant differences in inverse efficiency between **LR** and **HR** targets in either dimension. Therefore, the differences in inverse efficiency scores between the **LR** and **HR** targets are unlikely to primarily reflect the effect of reward on motor (i.e., late) processing.

In contrast, the significantly lower accuracy found in the **m** dimension for the **LR** than **HR** target may provide a better explanation or complement the response time explanation for the significantly higher (worse) inverse efficiency score for the **LRm** than **HRm** target. Decreases in accuracy have the same effect on inverse efficiency as increases in response time do, because inverse efficiency is not only composed of a response time component, but also of an accuracy component (inverse efficiency = response time/accuracy). In other words, regardless of the non-significantly longer response time for the **LRm** than **HRm** target, the significantly lower accuracy for the **LRm** than **HRm** target caould, at least in part, lead to the significantly higher (worse) inverse efficiency score in that dimension. And, since the accuracy findings reached significance in the **m** dimension of reward whereas the response time findings did not, accuracy as opposed to response time is likely to be the main or most important cause of the significant differences in inverse efficiency observed in that dimension. Similarly, although the lower accuracy found in the **p** dimension for the **LR** than **HR** target did not reach statistical significance, Experiment 2 suggests that the lack of statistical significance was likely simply due to the smaller subjective difference between the **LR** and **HR** targets in that dimension. Furthermore, the strength or the non-significant accuracy finding was larger than the strength of the non-significant response time finding in the **p** dimension as well.

Therefore, the significantly worse inverse efficiency for the **LR** than **HR** target in both reward dimensions (**m** and **p**) is also in line with recent research suggesting an effect of reward on feature visual perception (i.e., early processing). This is speculated to be the case because the differences in accuracy between the **LR** and **HR** targets were stronger than the differences in response time, as mentioned above, and because the differences in accuracy may reflect differences in visual perception more so than differences in motor processing, as previously discussed (Experiment 1: positive accuracy-sensitivity correlation). Furthermore, if differences in accuracy between the **LR** and **HR** targets reflected differences in motor processing alone and reflected no differences in visual perception, a speed-accuracy tradeoff would be expected. In other words, the non-significantly slower response time (i.e., less movement vigor) associated with the **LR** target would likely lead to fewer errors for **LR** targets than **HR** targets if **LR** targets were not visually perceived later than **HR** targets. By the same token, the non-significantly faster response time (i.e., more movement vigor) associated with the **HR** target would likely lead to more errors for **HR** targets than **LR** targets if **HR** targets were not visually perceived earlier than **LR** targets. This speed-accuracy tradeoff would be evidenced by both a non-significant main effect of inverse efficiency and a significant main effect of accuracy in the opposite direction to that observed. However, the lack of such outcomes demonstrates a lack of evidence for a speed-accuracy trade-off and, hence, a lack of compelling evidence that differences in accuracy reflect differences in motor processing. Instead, the findings lend support for the postulated assumption that the lower accuracy observed for the **LR** than **HR** target reflects the later visual perception of the **LR** than **HR** target. Thus, following the same line of reasoning, the worse inverse efficiency observed for the **LR** than **HR** target primarily reflects the same underlying process.

Given that a significant correlation between accuracy and inverse efficiency was not found in Experiment 1 for either dimension of reward, the assumption that accuracy and inverse efficiency primarily reflect the same underlying process, namely visual perception, seems somewhat counterintuitive at first glance. However, it is important to note that the non-significant relationship in both reward dimensions was nonetheless negative (i.e., as accuracy increased, inverse efficiency tended to decrease/improve), suggesting that they may nonetheless partly reflect the same underlying process. As mentioned previously, inverse efficiency is determined via a combination of response time and accuracy measures. And, even though differences in accuracy may reflect differences in visual perception between **LR** and **HR** targets, differences in response time may partly reflect both differences in motor processing and visual perception, as discussed previously. Consequently, the correlation between accuracy and inverse efficiency likely did not reach statistical significance due to the influence of the observed non-significant response time findings on the inverse efficiency score. The significant correlation between response time and inverse efficiency mentioned earlier, suggesting that response time reflects the same (or part of the same) underlying process as inverse efficiency, is also in support of this conclusion.

Finally, the significantly lower sensitivity found in the **m** dimension for the **LR** than **HR** target primarily lends support to the theory that reward influences visual perception as well. This was speculated to be the case because sensitivity is a known reflection of perceptual rather than motor processing. Also, there was no evidence of a speed-sensitivity trade-off. Similarly, although the lower sensitivity found in the **p** dimension for the **LR** than **HR** target did not reach statistical significance. Experiment 2 suggests that the lack of statistical significance was likely simply due to the smaller subjective difference between the **LR** and **HR** targets in that dimension. As a side note, sensitivity was also correlated with inverse efficiency, supporting the earlier conclusion that inverse efficiency partly reflects visual perception.

As expected, a main effect of Display Duration (150ms versus 33.33ms) was obtained for all behavioural measures in the **m** and **p** dimensions. In both reward dimensions, response time was significantly slower, accuracy was significantly lower, inverse efficiency was significantly worse and sensitivity was significantly lower for the 33.33ms than 150ms display duration. As evidenced by the lower *p*-values and higher effect sizes, the statistically significant findings were stronger in the **m** than in the **p** dimension.

Since the accuracy and sensitivity measures may reflect differences in visual perception as opposed to differences in motor processing between the **LR** and **HR** targets, as previously discussed, the main effect of Display Duration was likely observed for those two behavioural measures of performance due to the drop from a 150ms to a 33.33ms display duration substantially cutting into the covert processing time for both the **LR** and **HR** targets. Accuracy and sensitivity for both targets likely deteriorated with this drop in display duration because, although small, the difference in the timing of the N2pc (i.e., attentional selection) found between the **LR** and **HR** targets in the Kiss et al. (2009) study was nonetheless significant. Similarly, since the accuracy component of the inverse efficiency score may also partly reflect differences in visual perception between the **LR** and **HR** targets, as previously discussed, the main effect of Display Duration was likely observed for inverse efficiency partly for the same reason as it was observed for accuracy and sensitivity. Consequently, the same main effect of Display Duration for the response time measure may have been caused by greater uncertainty in responding following the 33.33ms than 150ms display duration, due to the decrease in covert processing time made available to the participant in the 33.33ms display. By the same token, since inverse efficiency is also made up of a response time component, as previously discussed, the main effect of Display Duration was also likely observed for inverse efficiency partly for the same reason as it was observed for the response time main effect.

A significant interaction between Target Reward Value (**LR** versus **HR**) and Display Duration (150ms versus 33.33ms) was not obtained in either dimension (**m** or **p**) for the response time measure. However, the expected direction of findings was obtained: non-significantly larger effect of decreases in display duration on the **LR** than on the **HR** target in the **p** dimension (opposite but negligible in the **m** dimension).

The non-significant interaction for the response time measure is not surprising since the main effect of Target Reward Value for response time also did not reach statistical significance. As discussed previously, response time may be influenced by visual perception and/or motor processing, and is more likely due to motor proceesing. Thus, the lack of significant findings for the response time measure may be due to the control implemented on go-fast/go-slow motor strategies in the current study.

In contrast, a significant interaction between Target Reward Value (**LR** versus **HR**) and Display Duration (150ms versus 33.33ms) was obtained in the **m** dimension for the accuracy, inverse efficiency and sensitivity measures, suggesting a larger effect of decreases in display duration on the **LRm** than on the **HRm** target. However, although this interaction did not reach significance in the **p** dimension for the accuracy, inverse efficiency and sensitivity measures, the expected direction of findings was obtained: non-significantly larger effect of decreases in display duration on the **LRp** than on the **HRp** target. As evidenced by the significant *p*-values and higher effect sizes in the **m** dimension and the similar yet non-significant direction of findings in the **p** dimension, the findings were stronger in the **m** than in the **p** dimension.

The significant Target Reward Value x Display Duration interactions for the accuracy, inverse efficiency and sensitivity measures in the **m** dimension are not surprising since the main effects of Target Reward Value for accuracy, inverse efficiency and sensitivity also reached statistical significance in that dimension. Since the accuracy and sensitivity measures may reflect differences in visual perception as opposed to differences in motor processing between the **LR** and **HR** targets, as previously discussed, the interactions for these two behavioural measures of performance were likely observed due to the drop from a 150ms to a 33.33ms display duration cutting into the visual processing time for the **LR** target slightly more than into the visual processing time for the **HR** target. This subtle difference between the **LR** and **HR** targets was observed even though a main effect of Display Duration was also found suggesting that a drop in display duration cuts substantially into the covert processing time for both targets. Accuracy and sensitivity for both targets likely deteriorated more for the **LR** than **HR** target with this drop in display duration because the small difference in the timing of the N2pc (i.e., covert processing) that was found between the **LR** and **HR** targets in the Kiss et al. (2009) study was nonetheless significant. Similarly, since the accuracy component of the inverse efficiency score may also partly reflect differences in visual perception between the **LR** and **HR** targets, as previously discussed, the significant Target Reward Value x Display Duration interaction was likely observed for inverse efficiency partly for the same reason as it was observed for accuracy and sensitivity. Although the larger accuracy, inverse efficiency and sensitivity effects of decreasing display duration for the **LR** than **HR** target did not reach statistical significance in the **p** dimension, Experiment 2 suggests that the lack of statistical significance was likely simply due to the smaller subjective difference between the **LR** and **HR** targets in that dimension.

It may be important to note that the 33.33ms display duration in the current experiment was by no means randomly determined. Preceding experiments were conducted separately for the **m** dimension and **p** dimension, in which the lowest display duration was 0.050s (rather than 0.035s). This pilot experiment led to the same pattern of results as the current experiment. However, most findings were simply trends that did not reach statistical significance. Therefore, the lowest display duration in the current experiment was decreased to 33.33ms in order to offer a greater perceptual challenge.

Independent samples *t*-tests. Independent sample *t*-tests were conducted to shed light on the inconsistencies between the **m** and **p** dimensions of reward. More specifically, throughout this paper, the difference in subjective reward value between the **LR** and **HR** target in the **m** dimension was speculated to be larger than the difference in subjective reward value between the **LR** and **HR** target in the **p** dimension. The discounting procedure used in Experiment 2 supported this conclusion. As expected, these *t*-tests demonstrated that the mean difference between the **LRm** and **HRm** target was significantly larger than the mean difference between the **LRp** and **HRp** target for the accuracy, inverse efficiency and sensitivity measures.

Conclusion

In summary, the behavioural measures and display-duration paradigm used in the current experiment lend support to the theory that reward influences the visual perception (i.e., early) stage of information processing along the “visual pereption-overt behaviour” continuum. Furthermore, the current experiment demonstrated that differences in visual perception of targets differing in reward value seem to be most obviously reflected by observed differences in accuracy, inverse efficiency and sensitivity between those targets.

Moreover, the data suggest that, not only is the reward value of visual targets and their consequent visual perception determined by the magnitude of reward associated with them but also by the subjective value they represent for the observer. This hypothesis is further assessed in Experiment 4.

Experiment 4

Determining the cause of the differences between the magnitude and probability dimensions in Experiment 3

The purpose of Experiment 4 was to determine whether the greater statistical strength of findings observed in Experiment 3 for the **m** than the **p** dimension of reward was due to the potentially larger difference in subjective reward value between the **LR** and **HR** target in the **m** than in the **p** dimension, as suggested by Experiment 2.

In the current experiment, the reward value for the **HR** target in both dimensions (**m** and **p**) was maintained at $10, as in Experiment 3. If the greater statistical strength of findings observed in Experiment 3 for the **m** than the **p** dimension of reward was due to a larger difference in subjective reward value between the **LRm** and **HRm** targets than between the **LRp** and **HRp** targets, then reducing the size of the difference in subjective reward value between the **LR** and **HR** targets in the **m** dimension in the current experiment would lead to findings of a similarly weak statistical strength as those found in the **p** dimension in Experiment 3. In order to accomplish this, the subjective reward value of the **LRm** target was increased from $1 in Experiment 3 to $5 in the current experiment. (The $5 reward value for the **LRm** target in the current experiment was chosen to approximate the subjective reward value of the **LRp** target in Experiment 3, as determined by Experiment 2.) Therefore, the difference in subjective reward value between the **LRm** and **HRm** targets was decreased from a $9 difference in Experiment 3 to a $5 difference in the current experiment.

Likewise, if the weaker statistical strength of findings observed in Experiment 3 for the **p** than the **m** dimension of reward was due to a smaller difference in subjective reward value between the **LRp** and **HRp** targets than between the **LRm** and **HRm** targets, then increasing the size of the difference in subjective reward value between the **LR** and **HR** target in the **p** dimension, would lead to findings of a similarly strong statistical strength as those found in the **m** dimension in Experiment 3. This was accomplished by reducing the subjective reward value of the **LRp** target from a 10% chance for $10 in Experiment 3 (subjective reward value of approximately $5, as determined by Experiment 2) to a 1% chance for $10 in the current experiment (subjective reward value of approximately $1, as determined by the discounting procedure described later). Therefore, the difference in subjective reward value between the **LRp** and **HRp** target was increased from a $5 difference in Experiment 3 to an approximately $9 difference in the current experiment. The 1% probability for the **LRp** target in the current experiment was chosen to approximate the subjective reward value of the **LRm** target in Experiment 3 ($1).

In summary, if the greater statistical strength of findings observed in Experiment 3 for the **m** than the **p** dimension of reward was due to the potentially larger difference in subjective reward value between the **LR** and **HR** targets in the **m** than in the **p** dimension, this experiment would lead to a reversal in the statistical strength of findings between dimensions. More specifically, whereas stronger statistical findings were obtained in the **m** than **p** dimension in Experiment 3, stronger statistical findings were expected in the **p** than in the **m** dimension in the current experiment. If, in contrast, the differences in statistical strength between dimensions in Experiment 3 were due to inherent characteristics of the reward dimensions, this reversal of findings should not be obtained. As was Experiment 3, the current experiment was also divided into 2 components: Experiment 4A (Magnitude dimension) and Experiment 4B (Probability dimension).

Experiment 4A: Reward Magnitude Dimension

In the magnitude component of Experiment 4, it was expected that target identification response times would be slower, error rates would be higher, inverse efficiency would be poorer and sensitivity would be lower for Low-Reward-Magnitude targets (**LRm**) than for High-Reward-Magnitude targets (**HRm**) and for 0.035s display durations than for 0.150s display durations. It was also expected that the effect of decreasing display duration would be more detrimental to target identification performance for the **LRm** target than for the **HRm** target, suggesting that the **LRm** target requires a longer processing time to be visually perceived than the **HRm** target. Based on the findings in Experiment 1 and 3, the accuracy, inverse efficiency and sensitivity measures were expected to show stronger statistical findings than the response time measure. Significant findings for accuracy, inverse efficiency and sensitivity in the presence or absence of significant findings in response time would suggest reward influences on the visual perception (i.e, early) stage of information processing along the "visual perception-overt behaviour" continuum. However, significant differences in response time in the absence of differences in accuracy, inverse efficiency and sensitivity would suggest a lack of reward influences on the visual perception (i.e., early) stage and evidence for differences in the motor (i.e, late) stage of information processing along the "visual perception-overt behaviour" continuum.

Also, compared to Experiment 3, the statistical findings from the **m** dimension in the current experiment were expected to be weaker (more closely resembling the statistical strength of findings in the **p** than **m** dimension of Experiment 3).

Methodology

Participant sample

Participants in this experiment consisted of 4 female and 4 male (mean age = 24) Concordia University undergraduate psychology students with self-reported normal vision, drawn from the Psychology Department's Participant Pool. They were treated in accordance with the guidelines set by the "Concordia University Human Research Ethics Committee".

Apparatus and laboratory space

The apparatus and laboratory space used in this experiment were the same as those used in Experiment 1 and 3.

Stimuli

The stimuli used in this experiment were the same as those used in Experiment 1 and 3.

Procedure

The procedure used in the current experiment was the same as that used in Experiment 3.

Reward manipulation

All participants received 2 course credits simply for participating in the study. In addition, at the end of each participant's testing session, a random-number generator was used to select one of the trials therein.

If the randomly selected trial contained a Low-Reward-Magnitude target (**LRm**), a $5 monetary reward was given. If it contained a High-Reward-Magnitude target (**HRm**), a $10 monetary reward was given. However, if an incorrect or late response (after the 3.000s) was made in the trial that was randomly selected, no monetary reward was given. For half of the participants, the **LRm** was red and the **HRm** was green. For the other half of the participants, the **LRm** was green and the **HRm** was red. Participants were informed of these reward contingencies prior to the start of the experiment.

Results

The raw data generated by each participant were automatically exported from VPixx (v.2.32) to Excel (v.12.3.0). Excel was used to summarize each participant's raw data into "**LRm** target in **150ms** display"**, "LRm** target in **33.33ms** display", "**HRm** target in **150ms** display"and "**HRm** target in **33.33ms** display" means for the response time, accuracy, inverse efficiency and sensitivity (d') behavioural measures. This resulted in a total of 16 means.

Repeated Measures ANOVAs

SPSS software (v.19) was used to conduct a separate 2 x 2 repeated measures analysis of variance on the response time, accuracy, inverse efficiency and sensitivity (d') behavioural measures (see Appendix B for complete proofs). For each of the 4 analyses, Target Reward Value had 2 levels (**LRm**, **HRm**) and Display Duration had 2 levels (**150ms**, **33.33ms**).

Given that the subjective difference in reward value between the LRm and HRm targets was decreased in the current experiment as compared to Experiment 3A (m dimension), significant interactions between Target Reward Magnitude and Display Duration were not expected for any behavioural measure. In other words, the findings were expected to be similarly weak as those of Experiment 3B (**p** dimension).

Response time. The 2 x 3 repeated measures ANOVA conducted on the response time data resulted in a non-significant main effect of Target Reward Magnitude, $F(1, 7) = 2.628$, $p = 0.15$, $\eta^2 = 0.27$, a significant main effect of Display Duration, $F(1, 7) = 7.682$, $p = 0.03$, $\eta^2 = 0.52$, and a non-significant interaction between Target Reward Magnitude and Display Duration, $F(1, 7) = 0.028$, $p = 0.87$, $\eta^2 = 0.00$ (see Table B22).

The non-significant main effect of Target Reward Magnitude showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean response time for the **LRm** target (*M* = 0.462s, *SE* = 0.008s) did not differ significantly from the mean response time for the **HRm** target (*M* = 0.450s, *SE* = 0.008s).

The significant main effect of Display Duration showed that, regardless of the target reward magnitude manipulation (**LRm** versus **HRm**), the mean response time for the **150ms** display duration (*M* = 0.436s, *SE* = 0.005s) was significantly faster than the mean response time for the **33.33ms** display duration (*M* = 0.476s, *SE* = 0.014s) (see Figure 29).

As expected, the non-significant interaction between Target Reward Magnitude and Display Duration showed that the mean difference in response time between the **150ms** display duration and **33.33ms** display duration for the **LRm** target (*M* = -0.043s, *SE* = 0.024s) was not larger (or smaller) than the mean difference in response time between the **150ms** and **33.33ms** display duration for the **HRm** target (*M* = -0.038s, *SE* = 0.013s).

Accuracy (% correct). The 2 x 2 repeated measures ANOVA conducted on the accuracy data resulted in a non-significant main effect of Target Reward Magnitude, $F(1, 7) = 1.656$, $p = 0.24$, $\eta^2 = 0.19$, a significant main effect of Display Duration, $F(1, 7) = 159.609$, $p = 0.00$, $\eta^2 = 0.96$, and a non-significant interaction between Target Reward Magnitude and Display Duration, $F(1, 7) = 2.655$, $p = 0.15$, $\eta^2 = 0.28$ (see Table B23).

The non-significant main effect of Target Reward Magnitude showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean

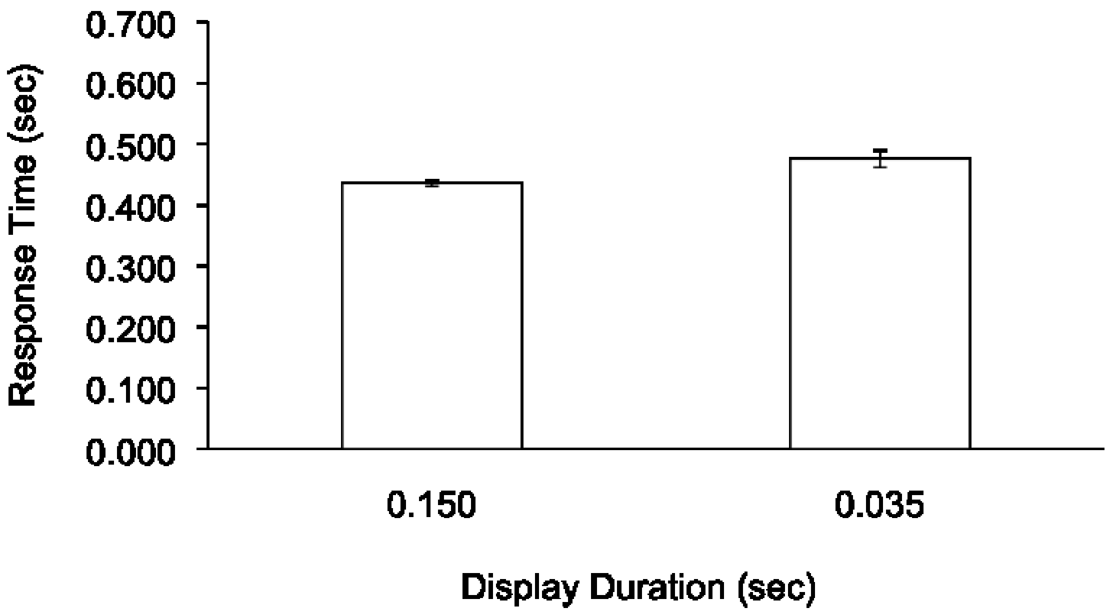

Figure 29. Mean response time (+*SE*) for the significant main effect of Display Duration in Experiment 4A, $p = 0.03$.

accuracy for the **LRm** target (*M* = 84.4%, *SE* = 1.2%) was not significantly different from the mean accuracy for the **HRm** target (*M* = 87.3%, *SE* = 1.3%).

The significant main effect of Display Duration showed that, regardless of the target reward magnitude manipulation (**LRm** versus **HRm**), the mean accuracy for the **150ms** display duration (*M* = 94.6%, *SE* = 0.8%) was significantly better than the mean accuracy for the **33.33ms** display duration (*M* = 77.1%, *SE* = 1.0%) (see Figure 30).

As expected, the non-significant interaction between Target Reward Magnitude and Display Duration showed that the mean difference in accuracy between the **150ms** display duration and **33.33ms** display duration for the **LRm** target (*M* = 21.0%, *SE* = 2.6%) was not larger (or smaller) than the mean difference in accuracy between the **150ms** and **33.33ms** display duration for the **HRm** target (*M* = 14.1%, *SE* = 2.4%).

Inverse efficiency. The 2 x 2 repeated measures ANOVA conducted on the inverse efficiency data resulted in a non-significant main effect of Target Reward Magnitude, $F(1, 7) = 5.029$, $p = 0.06$, $\eta^2 = 0.42$, a significant main effect of Display Duration, $F(1, 7) = 48.181$, $p = 0.00$, $\eta^2 = 0.87$, and a non-significant interaction between Target Reward Magnitude and Display Duration, $F(1, 7) = 2.246$, $p = 0.18$, $\eta^2 = 0.24$ (see Table B24).

The non-significant main effect of Target Reward Magnitude showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean inverse efficiency for the **LRm** target (*M* = 0.562s, *SE* = 0.015s) did not differ

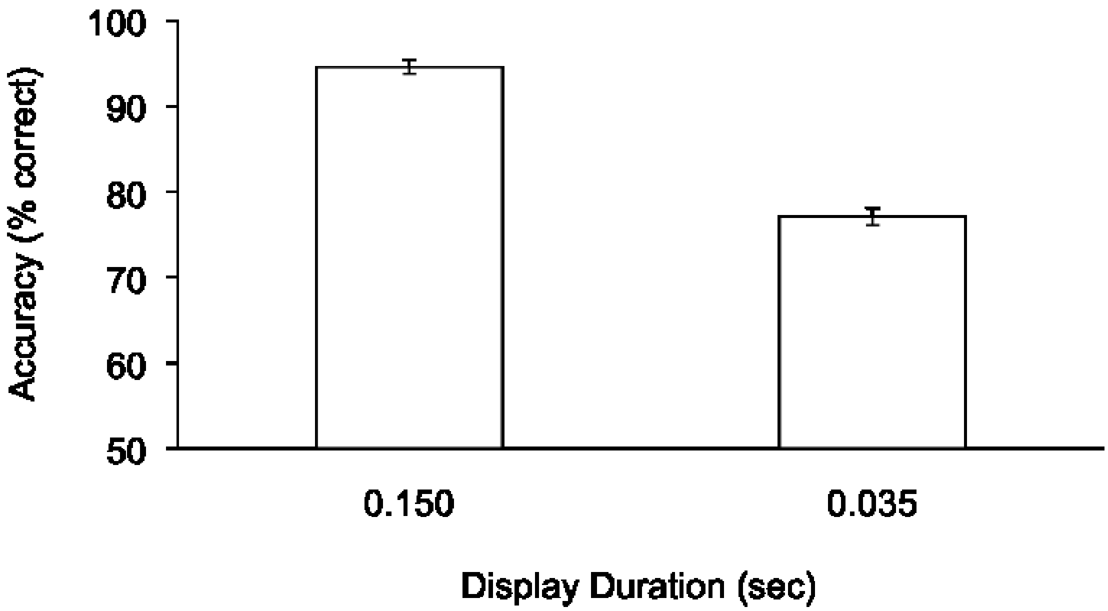

Figure 30. Mean accuracy (+*SE*) for the significant main effect of Display Duration in Experiment 4A, $p = 0.00$.

significantly from the mean inverse efficiency for the **HRm** target (*M* = 0.522s, *SE* = 0.010s).

The significant main effect of Display Duration showed that, regardless of the target reward magnitude manipulation (**LRm** versus **HRm**), the mean inverse efficiency for the **150ms** display duration (*M* = 0.461s, *SE* = 0.006s) was significantly better than the mean inverse efficiency for the **33.33ms** display duration (*M* = 0.623s, *SE* = 0.020s) (see Figure 31).

As expected, the non-significant interaction between Target Reward Magnitude and Display Duration showed that the mean difference in inverse efficiency between the **150ms** and **33.33ms** display durations for the **LRm** target (*M* = -0.193s, *SE* = 0.040s) was not larger (or smaller) than the mean difference in inverse efficiency between the **150ms** and **33.33ms** display durations for the **HRm** target (*M* = -0.131s, *SE* = 0.019s).

Sensitivity (d'). The 2 x 2 repeated measures ANOVA conducted on the sensitivity data resulted in a non-significant main effect of Target Reward Magnitude, $F(1, 7) = 2.202$, $p = 0.18$, $\eta^2 = 0.24$, a significant main effect of Display Duration, $F(1, 7) = 6.691$, $p = 0.04$, $\eta^2 = 0.49$, and a non-significant interaction between Target Reward Magnitude and Display Duration, $F(1, 7) = 0.006$, $p = 0.94$, $\eta^2 = 0.00$ (see Table B25).

The non-significant main effect of Target Reward Magnitude showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean sensitivity for the **LRm** target (*M* = 1.993, *SE* = 0.096) did not differ significantly from the mean sensitivity for the **HRm** target (*M* = 2.343, *SE* = 0.211).

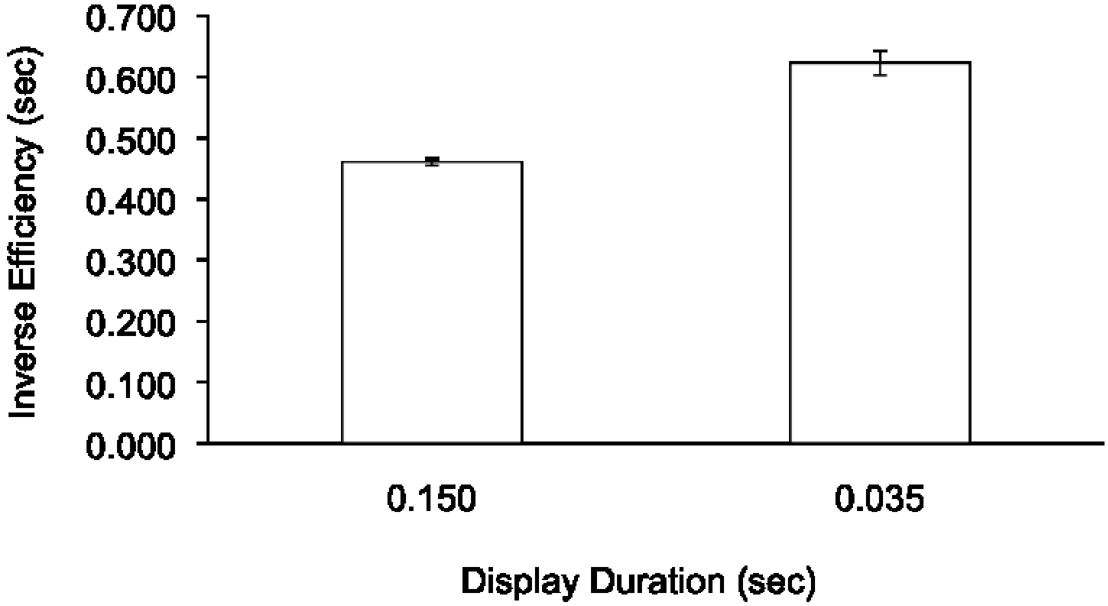

Figure 31. Mean inverse efficiency (+*SE*) for the significant main effect of Display Duration in Experiment 4A, $p = 0.00$.

The significant main effect of Display Duration showed that, regardless of the target reward magnitude manipulation (**LRm** versus **HRm**), the mean sensitivity for the **150ms** display duration (*M* = 2.531, *SE* = 0.117) was significantly higher than the mean sensitivity for the **33.33ms** display duration (*M* = 1.804, *SE* = 0.227) (see Figure 32).

As expected, the non-significant interaction between Target Reward Magnitude and Display Duration showed that the mean difference in sensitivity between the **150ms** and **33.33ms** display duration for the **LRm** target (*M* = 0.733, *SE* = 0.292) was not larger (or smaller) than the mean difference in sensitivity between the **150ms** and **33.33ms** display duration for the **HRm** target (*M* = 0.720, *SE* = 0.293).

ANOVA summary. As expected, contrary to Experiment 3A (**m** dimension), significant interactions between Target Reward Magnitude and Display Duration were not obtained in this experiment (**m** dimension) for any of the behavioural measures. However the non-significant findings were in the expected direction: non-significant larger mean differences between display durations for the **LRm** target than for the **HRm** target, for measures predominantly reflecting early processing (i.e., accuracy, inverse efficiency and sensitivity).

The fact that these interactions were not significant in the current experiment (**m** dimension), but were in Experiment 3A (**m** dimension) suggests that the **m** dimension is not inherently different from the **p** dimension. Rather, given that the subjective difference in reward value between the **LRm** and **HRm** targets was decreased in the current experiment (**m** dimension) as compared to Experiment 3A (**m** dimension), the non-significant interactions in the current experiment suggest that the difference in

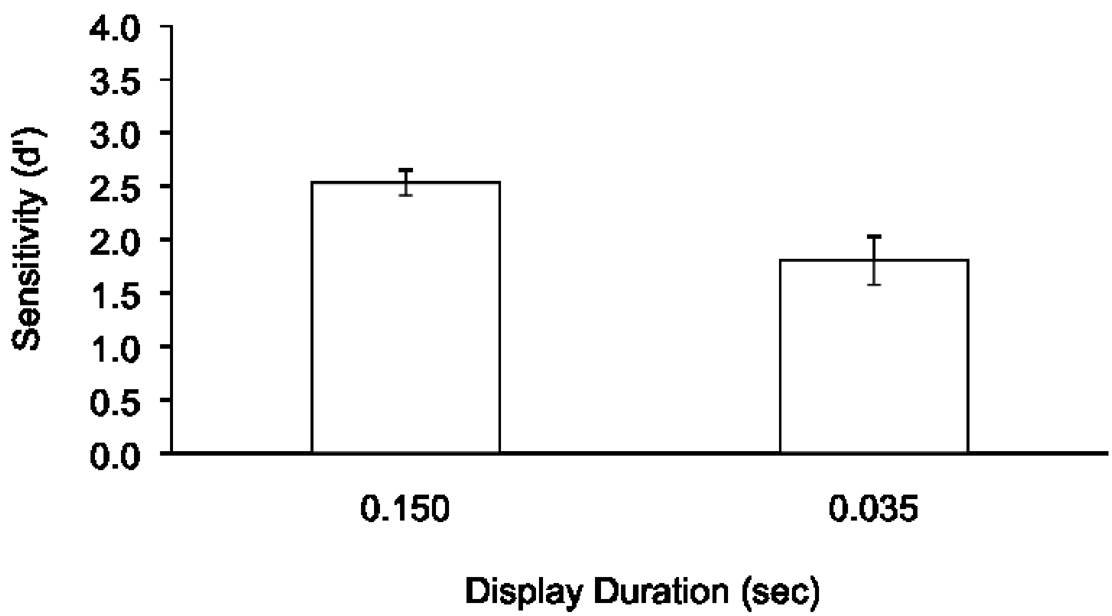

Figure 32. Mean sensitivity (+*SE*) for the significant main effect of Display Duration in Experiment 4A, $p = 0.04$.

subjective reward value between the **LRm** and **HRm** target needs to be sufficiently large for statistical significance to be obtained.

Experiment 4B: Reward Probability Dimension

In the probability component of Experiment 4, it was expected that target identification response times would be slower, error rates would be higher, inverse efficiency would be poorer and sensitivity would be lower for Low-Reward-Probability targets (**LRp**) than for High-Reward-Probability targets (**HRp**) and for 33.33ms display durations than for 150ms display durations. It was also expected that the effect of decreasing display duration would be more detrimental to target identification performance for the **LRp** target than for the **HRp** target, suggesting that the **LRp** target requires a longer processing time to be visually perceived than the **HRp** target. Based on the findings in Experiment 1 and 3, the accuracy, inverse efficiency and sensitivity measures were expected to show stronger statistical findings than the response time measure. Significant findings for accuracy, inverse efficiency and sensitivity in the presence or absence of significant findings in response time would suggest reward influences on the visual perception (i.e, early) stage of information processing along the "visual perception-overt behaviour" continuum. However, significant differences in response time in the absence of differences in accuracy, inverse efficiency and sensitivity would suggest a lack of reward influences on the visual perception (i.e, early) stage and evidence for differences in the motor (i.e., late) stage of information processing along the "visual perception-overt behaviour" continuum.

Also, as compared to Experiment 3, the statistical findings from the **p** dimension in the current experiment were expected to be stronger (more closely resembling the statistical strength of findings in the **m** than **p** dimension of Experiment 3).

Methodology

Participant sample

Participants in this experiment consisted of 6 female and 2 male (mean age = 22) Concordia University undergraduate psychology students with self-reported normal vision, drawn from the Psychology Department's Participant Pool. They were treated in accordance with the guidelines set by the "Concordia University Human Research Ethics Committee".

Apparatus and laboratory space

The apparatus and laboratory space used in this experiment were the same as those used in Experiment 1 and 3.

Stimuli

The stimuli used in this experiment were the same as those used in Experiment 1 and 3.

Procedure: Visual search task

The visual search procedure used in the current experiment was the same as that used in Experiment 3.

Reward manipulation: Visual search task

All participants received 2 course credits simply for participating in the study. In addition, at the end of each participant's testing session, a random-number generator was used to select one of the trials therein.

If the randomly selected trial contained a Low-Reward-Probability target (**LRp**), a $10 monetary reward was given with 1% probability (A random number generator with numbers 1 through 100 was used. If the number 1 was drawn, the $10 reward was given; if any of the other numbers were drawn, it wasn't). If it contained a High-Reward-Probability target (**HRp**), a $10 monetary reward was given with 100% probability. However, if an incorrect or late response (after the 3s) was made in the trial that was randomly selected, no monetary reward was given. For half of the participants, the **LRp** was red and the **HRp** was green. For the other half of the participants, the **LRp** was green and the **HRp** was red. Participants were informed of these reward contingencies prior to the start of the experiment.

Procedure: Discounting task

The same participants from the visual component of this experiment subsequently performed the discounting task. They were treated in accordance with the guidelines set by the "Concordia University Human Research Ethics Committee". The discounting task used in the current experiment was similar to that used in Experiment 2, except with a different probabilistic reward (see Appendix C). The subjective reward value of the **LRp** target in the current experiment was determined to be approximately $1 (*M* = $1.30, *SE* = $0.06) and, thus as expected was approximately equal to the subjective value of the **LRm** target in Experiment 3.

Results

The raw data generated by each participant were automatically exported from VPixx (v.2.32) to Excel (v.12.3.0). Excel was used to summarize each participant's raw data into "**LRp** target in **150ms** display"**, "LRp** target in **33.33ms** display"**,** "**HRp** target in **150ms** display"and "**HRp** target in **33.33ms** display" means for the response time, accuracy, inverse efficiency and sensitivity (d') behavioural measures. This resulted in a total of 16 means.

Repeated Measures ANOVAs

SPSS software (v.19) was used to conduct a separate 2 x 2 repeated measures analysis of variance on the response time, accuracy, inverse efficiency and sensitivity (d') behavioural measures (see Appendix B for complete proofs). For each of the 4 analyses, Target Reward Value had 2 levels (**LRp**, **HRp**) and Display Duration had 2 levels (**150ms**, **33.33ms**).

Given that the subjective difference in reward value between the **LRp** and **HRp** targets was increased in the current experiment as compared to Experiment 3B (**p** dimension), significant interactions between Target Reward Probability and Display Duration were expected for all behavioural measures predominantly reflecting early processing, as suggested by the findings from Experiment 1 (i.e., for accuracy, inverse efficiency and sensitivity; not for response time). These interactions were expected to show larger mean differences between display durations for the **LRp** target than for the **HRp** target, suggesting that the **LRp** target requires a longer processing time to be visually perceived than the **HRp** target. In other words, the findings were expected to be similarly strong as those of Experiment 3A (**m** dimension).

Response time. The 2 x 2 repeated measures ANOVA conducted on the response time data resulted in non-significant main effect of Target Reward Probability, $F(1, 7) = 5.098$, $p = 0.06$, $\eta^2 = 0.42$, a significant main effect of Display Duration, $F(1, 7) = 14.225$, $p = 0.01$, $\eta^2 = 0.67$, and a non-significant interaction between Target Reward Probability and Display Duration, $F(1, 7) = 0.004$, $p = 0.95$, $\eta^2 = 0.00$ (see Table B26).

The non-significant main effect of Target Reward Probability showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean response time for the **LRp** target (*M* = 0.470s, *SE* = 0.010s) did not differ significantly from the mean response time for the **HRp** target (*M* = 0.452s, *SE* = 0.006s).

The significant main effect of Display Duration showed that, regardless of the target reward probability manipulation (**LRp** versus **HRp**), the mean response time for the **150ms** display duration (*M* = 0.437s, *SE* = 0.004s) was significantly faster than the mean response time for the **33.33ms** display duration (*M* = 0.485s, *SE* = 0.013s) (see Figure 33).

As expected, the non-significant interaction between Target Reward Probability and Display Duration showed that the mean difference in response time between the **150ms** display duration and **33.33ms** display duration for the **LRp** target (*M* = 0.225s, *SE* = 0.030s) was not larger (or smaller) than the mean difference in response time between the **150ms** and **33.33ms** display duration for the **HRp** target (*M* = 0.096s, *SE* = 0.030s).

Accuracy (% correct). The 2 x 2 repeated measures ANOVA conducted on the accuracy data resulted in a significant main effect of Target Reward Probability, $F(1, 7) = 23.038$, $p = 0.00$, $\eta^2 = 0.77$, a significant main effect of Display Duration,

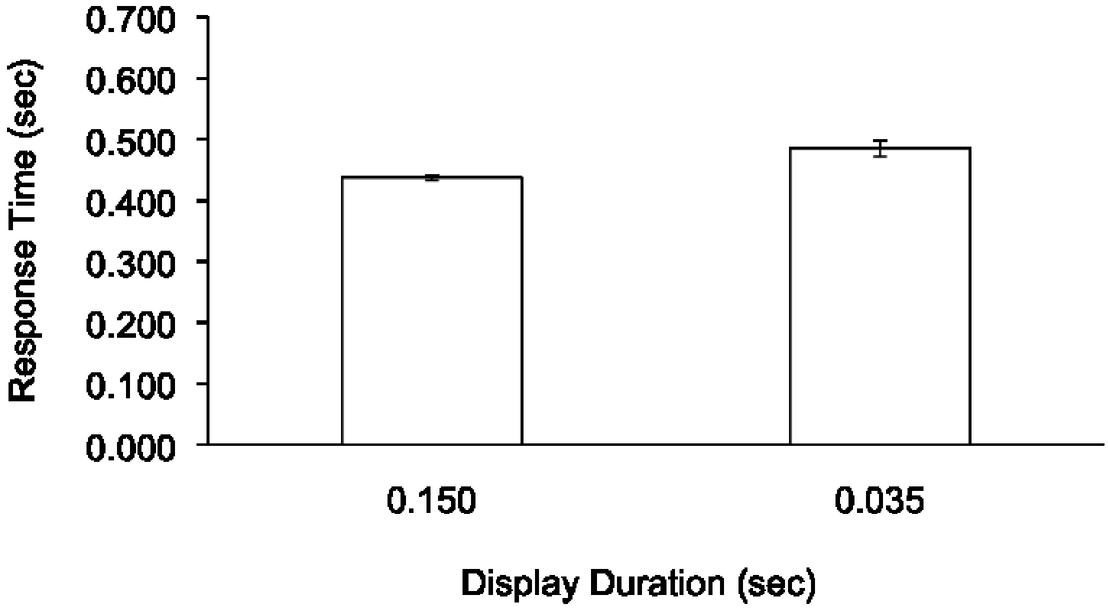

Figure 33. Mean response time (+*SE*) for the significant main effect of Display Duration in Experiment 4B, $p = 0.01$.

$F(1, 7) = 68.332$, $p = 0.00$, $\eta^2 = 0.91$, and a significant interaction between Target Reward Probability and Display Duration, $F(1, 7) = 19.785$, $p = 0.00$, $\eta^2 = 0.74$ (see Table B27).

The significant main effect of Target Reward Probability showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean accuracy for the **LRp** target (*M* = 82.6%, *SE* = 0.8%) was significantly lower than the mean accuracy for the **HRp** target (*M* = 90.3%, *SE* = 1.4%).

The significant main effect of Display Duration showed that, regardless of the target reward probability manipulation (**LRp** versus **HRp**), the mean accuracy for the **150ms** display duration (*M* = 94.9%, *SE* = 0.8%) was significantly higher than the mean accuracy for the **33.33ms** display duration (*M* = 78.0%, *SE* = 1.6%).

As expected, the significant interaction between Target Reward Probability and Display Duration showed that the mean difference in accuracy between the **0.150s** and **0.035s** display duration for the **LRp** target (*M* = 24.6%, *SE* = 2.4%) was larger than the mean difference in accuracy between the **0.150s** and **0.035s** display duration for the **HRp** target (*M* = 9.1%, *SE* = 2.9%) (see Figure 34 and Table 28).

Inverse efficiency. The 2 x 2 repeated measures ANOVA conducted on the inverse efficiency data resulted in a significant main effect of Target Reward Probability, $F(1, 7) = 25.492$, $p = 0.00$, $\eta^2 = 0.79$, a significant main effect of Display Duration, $F(1, 7) = 58.178$, $p = 0.00$, $\eta^2 = 0.89$, and a significant interaction between Target Reward Probability and Display Duration, $F(1, 7) = 10.370$, $p = 0.02$, $\eta^2 = 0.60$ (see Table B29).

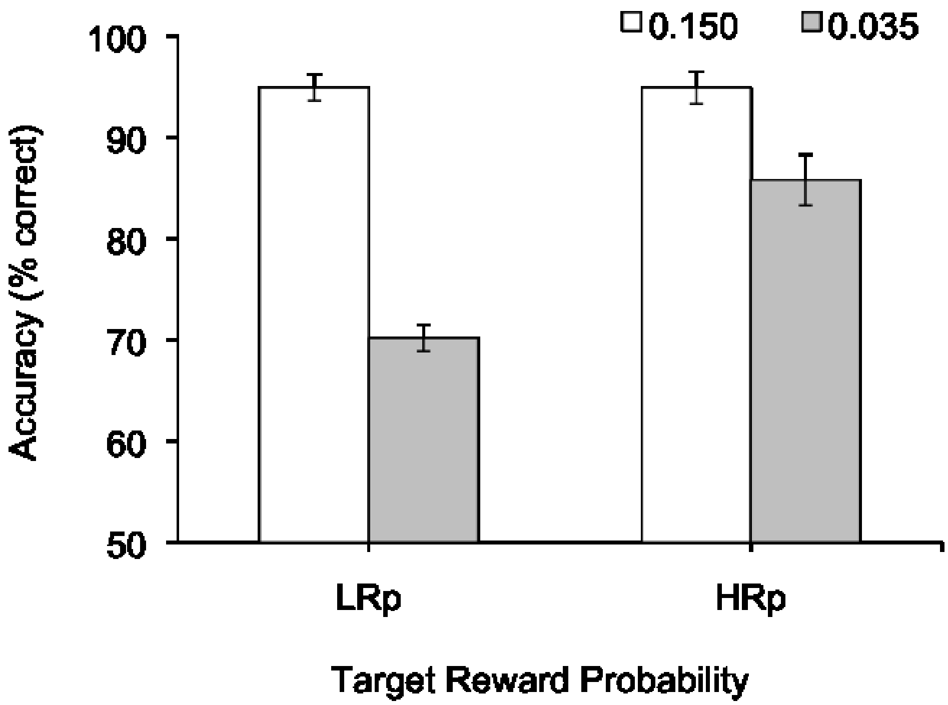

Figure 34. Mean accuracy (+*SE*) for the significant Target Reward Probability x Display Duration interaction in Experiment 4B, $p = 0.00$.

The significant main effect of Target Reward Probability showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean inverse efficiency for the **LRp** target (*M* = 0.588s, *SE* = 0.015s) was significantly worse than the mean inverse efficiency for the **HRp** target (*M* = 0.505s, *SE* = 0.008s).

The significant main effect of Display Duration showed that, regardless of the target reward probability manipulation (**LRp** versus **HRp**), the mean inverse efficiency for the **150ms** display duration (*M* = 0.462s, *SE* = 0.007s) was significantly better than the mean inverse efficiency for the **33.33ms** display duration (*M* = 0.631s, *SE* = 0.019s).

As expected, the significant interaction between Target Reward Probability and Display Duration showed that the mean difference in inverse efficiency between the **150ms** and **33.33ms** display duration for the **LRp** target (*M* = -0.233s, *SE* = 0.033s) was larger than the mean difference in inverse efficiency between the **150ms** and **33.33ms** display duration for the **HRp** target (*M* = -0.106s, *SE* = 0.025s) (see Figure 35 and Table 30).

Sensitivity (d'). The 2 x 2 repeated measures ANOVA conducted on the sensitivity data resulted in a significant main effect of Target Reward Probability, $F(1, 7) = 5.852$, $p = 0.05$, $\eta^2 = 0.46$, a significant main effect of Display Duration, $F(1, 7) = 9.102$, $p = 0.02$, $\eta^2 = 0.57$, and a significant interaction between Target Reward Probability and Display Duration, $F(1, 7) = 10.141$, $p = 0.02$, $\eta^2 = 0.59$ (see Table B31).

The significant main effect of Target Reward Probability showed that, regardless of the display duration manipulation (**150ms** versus **33.33ms)**, the mean

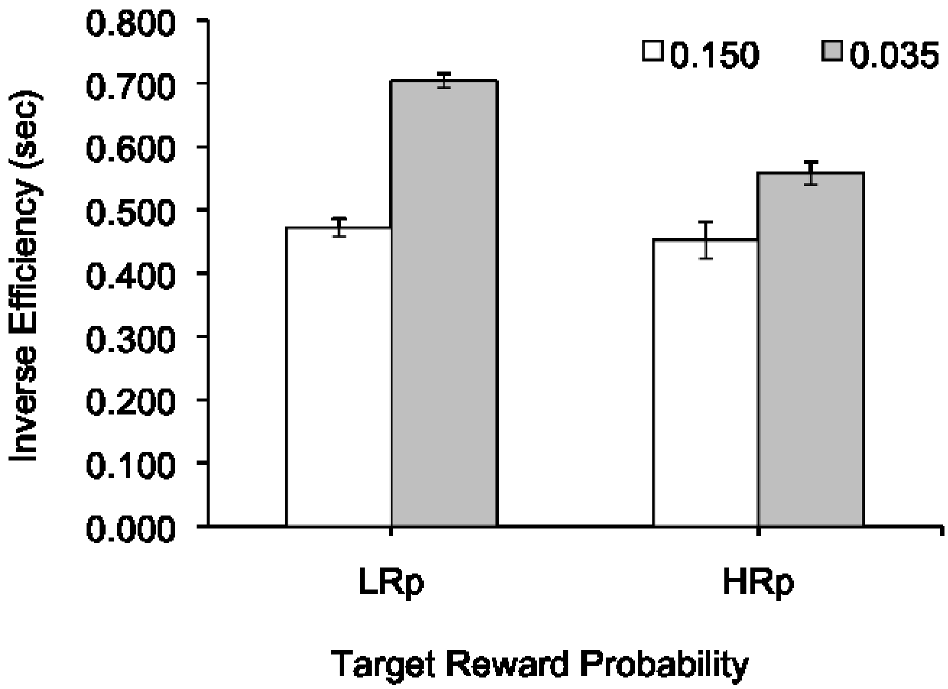

Figure 35. Mean inverse efficiency (+*SE*) for the significant Target Reward Probability x Display Duration interaction in Experiment 4B, $p = 0.02$.

sensitivity for the **LRp** target (*M* = 1.760, *SE* = 0.054) was significantly lower than the mean sensitivity for the **HRp** target (*M* = 2.338, *SE* = 0.217).

The significant main effect of Display Duration showed that, regardless of the target reward probability manipulation (**LRp** versus **HRp**), the mean sensitivity for the **150ms** display duration (*M* = 2.491, *SE* = 0.117) was significantly higher than the mean sensitivity for the **33.33ms** display duration (*M* = 1.607, *SE* = 0.225).

As expected, the significant interaction between Target Reward Probability and Display Duration showed that the mean difference between the **0.150s** and **0.035s** display duration for the **LRp** target (*M* = 1.017, *SE* = 0.291) was larger than the mean difference in sensitivity between the **150ms** and **33.33ms** display duration for the **HRp** target (*M* = 0.750, *SE* = 0.301) (see Figure 36 and Table 32).

ANOVA summary. As expected, contrary to Experiment 3B (**p** dimension), significant interactions between Target Reward Probability and Display Duration were obtained in this experiment (**p** dimension) for all behavioural measures predominantly reflecting early processing, as suggested by the findings from Experiment 1 (i.e., for accuracy, inverse efficiency and sensitivity; not for response time). As expected, these interactions showed larger mean differences between display durations for the **LRp** target than for the **HRp** target, suggesting that the **LRp** target requires a longer processing time to be visually perceived than the **HRp** target.

The fact that these interactions were significant in the current experiment (**p** dimension), but were not significant in Experiment 3B (**p** dimension) suggests that the **p** dimension is not inherently different from the **m** dimension. Rather, given that the subjective difference in reward value between the **LRp** and **HRp** targets was increased in

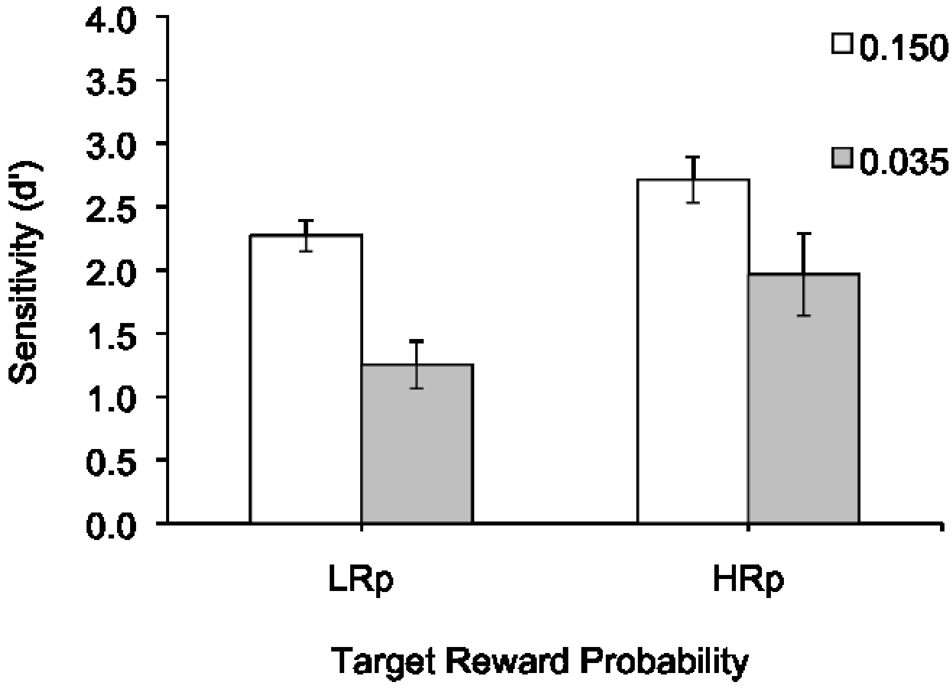

Figure 36. Mean sensitivity (+*SE*) for the significant Target Reward Probability x Display Duration interaction in Experiment 4B, $p = 0.02$.

the current experiment (**p** dimension) as compared to Experiment 3B (**p** dimension), the significant interactions in the current experiment suggest that the difference in subjective reward value between the **LRp** and **HRp** target needs to be sufficiently large forstatistical significance to be obtained.

Independent samples *t*-tests (Experiments 4A and 4B)

As evidenced by the repeated measures ANOVAs conducted in Experiments 4A (**m** dimension) and 4B (**p** dimension), there were some inconsistencies between the **m** and **p** dimensions of reward. More specifically, as expected, although a similar pattern of findings emerged in both dimensions, weaker statistical findings were found in the **m** dimension than in the **p** dimension. These observed inconsistencies were speculated to be due to a smaller subjective difference in reward value between the **LR** and **HR** target in the **m** dimension than in the **p** dimension, as suggested by Experiment 2. Statistical comparisons were conducted to confirm the observation that the mean difference for all behavioural measures of performance was smaller between the **LRm** and **HRm** targets than between the **LRp** and **HRp** targets.

SPSS software (v.19) was used to conduct a series of independent samples *t*-tests, comparing the **m** dimension mean difference between **LR** and **HR** targets to the **p** dimension mean difference between **LR** and **HR** targets. A separate *t*-test was conducted for each behavioural measure of performance (see Appendix B for complete proofs).

Response time. The mean difference in response time between **LR** and **HR** targets in the **m** dimension (M = 0.012s, SE = 0.007s) did not differ significantly from the mean difference in response time between **LR** and **HR** targets in the **p** dimension (M = 0.018s, SE = 0.008s), $t(14)$ = -0.742, p = 0.48, g = .24 (see Table B33).

Accuracy (% correct). As seen in Figure 37, the mean difference in accuracy between **LR** and **HR** targets in the **m** dimension (*M* = -2.9%, *SE* = 6.5%) was significantly smaller than the mean difference in accuracy between, *g* = .50 **LR** and **HR** targets in the **p** dimension (*M* = 15.5%, *SE* = 9.1%), *t*(14) = 8.469, *p* = 0.00 (see Table B33).

Inverse efficiency. As seen in Figure 38, the mean difference in inverse efficiency between **LR** and **HR** targets in the **m** dimension (*M* = 0.040s, *SE* = 0.018s) was significantly smaller than the mean difference in inverse efficiency between **LR** and **HR** targets in the **p** dimension (*M* = 0.083s, *SE* = 0.016s), *t*(14) = -4.560, *p* = 0.00, *g* = .84 (see Table B33).

Sensitivity (d'). As seen in Figure 39, the mean difference in sensitivity between **LR** and **HR** targets in the **m** dimension (*M* = -0.350, *SE* = 0.236) was significantly smaller than the mean difference in sensitivity between **LR** and **HR** targets in the **p** dimension (*M* = -0.578, *SE* = 0.239), *t*(14) = 2.599, *p* = 0.04, *g* = .30 (see Table B33).

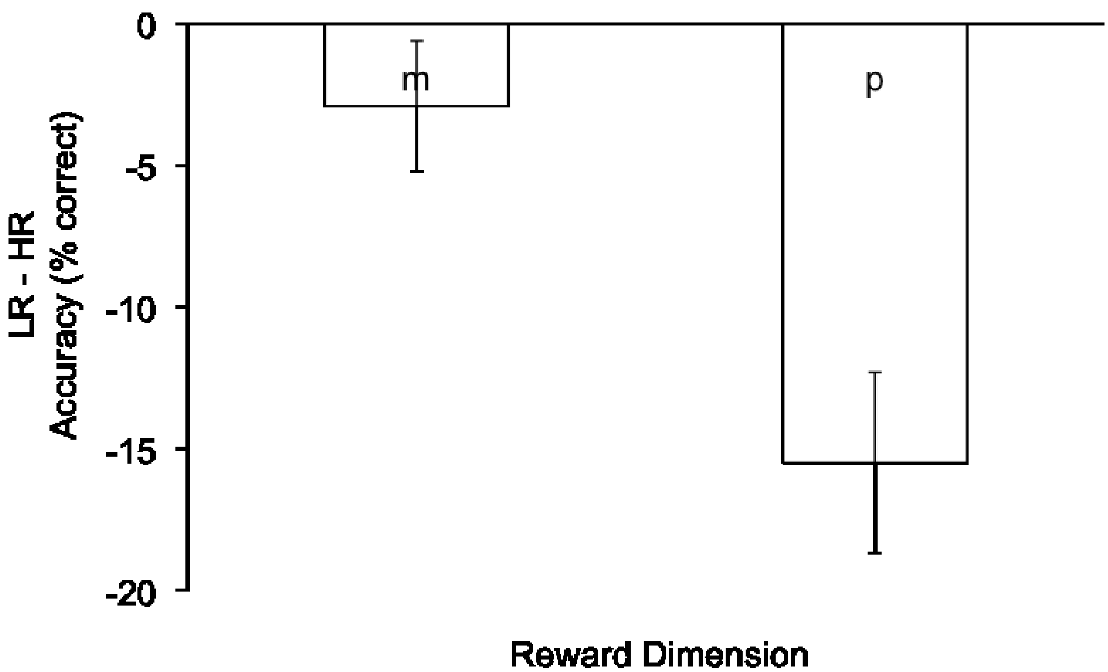

Figure 37. Mean difference (+*SE*) in accuracy between **HR** and **LR** target in the **m** and **p** dimension, in Experiment 4, $p = 0.00$.

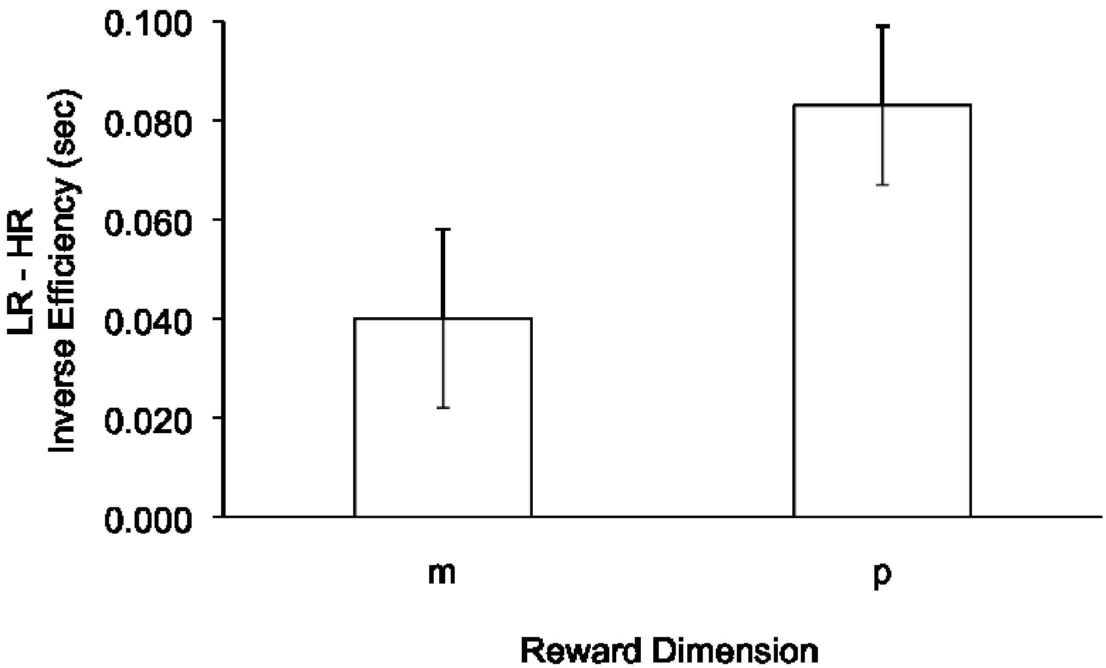

Figure 38. Mean difference (+*SE*) in inverse efficiency between **HR** and **LR** target in the **m** and **p** dimension, in Experiment 4, $p = 0.00$.

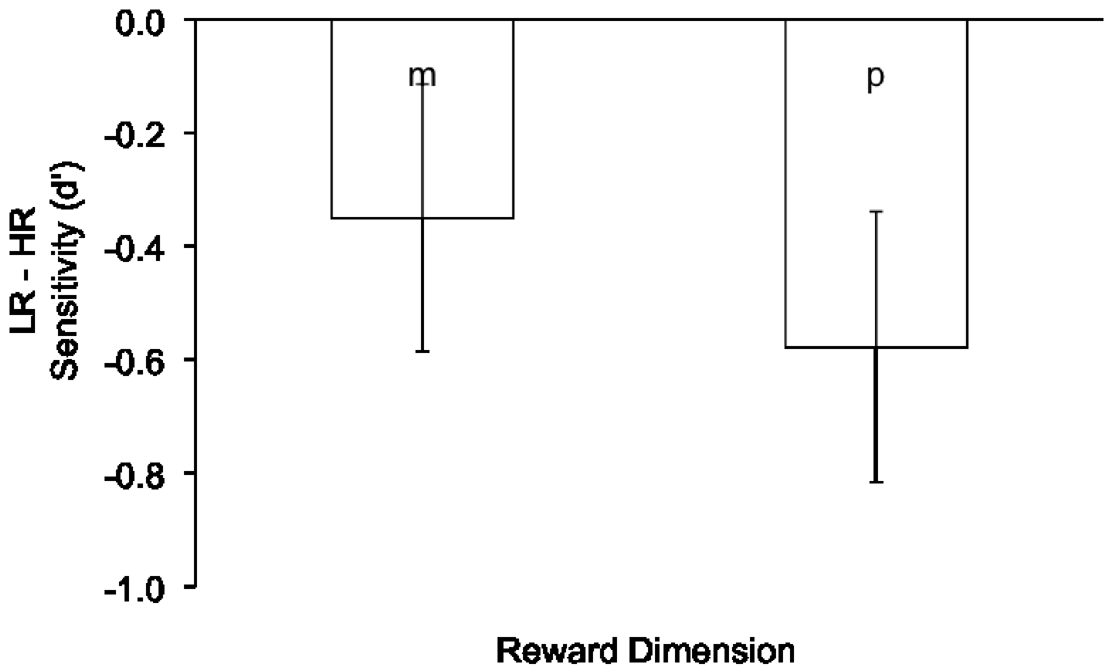

Figure 39. Mean difference (+*SE*) in sensitivity between **HR** and **LR** target in the **m** and **p** dimension, in Experiment 4, $p = 0.04$.

Discussion (Experiments 4A and 4B)

Summary of findings

Repeated Measures ANOVAs. The repeated measures ANOVAs conducted on the **m** dimension of reward (Experiment 4A) and **p** dimension of reward (Experiment 4B) led to a somewhat comparable pattern of findings, as expected. They were also similar to those in Experiment 3. However, findings in the current experiment were notably stronger in the **p** dimension than in the **m** dimension (rather than being stronger in the **m** dimension than in the **p** dimension, as in Experiment 3), also as expected. This discrepancy was anticipated due to the possibly larger difference in subjective reward value between the **LR** and **HR** targets in the **p** than in the **m** dimension in the current experiment (as opposed to the possibly larger difference in subjective reward value between the **LR** and **HR** targets in the **m** than in the **p** dimension in Experiment 3). Furthermore, as expected, findings for the response time measure were weaker than those for the accuracy, inverse efficiency and sensitivity measures (similar findings in Experiment 1 and Experiment 3). The specific findings from the current experiment relative to those in Experiment 3 are outlined below.

A statistically significant main effect of Target Reward Value (**LR** versus **HR**) was not obtained in either dimension (**m** or **p**) for the response time measure. However, the expected direction of findings was obtained: non-significantly longer response time for the **LR** than **HR** target in both dimensions. As evidenced by the lower *p*-values and higher effect sizes, the non-significant findings were stronger in the **p** than in the **m** dimension, also as expected. The same pattern of findings was obtained in

Experiment 3, apart from their statistical strength being reversed between the **m** and **p** dimensions in the current experiment, as expected.

As expected, a statistically significant main effect of Target Reward Value (**LR** versus **HR**) was obtained in the **p** dimension for the accuracy, inverse efficiency and sensitivity measures, indicating lower accuracy, worse inverse efficiency and lower sensitivity for the **LRp** than **HRp** target. However, although this main effect did not reach statistical significance in the **m** dimension for the accuracy, inverse efficiency and sensitivity measures, the same direction of findings was obtained. As evidenced by the lower *p*-values and higher effect sizes, the statistically significant findings and trends were stronger in the **p** than in the **m** dimension, as expected. The same pattern of findings was obtained in Experiment 3, apart from the statistical strength of findings being reversed between the **m** and **p** dimensions, as expected. Also different was that inverse efficiency reached statistical significance in Experiment 3 in both the **m** and **p** dimensions, whereas it only reached statistical significance in the current experiment in the **p** dimension. This discrepancy was not of major concern, however, because the difference in statistical strength of findings between the **m** and **p** dimensions nonetheless remained in the predictable direction in both Experiment 3 and in the current experiment (i.e., smaller *p*-value and larger effect size for the **m** than **p** dimension in Experiment 3 and smaller *p*-value and larger effect size for the **p** than **m** dimension in the current experiment).

As expected, a main effect of Display Duration (150ms versus 33.33ms) was obtained for all behavioural measures of performance in the **m** and **p** dimensions. In both reward dimensions, response time was significantly slower, accuracy was significantly lower, inverse efficiency was significantly worse and sensitivity was significantly lower for the 33.33ms than 150ms display duration. As evidenced by the lower *p*-values and/or higher effect sizes for most measures (apart from accuracy), the statistically significant findings were overall stronger in the **p** than in the **m** dimension. The same pattern of findings was obtained in Experiment 3, apart from the statistical strength of findings being reversed between the **m** and **p** dimensions, as expected.

A significant interaction between Target Reward Value (**LR** versus **HR**) and Display Duration (150ms versus 33.33ms) was not obtained in either dimension for the response time measure. However, the non-significant findings were in the expected direction: a larger effect of decreases in display duration on the **LR** than on the **HR** target in the **m** dimension (opposite but negligible in the **p** dimension). The same pattern of findings was obtained in Experiment 3.

In contrast, a significant interaction between Target Reward Value (**LR** versus **HR**) and Display Duration (150ms versus 33.33ms) was obtained in the **p** dimension for the accuracy, inverse efficiency and sensitivity measures, suggesting a larger effect of decreases in display duration on the **LRp** than on the **HRp** target. Although this interaction did not reach significance in the **m** dimension for the accuracy, inverse efficiency and sensitivity measures, the same direction of findings was obtained. As evidenced by the significant *p*-values and higher effect sizes in the **p** dimension and the non-significant trends and lower effect sizes in the **m** dimension, the findings were stronger in the **p** than in the **m** dimension. The same pattern of findings was obtained in Experiment 3, apart from the statistical strength of findings being reversed between the **m** and **p** dimensions, as expected.

Independent samples *t*-tests. A set of independent sample *t*-tests were conducted to shed light on the inconsistencies between the **m** and **p** dimensions of reward. More specifically, in the current experiment, the difference in subjective reward value between the **LR** and **HR** target in the **p** dimension was speculated to be larger than the difference in subjective reward value between the **LR** and **HR** target in the **m** dimension. As expected, these *t*-tests demonstrated that the mean difference between the **LRp** and **HRp** target was significantly larger than the mean difference between the **LRm** and **HRm** target for the accuracy, inverse efficiency and sensitivity measures. Although the findings for the response time measure did not reach statistical significance, they were in the same direction. The same pattern of findings was obtained in Experiment 3, apart from the statistical strength of findings being reversed between the **m** and **p** dimensions, as expected.

Conclusion

In summary, similarly to Experiment 3, the behavioural assessment conducted in the current experiment lends support to the theory that reward influences the visual perception (i.e, early) information processing stage along the "visual perception-overt behaviour" continuum. Furthermore, as did Experiment 3, the current experiment demonstrated that differences in visual perception between targets differing in reward value seem to be most obviously reflected by differences in accuracy, inverse efficiency and sensitivity between those targets.

Moreover, the data from the current experiment corroborate the conclusion drawn in Experiment 3, namely that the differences in statistical strength between the **m** an **p** dimensions of reward found in Experiment 3 were due to the larger difference in subjective reward value between the **LR** and **HR** targets in the **m** than in the **p** dimension. Preliminary evidence for this conclusion was provided in Experiment 2 and further evidence was obtained in the current experiment by reversing the size of the difference in subjective reward value between the two dimensions. Thus, the findings from Experiment 3 combined with those of the current experiment lend support to the conclusion that, not only is the reward value of visual targets and their consequent visual perception determined by the magnitude of reward associated with them, but also by the subjective value they represent for the observer.

General Discussion

Past research

In summary, it is widely agreed upon that a significant portion of human and non-human animal behaviour is goal-directed, and that goal-directed behaviours are mediated by their associated outcomes (Adams & Dickinson, 1981; Balleine & Dickinson, 1998; Colwill & Rescorla, 1985; de Wit, Kosaki, Balleine, & Dickinson, 2006). Consequently, it is not surprising that rewarding outcomes, such as money and consumables (e.g., food, drink), have reliably been shown to shape overt goal-directed behaviours. Such overt behaviours are reported to include explicit choices (e.g., Green & Myerson, 2004; Myerson & Green, 1995) body/limb movements (e.g., Opris et al., 2011) and eye movements (e.g. Milstein & Dorris, 2007).

Oftentimes, a reward may be acquired by performing a specific behaviour in response to a visual target. Under such circumstances, research has demonstrated that the reward covertly influences the late neural stages of information processing along the "visual-perception-overt behaviour" continuum. These stages include the motor processing immediately preceding the performance of the overt behaviour needed to acquire the reward associated with the perceived visual target.

Although not as well documented, research has also more recently implicated reward in covertly influencing even the earliest stage of information processing along the "visual-perception-overt behaviour" continuum, namely feature visual perception (e.g., Kiss et al., 2009; Kristjansson et al., 2010). However, performance in these studies is typically assessed using either a single overt behavioural measure (e.g., inverse efficiency in Kristjansson et al., 2010) or a combination of overt behavioural measures (e.g., response time accuracy and inverse efficiency in Kiss et al., 2009) following key-press responses by observers. Therefore, given the well-documented effects of reward on motor (i.e, late) processing, key-press data from these studies may not necessarily be reflecting the effects of reward on visual (i.e., early) processing, in whole or in part.

In summary, behavioural evidence suggesting that monetary rewards affect feature visual perception includes slower response time, lower accuracy and worse inverse efficiency for **LR** than **HR** targets. As determined by the current study, it is important to acknowledge that certain behavioural measures (e.g., inverse efficiency, accuracy and sensitivity) may be more likely to reflect the influence of reward on visual perception than are others (e.g., response time). Therefore, depending upon the measure(s) chosen in the given study, the conclusions drawn as to the effects of monetary reward on visual perception (as opposed to motor processing) may be more or less reliable. By the same token, the use of multiple behavioural measures as opposed to a single behavioural measure is obviously preferable.

The experiment conducted by Kiss et al. (2009) was the first to provide more compelling evidence of reward influences on feature visual perception. In this study, not only did the researchers acquire behavioural measures, as previously mentioned (i.e., response time, accuracy and inverse efficiency), but also EEG measures (i.e., N2pc and SPCN). Kiss et al. (2009) found that these ERP signatures varied as a function of reward. Most notably, the N2pc, reliably associated with attentional selection of visual targets for judgment and report (e.g., Eimer, 1996; Girelli & Luck, 1997; Woodman & Luck, 1999), appeared later and was of a lower amplitude for **LR** than **HR** targets. Therefore Kiss et al.

(2009) concluded that **LR** visual targets are attended-to later than are **HR** visual targets. In turn, given the independently documented effects of attention on feature visual perception, these results indirectly suggested that reward influences feature visual perception. Kiss et al. (2009) also found a significant positive correlation between the N2pc and inverse efficiency, suggesting that inverse efficiency is a behavioural measure that reflects the same (or part of the same) underlying process as the N2pc, namely visual perception.

Current study

One of the major aims of the current study was to provide a more thorough behavioural assessment than that offered by previous experiments of the differences in feature visual perception between **LR** and **HR** targets. More specifically, in order to either corroborate or challenge the conclusions drawn from previous research, display duration was manipulated between visual search task trials in the current experiment. The rationale behind this manipulation was that shortening the display duration of a visual search trial containing a **LR** target would lead to a greater deterioration of behavioural performance than shortening the display duration of a visual search trial containing a **HR** target if, in fact, **LR** targets are visually perceived later than are **HR** targets. Results from Experiment 3 of the current study were in line with these expectations and, thus, corroborated the conclusions drawn by previous researchers.

A related aim of the current study was to provide, for the first time, an assessment of the degree to which different behavioural measures may reflect visual (i.e., early) processing as opposed to motor (i.e., late) processing along the "visual perception-ovet behaviour" continuum. Prior to this study, only inverse efficiency had empirically been demonstrated to (at least partly) reflect visual processing, due to the positive correlation found between that behavioural measure of performance and the timing of the N2pc (Kiss et al., 2009). Therefore, in addition to the behavioural measures used by previous studies (i.e., response time, accuracy and inverse efficiency), a measure of sensitivity (d'), known to vary as a function of perceptual processing rather than motor processing, was added to the current study. Furthermore, correlation analyses were performed in Experiment 1 between all behavioural measures used in the current study in order to assess the nature of the relationship between them. Via a combination of the results obtained from each of the behavioural measures and the correlations between them, the strongest measures of differences in feature visual processing between **LR** and **HR** targets were determined to be inverse efficiency, accuracy and sensitivity. This finding is important in guiding the choice of behavioural measures in future experiments of this nature and in guiding the conclusions that are subsequently drawn in such experiments.

The third major aim of the current study was to expand our knowledge of reward influences on feature visual perception, not only in the magnitude (**m**) dimension of reward, but also in the probability (**p**) dimension of reward. In order to accomplish this, the visual search experiments in the current study were divided into two components. The same experimental protocols were employed in both the **m** and **p** components and the findings from each component were compared. The pattern of results obtained was similar for both dimensions of reward in the current study, suggesting that the influence of reward on feature visual perception was similar between them. Nonetheless, some subtle differences were observed.

In turn, these subtle differences between reward dimensions seemed noteworthy and led to the fourth, yet unexpected, aim of the current study. Namely, determining whether the extent of differences in subjective reward value between **LR** and **HR** targets affects feature visual perception. Given the apparently larger difference between **LR** and **HR** mean responses for the accuracy, inverse efficiency and sensitivity measures in the **m** than **p** dimension of reward found in Experiment 1, the difference in subjective reward value between the **LRm** and **HRm** targets was hypothesized to be larger than the difference in subjective reward value between the **LRp** and **HRp** targets. In Experiment 2, a simple discounting procedure was conducted, which confirmed this speculation. In light of this finding, the lower statistical strength of findings in the **m** dimension as compared to the **p** dimension obtained in Experiment 1 was surprising. However, following a series of comparisons of the range and variance between participant responses in each dimension, it was determined that it was simply a larger range and variance in the **m** than in the **p** dimension that led to this surprising discrepancy. In contrast, in Experiment 3, where display duration was manipulated, the range and variability between participant responses seemed to be similar in both reward dimensions, perhaps due to the greater task demands. Therefore, as expected, both the mean differences between **LRm** and **HRm** targets were larger than the mean differences between **LRp** and **HRp** targets, and the statistical findings were stronger in the **m** than in the **p** dimension.

In Experiment 4, the difference in subjective reward value between the **LR** and **HR** targets was decreased for the **m** dimension and increased for the **p** dimension, as compared to Experiment 3. As expected, the mean differences and strength of statistical findings were reversed between dimensions, confirming that the different size of subjective differences between **LR** and **HR** targets, rather than inherent differences between the **m** and **p** dimensions, were impacting behavioural measures of feature visual perception.

The reward-attention relationship

Attention and reward are two of the most studied factors affecting behaviour. However, they have largely been investigated independently. Attention has traditionally been studied in light of its effects on early stages of visual information processing, whereas reward has traditionally been studied in light of later stages of visual information processing along the “visual perception-overt behaviour” continuum.

More specifically, a substantial amount of research has investigated and found the neural correlates of attention in visual areas such as V4 (e.g., Ghose & Maunsell, 2008; McAdams & Maunsell, 1999; Reynolds, Chelazzi, & Desimone, 1999), V2 (e.g., Fang, Boyaci, & Kersten, 2009; Reynolds et al., 1999), V1 (Kamitani & Tong, 2006; Wörgötter et al., 1998) and as early as in the LGN (e.g., McAlonan, Cavanaugh, & Wurtz, 2008; McAlonan, Cavanaugh, & Wurtz, 2006). Conversely, research has predominantly investigated and found the neural correlates of reward on later stages of visual information processing, closer to mechanisms related to visual-motor transformations (e.g., Schultz, Tremblay, & Hollerman, 2000), decision-making (e.g., Glimcher & Rustichini, 2004; Hampton & O'doherty, 2007) and overt behavior (e.g., Behrens, Woolrich, Walton, & Rushworth, 2007).

More recent studies have, however, begun to suggest an effect of reward on early neural processing as well (e.g., Serences, 2008; Shuler & Bear, 2006). However, other research has suggested that reward may modulate perceptual performance, not directly, buy instead via the influence of reward on attention (e.g., Della Libera & Chelazzi, 2006; Kiss et al. 2009). Furthermore, it has been suggested that many of these experimental paradigms may confound the effects of reward with those of attention (e.g., Maunsell, 2004), seeing as the outcome of responding correctly in attention experiments is often a reward (extrinsic of intrinsic). Thus, it is important to note that the reward-attention relationship is subject to some debate.

Given that the N2pc is a known reflection of attentional processing, the EEG findings from the Kiss et al. (2009) study (i.e., later N2pc and, hence, later attentional selection for **LR** than **HR** targets), combined with the behavioural findings of the current study that confirmed the conclusions drawn in that study, lend some support to the hypothesis that reward acts via attention to affect early feature visual processing, at least in part. By the same token, however, these studies do not allow for the conclusion that, in addition to acting via attention, reward doesn't additionally act on early visual processing through more direct channels. This should be the subject of future research (and is re-examined in the following section).

Future directions

Other behavioural measures of visual (early) processing. In the current study, a number of behavioural measures were suggested to be reflective of reward influences on feature visual perception between targets differing in reward value, some to a greater and some to a lesser extent. Future research could expand on this repertoire of behavioural measures.

For instance, a digit retention task study conducted by Bijleveld et al. (2009) has suggested that reward value influences pupil dilation. More specifically, the researchers found that pupil dilation was greater in **HR** (0.31mm) than in **LR** (0.22mm) conditions in a 5-digit retention task. To date, a study investigating pupil dilation as a function of reward value has yet to be conducted within the context of the feature visual search task used in the current study. By comparing pupil dilation to the current study's behavioural measures and to the N2pc, within the same feature visual search experiment, conclusions can be drawn as to whether (and to what extent) pupil dilation reflects reward influences on feature visual perception in such a task.

Interestingly, Bijleveld et al. (2009) also found that both supraliminal and subliminal rewards affected pupil dilation in the same way. This finding suggests that conscious awareness may not be necessary for this process. In turn, this finding implies that, in addition to reward acting on early visual processing via attention, reward value may also act on early visual processing through an independent channel.

In addition, the current study could be repeated while simultaneously recording fixational eye-movements (i.e., microsaccades) and comparing them across **LR** and **HR** visual search trials. During periods of fixation between saccades, the eye is not entirely immobile. Involuntary eye movements smaller than voluntary saccades are produced. Microsaccades are the largest and fastest of the fixational eye movements (Martinez-Conde et al., 2009), occurring involuntarily once or twice per second (Rolfs, 2009). They have been demonstrated not only in humans but also in other vertebrate animals with a fovea. Microsaccades have been shown to be linked to several perceptual phenomena, which makes them an interesting area of study. Among other functions, research has demonstrated that microsaccades play a valuable role in maintaining target visibility via the prevention of visual fading caused by retinal fatigue when fixating on a stimulus for a prolonged period of time. They have also been shown to improve visual acuity beyond the spatial resolution allowable by photoreceptors in the stationary retina. Microsaccades are also correlated to the perception of illusory motion, perhaps accounting for its occurrence.

Another feature of microsaccades, which makes them an interesting area of study in the context of reward influences on the visual perception (i.e., early) stage of information processing along the "visual perception-overt behaviour" continuum, is that they share physiological and behavioural characteristics with saccades. The existence of these shared characteristics between eye movement types is important because they suggest a common oculomotor origin (Martinez-Conde et al., 2009). In turn, the existence of a shared oculomotor origin between saccades and microsaccades is important because saccades have repeatedly and reliably been linked to phenomena beyond the perceptual realm. Most importantly, saccadic eye movements have been shown to be related to cognitive constructs such as attention (Corbetta et al., 1998). Shared neural mechanisms between the two eye-movement types therefore suggest that attention may also play a key role in generating microsaccades. This postulation has also been corroborated by behavioural findings.

Thus, repeating the current study while simultaneously recording microsaccades and comparing them across **LR** and **HR** visual search trials would be worthwhile. Given their postulated connection to attention, microsaccades may provide a behavioural measure similar to that provided by the N2pc in the Kiss et al. (2009) study.

Moreover, if microsaccades are shown to be affected by reward in such a study, it would lend further support to the theory that the influence exerted by reward on feature visual perception is at least partially accomplished via attentional mediation.

Individual differences. A recent study (Hickey, Chelazzi & Theeuwes, 2010) demonstrated that reward priming in a shape (orientation) singleton visual search task was dependent upon the personality of the observer. More specifically, participants with reward-seeking personalities showed a greater reward priming effect than participants with non-reward-seeking personalities.

This effect of personality would also be interesting to assess in the context of colour singleton visual search (as used in the current study), to determine whether results from orientation feature visual search generalize to colour feature visual search. Furthermore, the display duration experiment form the current study could be repeated, this time by dividing participants into reward-seeking and non-reward seeking personality groups. By also adding EEG recordings to determine the timing of the N2pc, such an experiment would provide more information as to whether such personality traits modulate the reward influences observed in feature visual perception.

Conclusion

In closing, this study lends support to the claim that reward affects feature visual perception, in addition to motor processing along the “visual perception-overt behaviour” continuum. Furthermore, this study has determined that certain behavioural measures of performance may be better suited to reflect differences in visual perception between targets differing in reward value (i.e., accuracy, inverse efficiency and sensitivity/d’). Moreover, the difference in subjective reward value between **LR** and **HR** visual targets was shown to play a valuable role in our ability to detect reward-related effects on visual perception. Although this research cannot solve the debate regarding the existence or nature of the reward-attention relationship, it does lend support to the hypothesis that reward, at least partially, acts via attention to influence feature singleton visual perception.

References

Adams, C. D., Dickinson, A. (1981). Instrumental responding following reinforcer devaluation. *Quarterly Journal of Experimental Psychology B, 33*, 109-121.

Balleine, B. W., Dickinson, A. (1998). Goal-directed instrumental action: Contingency and incentive learning and their cortical substrates. *Neuropharmacology, 37*, 407-419.

Basso, M. A., Wurtz, R. H. (1998). Modulation of neuronal activity in superior colliculus by changes in target probability. *Journal of Neuroscience, 15*, 7519 -7534.

Behrens, T., Woolrich, M., Walton, M., & Rushworth, M. (2007). Learning the value of information in an uncertain world. *Nature Neuroscience, 10*, 1214-1221.

Bijleveld, E., Custers, R., & Aarts, H. (2009). The unconscious eye opener: Pupil dilation reveals strategic recruitment of resources upon presentation of subliminal reward cues. *Psychological Science (Short Report), 3*(2), 1-3.

Campos, M., Breznen, B., Bernheim, K., & Andersen, R. A. (2005). Supplementary motor area encodes reward expectancy in eye-movement tasks. *Journal of Neurophysiology, 94*, 1325-1335.

Cave, K. R., & Wolfe, J. M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology, 22*, 225-271.

Churchland, M. M., Santhanam, G., & Shenoy, K. V. (2006a). Preparatory activity in premotor and motor cortex reflects the speed of the upcoming reach. *Journal of Neurophysiology, 96*, 3130-3146.

Colwill, R. M., Rescorla, R. A. (1985). Postconditioning devaluation of a reinforcer affects instrumental responding. *Journal of Experimental Psychology: Animal Behavior Processes, 11*, 120-132.

Corbetta, M., Akbudak, E., Conturo, T. E., Snyder, A. Z., Ollinger, J. M., Drury, H. A., Linenweber, M. R., Petersen, S. E., Raichle, M. E., Van Essen, D. C., and Shulman, G. L. (1998). A common network of functional areas for attention and eye movements. *Neuron, 21*, 761-773.

Dell'Acqua, R., Sessa, P., Jolicœur, P., & Robitaille, N. (2006). Spatial attention freezes during the attentional blink. *Psychophysiology, 43*, 394-400.

Della Libera, C., & Chelazzi, L. (2006). Visual selective attention and the effects of monetary rewards. *Psychological Science, 17*, 222-227.

Dickinson, A., de Wit, S. (2003). The interaction between discriminative stimuli and outcomes during instrumental learning. *Quarterly Journal of Experimental Psychology B, 56*, 127-139.

Ding, L., & Hikosaka, O. (2006). Temporal development of asymmetric reward-induced bias in macaques. *Journal of Neurophysiology, 97*, 57-61.

Dorris, M. C., Munoz, D. P. (1998). Saccadic probability influences motor preparation signals and time to saccadic initiation. *Journal of Neuroscience, 18*, 7015-7026.

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology, 99*, 225-234.

Eimer, M., & Kiss, M. (2008). Involuntary attentional capture is determined by task set: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 20*, 1423-1433.

Epelboim, J., Steinman, R. M., Kowler, E., Pizlo, Z., Erkelens, C. J., & Collewijn, H. (1997). Gaze-shift dynamics in two kinds of sequential looking tasks. *Vision Research, 37*, 2597-2607.

Estle, S. J., Green, L., Myerson, J., & Holt, D. D. (2007). Discounting of monetary and directly consumable rewards. *Psychological Science, 18*(1), 58-63.

Fang, F., Boyaci, H., & Kersten, D. (2009). Border ownership selectivity in human early visual cortex and its modulation by attention. *Journal of Neuroscience, 29*, 460-465.

Fecteau, J. H., Munoz, D. P. (2006). Salience, relevance, and firing: A priority map for target selection. *Trends Cognitive Science, 10*, 382-390.

Found, A., & Müller, H. J. (1996). Searching for unknown feature targets on more than one dimension: Investigating a "dimension-weighting" account. *Perception & Psychophysics, 58*, 88-101.

Gardiner, T. W., and Nelson, R. J. (1992). Striatal neuronal activity during the initiation of hand movements made in response to visual and vibratory cues. *Experimental Brain Research, 92*, 15-26.

Ghose, G., & Maunsell, J. (2008). Spatial summation can explain the attentional modulation of neuronal responses to multiple stimuli in area V4. *Journal of Neuroscience, 28*, 5115-5126.

Girelli, M., & Luck, S. J. (1997). Are the same attentional mechanisms used to detect visual search targets defined by color, orientation, and motion? *Journal of Cognitive Neuroscience, 9*, 238-253.

Glimcher, P., & Rustichini, A. (2004). Neuroeconomics: The consilience of brain and decision. *Science, 306*, 447-452.

Green, D. M., & Swets J. A. (1966). *Signal Detection Theory and Psychophysics*. New York: Wiley.

Green, L., & Myerson, J. (2004). A discounting framework for choice with delayed and probabilistic rewards. *Psychological Bulletin,130(*5), 769-792.

Guitton, D., Volle, M. (1987). Gaze control in humans: Eye-head coordination during orienting movements to targets within and beyond the oculomotor range. *Journal of Neurophysiology, 58*, 427-459.

Hampton, A., & O'doherty, J. (2007). Decoding the neural substrates of reward-related decision making with functional MRI. *Proclamations of the National Academy of Sciences: USA, 104*, 1377-1382.

Hayden, B. Y., Nair, A., McCoy, A. N., & Platt, M. L. (2008). Posterior cingulate cortex mediates outcome-contingent allocation of behavior. *Neuron, 60*, 19-25.

Hickey, C., Chelazzi, L. & Theeuwes, J. (2010). Reward guides vision when it's your thing: Trait reward-seeking in reward-mediated visual priming. *PLoS ONE, 5*(11), e14087.

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience, 18*, 604-613.

Hikosaka, O., Wurtz, R. H. (1983). Visual and oculomotor functions of monkey substantia nigra pars reticulata III. Memory-contingent visual and saccade responses. *Journal of Neurophysiology, 49*, 1268-1284.

Hopf, J. M., Luck, S. J., Girelli, M., Hagner, T., Mangun, G. R., & Scheich, H. (2000). Neural sources of focused attention in visual search. *Cerebral Cortex, 10*, 1233-1241.

Ivry, R. B., & Cohen, A. (1990). Discrimination of short and long range apparent motion in visual search. *Journal of Experimental Psychology: Human Perception & Performance, 16*, 317-331.

Julesz, B. (1984). A brief outline of the texton theory of human vision. *Trends in Neurosciences, 7*, 41-45.

Kamitani, Y., & Tong, F. (2006). Decoding seen and attended motion directions from activity in the human visual cortex. *Current Biology, 16*, 1096-1102.

Kawagoe, R., Takikawa, Y., & Hikosaka, O. (1998). Expectation of reward modulates cognitive signals in the basal ganglia. *Nature Neuroscience, 1*, 411-416.

Kiss, M., Driver, J., & Eimer, M. (2009). Reward priority of visual target singletons modulates ERP signatures of attentional selection. *Psychological Sci*ence*, 20*(2), 245-251.

Kristjansson, A. (2006). Rapid learning in attention shifts: A review. *Visual Cognition, 13*, 324-362.

Kristjansson, A., & Campana, G. (2010). Where perception meets memory: A review of repetition priming in visual search tasks. *Attention, Perception, & Psychophysics, 72*, 5-18.

Kristjansson, A., Sigurjonsdottir, O., & Driver, J. (2010). Fortune and reversals of fortune in visual search: Reward contingencies for pop-out targets affect search efficiency and target repetition effects. *Attention, Perception, & Psychophysics, 72*(5), 1229-1236.

Lauwereyns, J., Watanabe, K., Coe, B., & Hikosaka, O. (2002). A neural correlate of response bias in monkey caudate nucleus. *Nature, 418*, 413-417.

Lee, H., & Assad, J. (2003). Putaminal activity for simple reactions or self- timed movements. *Journal of Neurophysiology, 89*, 2528-2537.

Leon, M. I., & Shadlen, M. N. (1999). Effect of expected reward magnitude on the response of neurons in the dorsolateral prefrontal cortex of the macaque. *Neuron, 24*, 290-291.

Martinez-Conde, S., Macknik, S. L., Troncoso, X. G., and Hubel, D. H. (2009). Microsaccades: A neurophysiological analysis. *Trends in Neurosciences,32*(9), 463-475.

Maunsell, J. H. (2004). Neuronal representations of cognitive state: Reward or attention? *Trends in Cognitive Science, 8*, 261-265.

Mazza, V., Turatto, M., Umilta, C., & Eimer, M. (2007). Attentional selection and identification of visual objects are reflected by distinct electrophysiological responses. *Experimental Brain Research, 181*, 531-536.

McAdams, C., & Maunsell, J. (1999). Effects of attention on orientation-tuning functions of single neurons in macaque cortical area V4. *Journal of Neuroscience*, *19*, 431-441.

McAlonan, K., Cavanaugh, J., & Wurtz, R. H. (2008). Guarding the gateway to cortex with attention in visual thalamus. *Nature, 456*, 391-394.

McAlonan, K., Cavanaugh, J., & Wurtz, R. H. (2006). Attentional modulation of thalamic reticular neurons. *Journal of Neuroscience, 26*, 4444-4450.

McCollough, A. W., Machizawa, M. G., & Vogel, E. K. (2007). Electrophysiological measures of maintaining representations in visual working memory. *Cortex, 43*, 77-90.

Milstein, D. M., & Dorris, M. C. (2007). The influence of expected value on saccadic preparation. *The Journal of Neuroscience, 27*(18), 4810-4818.

Müller, H. J., Heller, D., & Ziegler, J. (1995). Visual search for singleton targets within and across feature dimensions. *Perception & Psychophysics, 57*, 1-17.

Müller, H. J., & Krummenacher, J. (2006). Visual search and selective attention. *Visual Cognition, 14*, 389-410.

Müller, H. J., Reimann, B., & Krummenacher, J. (2003). Visual search for singleton feature targets across dimensions: Stimulus and expectancy driven effects in dimensional weighting. *Journal of Experimental Psychology: Human Perception and Performance, 29*(5), 1021-1035.

Myerson, J., & Green, L. (1995). Discounting of delayed rewards: Models of individual choice. *Journal of the Experimental Analysis of Behavior, 64,* 263-276.

Opris, I., Lebedev, M., & Nelson, R. J. (2011). Motor planning under unpredictable reward: Modulations of movement vigor and primate striatum activity. *Frontiers in Neuroscience: Decision Neuroscience, 5*(61), 1-12.

Platt, M. L., & Glimcher, P. W. (1999). Neural correlates of decision variables in parietal cortex. *Nature, 400*, 233-238.

Reynolds, J., Chelazzi, L. & Desimone, R. (1999). Competitive mechanisms subserve attention in macaque areas V2 and V4. *Journal of Neuroscience, 19*, 1736-1753.

Rolfs, M. (2009). Microsaccades: Small steps on a long way. *Vision Research* (2009), doi: 10.1016/j.visres.2009.08.010.

Romo, R., Scarnati, E., and Schultz, W. (1992). Role of primate basal ganglia and frontal cortex in the internal generation of movements. *Experimental Brain Research, 91*, 385–395.

Schall, J. D. (2004). On building a bridge between brain and behavior. *Annual Review of Psychology, 55*, 23-50.

Schubo, A., Schroger, E., Meinecke, C., & Müller, H. J. (2007). Attentional resources and popout detection in search displays. *Neuro Report, 18*,1589-1593.

Schultz, W., Tremblay, L. & Hollerman, J. (2000). Reward processing in primate orbitofrontal cortex and basal ganglia. *Cerebral Cortex, 10*, 272-284.

Serences, J. T. (2008). Value-based modulations in human visual cortex. *Neuron, 60*, 1169-1181.

Shadmehr, R., de Xivry, J. J. O., Xu-Wilson, M., & Shih, T-Y. (2010). Temporal discounting of reward and the cost of time in motor control. *The Journal of Neuroscience, 30*(31):10507-10516.

Shadmehr, R. (2010). Control of movements and temporal discounting of reward. *Current Opinion in Neurobiology, 20*, 726–730.

Shuler, M., & Bear, M. (2006). Reward timing in the primary visual cortex. *Science, 311*, 1606-1609.

Somers, D. C., Dale, A. M., Seiffert, A. E., & Tootell, R. B. H. (1999). Functional MRI reveals spatially specific attentional modulation in human primary visual cortex. *Proclamations of the National Academy of Sciences: USA, 96*, 1663-1668.

Sparks, D. L. (1999). Conceptual issues related to the role of the superior colliculus in the control of gaze. *Current Opinion in Neurobiology, 9*, 698-707.

Sugrue, L. P., Corrado, G. S., and Newsome, W. T. (2004). Matching behavior and the representation of value in the parietal cortex. *Science, 304*, 1782–1787.

Takikawa, Y., Kawagoe, R., Nakahara, H. I. H., & Hikosaka, O. (2002). Modulation of saccadic eye movements by predicted reward outcome. *Experimental Brain Research, 142*, 284-291.

Takikawa, Y., Kawagoe, R., Itoh, H., Nakahara, H., & Hikosaka, O. (2002). Modulation of saccadic eye movements by predicted reward outcome. *Experimental Brain Research, 142*, 284-291.

Theeuwes, J. (1994). Bottom-up capture and attentional set: Selective search for colour and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 799-806.

Theeuwes, J. (1992). Perceptual selectivity for colour and form. *Perception & Psychophysics, 51*, 599-606.

Thompson, K. G., Bichot, N. P. (2005). A visual salience map in the primate frontal eye field. *Progress in Brain Research, 147*, 251-262.

Treisman, A. (1988). Features and Objects: The fourteenth Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology, 40A*, 201-237.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97-136.

Trick, L. M., & Enns, J. T. (1998). Life-span changes in attention: The visual search task. *Cognitive Development, 13*(3), 369-386.

Tsujimoto, S., Genovesio, A., & Wise, S. P. (2010). Evaluating self-generated decisions in frontal pole cortex of monkeys. *Nature Neuroscience, 13*, 120-126.

Turner, R. S., & Anderson, M. E. (1997). Pallidal discharge related to the kinematics of reaching movements in two dimensions. *Journal of Neurophysiology, 77*, 1051-1074.

Turner, R. S., & Desmurget, M. (2010). Basal ganglia contributions to motor control: A vigorous tutor. *Current Opinion in Neurobiology, 20*, 704-716.

Vogel, E. K., & Machizawa, M. G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature, 428*, 784-751.

Vuillermier, P., & Driver, J. (2007). Modulation of visual processing by attention and emotion: Windows on causal interactions between human brain regions. *Philosophical Transactions of the Royal Society B, 362*, 837–855.

Wang, Q., Cavanagh, P., & Green, M. (1994). Familiarity and pop-out in visual search. *Perception & Psychophysics, 56*, 495-500.

Wang, D., Kristjansson, A., & Nakayama, K. (2005). Efficient visual search without top-down or bottom-up guidance. *Perception & Psychophysics, 67*, 239-253.

de Wit, S., Kosaki, Y., Balleine, B. W., & Dickinson, A. (2006). Dorsomedial prefrontal cortex resolves response conflict in rats. *The Journal of Neuroscience, 26*(19), 5224-5229.

Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review, 1*(2), 202-238.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception & Performance, 15*, 419-433.

Wolfe, J., & Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nature Reviews Neuroscience, 5*, 1-7.

Woodman, G. F., & Luck, S. J. (1999). Electrophysiological measurement of rapid shifts of attention during visual search. *Nature, 400*, 867-869.

Wörgötter, F., Suder, K., Yongqiang, Z., Kerscher, N., Eysel, U. T., & Funke, K. (1998). State-dependent receptive-field restructuring in the visual cortex. *Nature, 396*, 165-168.

Appendix A

Consent Forms

(All Experiments)

Consent form used in Experiment 1 (Magnitude component):
Red target = HRm; Green target = LRm

UNIVERSITÉ Concordia UNIVERSITY

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess visual search performance under different conditions.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.

- I will perform a visual search for a target stimulus in a series of computer-generated displays, for approximately 90 minutes. The target stimulus on each trial will randomly be either a red or a green diamond among grey distractor diamonds. There is an equal likelihood that the red or green target will appear on each trial. My task on each trial is to report whether the notch on the target is on the top or bottom, as accurately and as quickly as possible, using the pre-assigned keys.

- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the space bar on the computer keyboard.

- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.

- At the end of the experiment, I will receive 2 course credits simply for participating. In addition, one of the trials will be randomly selected and, if I responded accurately and before the beep on that trial, I will receive a monetary bonus: $10 for a red-target trial or $1 for a green-target trial.

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential

- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ____

SIGNATURE: ____

EXPERIMENTER'S SIGNATURE: ____________________________________

DATE: ____

Consent form used in Experiment 1 (Magnitude component):
Green target = HRm; Red target = LRm

UNIVERSITÉ Concordia UNIVERSITY

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess visual search performance under different conditions.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.

- I will perform a visual search for a target stimulus in a series of computer-generated displays, for approximately 90 minutes. The target stimulus on each trial will randomly be either a red or a green diamond among grey distractor diamonds. There is an equal likelihood that the red or green target will appear on each trial. My task on each trial is to report whether the notch on the target is on the top or bottom, as accurately and as quickly as possible, using the pre-assigned keys.

- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the space bar on the computer keyboard.
- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.
- At the end of the experiment, I will receive 2 course credits simply for participating. In addition, one of the trials will be randomly selected and, if I responded accurately and before the beep on that trial, I will receive a monetary bonus: $10 for a green-target trial or $1 for a red-target trial.

C. Conditions of Participation

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.
- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.
- The data collected from this study may be published.
- My participation in this study will be kept confidential
- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.
- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ____

SIGNATURE: ____

EXPERIMENTER'S SIGNATURE: ________________________________

DATE: ____

Consent form used in Experiment 1 (Probability component):
Red target = HRp; Green target = LRp

UNIVERSITÉ Concordia UNIVERSITY

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess visual search performance under different conditions.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.

- I will perform a visual search for a target stimulus in a series of computer-generated displays, for approximately 90 minutes. The target stimulus on each trial will randomly be either a red or a green diamond among grey distractor diamonds. There is an equal likelihood that the red or green target will appear on each trial. My task on each trial is to report whether the notch on the target is on the top or bottom, as accurately and as quickly as possible, using the pre-assigned keys.

- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the space bar on the computer keyboard.

- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.

- At the end of the experiment, I will receive 2 course credits simply for participating. In addition, one of the trials will be randomly selected and, if I responded accurately and before the beep on that trial, I will receive a monetary bonus: $10 for sure for a red-target trial or $10 with a 10% chance for a green-target trial.

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential

- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ____

SIGNATURE: ____

EXPERIMENTER'S SIGNATURE: ________________________________

DATE: ____

Consent form used in Experiment 1 (Probability component):
Green target = HRp; Red target = LRp

UNIVERSITÉ Concordia UNIVERSITY

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess visual search performance under different conditions.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.
- I will perform a visual search for a target stimulus in a series of computer-generated displays, for approximately 90 minutes. The target stimulus on each trial will randomly be either a red or a green diamond among grey distractor diamonds. There is an equal likelihood that the red or green target will appear on each trial. My task on each trial is to report whether the notch on the target is on the top or bottom, as accurately and as quickly as possible, using the pre-assigned keys.

- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the space bar on the computer keyboard.

- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.

- At the end of the experiment, I will receive 2 course credits simply for participating. In addition, one of the trials will be randomly selected and, if I responded accurately and before the beep on that trial, I will receive a monetary bonus: $10 for sure for a green-target trial or $10 with a 10% chance for a red-target trial.

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential

- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ______________________________________

SIGNATURE: ______________________________________

EXPERIMENTER'S SIGNATURE: ______________________________

DATE: ______________________________________

Consent form used in Experiment 2 and Experiment 4B (discounting task component)

UNIVERSITÉ Concordia UNIVERSITY

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess some properties of decision-making with monetary rewards.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will complete a brief questionnaire in the presence and under the instruction of the experimenter.
- The questionnaire will be composed of a series of questions containing choices between 2 monetary amounts. My task is to circle the monetary amount that I prefer on each question the experiment asks me to read silently.
- At the end of the experiment, one of the questions I responded to will be randomly selected. I will then receive the associated certain reward or have a 10% chance of receiving the associated probabilistic reward (depending on the choice I made on that question).

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential

- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ____

SIGNATURE: ____

EXPERIMENTER'S SIGNATURE: ____________________________________

DATE: ____

Consent form used in Experiments 3A and 4A (Magnitude):
Red target = HRm; Green target = LRm

UNIVERSITÉ Concordia UNIVERSITY

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess visual search performance under different conditions.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.

- I will perform a visual search for a target stimulus in a series of computer-generated displays, for approximately 90 minutes. The presentation duration of the display will vary randomly from trial to trial. The target stimulus on each trial will randomly be either a red or a green diamond among grey distractor diamonds. There is an equal likelihood that the red or green target will appear on each trial. My task on each trial is to report whether the notch on the target is on the top or bottom, as accurately and as quickly as possible, using the pre-assigned keys.

- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the space bar on the computer keyboard.

- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.

- At the end of the experiment, I will receive 2 course credits simply for participating. In addition, one of the trials will be randomly selected and, if I responded accurately and before the beep on that trial, I will receive a monetary bonus: $10 for a red-target trial or $1 for a green-target trial.

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential

- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ____

SIGNATURE: ____

EXPERIMENTER'S SIGNATURE: ________________________________

DATE: ____

Consent form used in Experiments 3A and 4A (Magnitude):
Green target = HRm; Red target = LRm

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess visual search performance under different conditions.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.
- I will perform a visual search for a target stimulus in a series of computer-generated displays, for approximately 90 minutes. The presentation duration of the display will vary randomly from trial to trial. The target stimulus on each trial will randomly be either a red or a green diamond among grey distractor diamonds. There is an equal likelihood that the red or green target will appear on each trial. My task on each trial is to report whether the notch on the target is on the top or bottom, as accurately and as quickly as possible, using the pre-assigned keys.

- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the space bar on the computer keyboard.

- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.

- At the end of the experiment, I will receive 2 course credits simply for participating. In addition, one of the trials will be randomly selected and, if I responded accurately and before the beep on that trial, I will receive a monetary bonus: $10 for a green-target trial or $1 for a red-target trial.

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential

- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ____

SIGNATURE: ____

EXPERIMENTER'S SIGNATURE: ________________________________

DATE: ____

Consent form used in Experiments 3B and 4B (Probability):
Red target = HRp; Green target = LRp

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess visual search performance under different conditions.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.

- I will perform a visual search for a target stimulus in a series of computer-generated displays, for approximately 90 minutes. The presentation duration of the display will vary randomly from trial to trial. The target stimulus on each trial will randomly be either a red or a green diamond among grey distractor diamonds. There is an equal likelihood that the red or green target will appear on each trial. My task on each trial is to report whether the notch on the target is on the top or bottom, as accurately and as quickly as possible, using the pre-assigned keys.

- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the space bar on the computer keyboard.

- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.

- At the end of the experiment, I will receive 2 course credits simply for participating. In addition, one of the trials will be randomly selected and, if I responded accurately and before the beep on that trial, I will receive a monetary bonus: $10 for sure for a red-target trial or $10 with a 10% chance for a green-target trial.

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential

- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ____

SIGNATURE: ____

EXPERIMENTER'S SIGNATURE: ________________________________

DATE: ____

Consent form used in Experiments 3B and 4B (Probability):
Green target = HRp; Red target = LRp

Concordia Vision Laboratory

CONSENT FORM
FOR PARTICIPATION IN PSYCHOPHYSICAL RESEARCH

I hereby state my agreement to participate in a Ph.D. thesis study being conducted by Angela Vavassis, under the supervision of Dr. Michael von Grünau, in the Concordia Vision Laboratory (Department of Psychology, Concordia University).

A. PURPOSE

I have been informed that the purpose of this study is to assess visual search performance under different conditions.

B. PROCEDURES

I have been made aware of the following methodological proceedings:

- I will be seated alone in front of a computer monitor in a dimly lit room.
- I will perform a visual search for a target stimulus in a series of computer-generated displays, for approximately 90 minutes. The presentation duration of the display will vary randomly from trial to trial. The target stimulus on each trial will randomly be either a red or a green diamond among grey distractor diamonds. There is an equal likelihood that the red or green target will appear on each trial. My task on each trial is to report whether the notch on the target is on the top or bottom, as accurately and as quickly as possible, using the pre-assigned keys.

- In order to prevent eyestrain, I will be initiating all trials at my own pace by pressing the space bar on the computer keyboard.

- My head will be held in a stable position by a chin rest, but I will be able to move my head freely at any time between trials in the event that I experience any postural discomfort.

- At the end of the experiment, I will receive 2 course credits simply for participating. In addition, one of the trials will be randomly selected and, if I responded accurately and before the beep on that trial, I will receive a monetary bonus: $10 for sure for a green-target trial or $10 with a 10% chance for a red-target trial.

C. CONDITIONS OF PARTICIPATION

I understand the following:

- My participation is purely voluntary and I can decline to participate without negative consequences.

- I can withdraw my consent and discontinue my participation at any time during testing without negative consequences.

- The data collected from this study may be published.

- My participation in this study will be kept confidential

- There is no hidden motive of which I have not been informed. I will be debriefed as to the research question and expected results after completing the experiment.

- If I have any additional questions regarding my rights as a participant, I can contact the Psychology Department's Human Ethics Committee at 848-2424 x 2202.

I HAVE CAREFULLY READ AND UNDERSTOOD ALL OF THE ABOVE AND I FREELY CONSENT TO PARTICIPATE IN THIS RESEARCH.

NAME (please print): ______________________________________

SIGNATURE: ______________________________________

EXPERIMENTER'S SIGNATURE: ______________________________

DATE: ______________________________________

Appendix B

Source Tables

(All Experiments)

Table B1

Paired Samples t-tests for the Magnitude Dimension of Reward in Experiment 1

	Target Reward Magnitude				
	LRm	HRm	*t*	*df*	*p*
	(*n* = 8)				
Response Time	0.630 (0.030)	0.627 (0.030)	0.509	7	0.626
Accuracy	92.5 (2.7)	97.3 (1.1)	2.190	7	0.065
Inverse Efficiency	0.661 (0.042)	0.643 (0.035)	1.408	7	0.202
Sensitivity (d')	2.812 (0.258)	3.212 (0.223)	2.309*	7	0.054

Note. Standard Errors appear in parentheses below means.

* $p < .05$

Table B2

Paired Samples t-tests for the Probability Dimension of Reward in Experiment 1

	Target Reward Probability				
	LRp	HRp	*t*	*df*	*p*
	(*n* = 8)				
Response Time	0.627 (0.016)	0.622 (0.016)	0.791	7	0.455
Accuracy	96.5 (1.3)	97.5 (1.3)	2.506*	7	0.041
Inverse Efficiency	0.650 (0.016)	0.638 (0.015)	1.448	7	0.191
Sensitivity (d')	2.882 (0.154)	3.154 (0.148)	3.761**	7	0.007

Note. Standard Errors appear in parentheses below means.

*p < .05. **p < .01.

Table B3

One-way ANOVAs for non-significant differences between blocks in Experiment 1

Measure	*F*	*df*	*p*	η^2
		Magnitude Dimension		
Response Time	0.399 (0.003)	3 21	0.755	0.054
Inverse Efficiency	2.099 (0.004)	3 21	0.131	0.231
		Probability Dimension		
Response Time	0.257 (0.003)	3 21	0.855	0.035
Inverse Efficiency	2.560 (0.003)	3 21	0.082	0.268

Note. Standard Errors appear in parentheses below means.

Table B4

Independent Samples t-tests in Experiment 1: Mean Differences Between the Low-Reward (LR) and High-Reward (HR) Targets in the Magnitude (m) and Probability (p) Dimensions of Reward

	m	p	*t*	*df*	*p*
		(*n* = 8)			
Response Time	0.003 (0.005)	0.005 (0.007)	-0.512	7	0.624
Accuracy	-4.8 (2.2)	-1.0 (0.4)	-1.719	7	0.129
Inverse Efficiency	0.018 (0.013)	0.012 (0.008)	0.648	7	0.538
Sensitivity (d')	-0.400 (0.173)	-0.272 (0.072)	-0.831	7	0.433

Note. Standard Errors appear in parentheses below means.

Table B5

Range and Variance scores in Experiment 1

	Magnitude Dimension		Probability Dimension	
	LRm	HRm	LRp	HRp
		Response time		
Range	0.255	0.270	0.141	0.128
Variance	0.008	0.007	0.002	0.002
		Accuracy		
Range	16.8	10.1	11.3	11.6
Variance	0.6	0.1	0.1	0.1
		Inverse Efficiency		
Range	0.314	0.282	0.156	0.136
Variance	0.014	0.010	0.002	0.002
		Sensitivity (d’)		
Range	2.407	1.936	1.254	1.433
Variance	0.533	0.400	0.191	0.176

Table B6

Pearson Product-Moment Correlations Between Behavioural Measures of Performance for the Magnitude Dimension of Reward in Experiment 1

Measure	1	2	3	4
		(n = 8)		
1. Response Time	___	-0.019	0 .943**	-0.494
2. Accuracy		___	-0.244	0.712**
3. Inverse Efficiency			___	-0.719**
4. Sensitivity (d')				___

** $p < 0.01$.

Table B7

Pearson Product-Moment Correlations Between Behavioural Measures of Performance for the Probability Dimension of Reward in Experiment 1

Measure	1	2	3	4
		(n = 8)		
1. Response Time	___	0.297	0.855**	-0.060
2. Accuracy		___	-0.241	0.878**
3. Inverse Efficiency			___	-0.538*
4. Sensitivity (d')				___

* $p < 0.05$. ** $p < 0.01$.

Table B8

One-Way Analysis of Variance in Experiment 2

Source	df	*F*	*p*
	Between Subjects		
Target	2	3171.712***	0.000
	45	(0.102)	

Note. Values enclosed in parentheses represent mean square errors.

***$p < 0.001$.

Table B9

Bonferroni Pairwise Comparisons in Experiment 2

Comparison	Mean Difference$^{(i-j)}$	*p*
LRm^{i} *versus* LRp^{j}	-4.09*** (0.113)	0.000
LRm^{i} *versus* HRm/HRp^{j}	-9.00*** (0.113)	0.000
LRp^{i} *versus* HRm/HRp^{j}	-4.91*** (0.113)	0.000

Note. Standard Errors appear in parentheses below means.

*** $p < 0.001$

Table B10

Repeated Measures Analysis of Variance for Response Time in Experiment 3A

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Magnitude	1	5.123	0.423	0.058
Error	7	(0.000)		
Display Duration	1	14.619**	0.676	0.007
Error	7	(0.001)		
Reward Magnitude x Display Duration	1	0.001	0.000	0.973
Error	7	(0.001)		

Note. Mean Square Errors appear in parentheses below means.

**$p < 0.01$.

Table B11

Repeated Measures Analysis of Variance for Accuracy in Experiment 3A

Source	df	*F*	η^2	*p*
		Within Subjects		
Reward Magnitude	1	11.092*	0.613	0.013
Error	7	(0.003)		
Display Duration	1	64.582**	0.902	0.000
Error	7	(0.004)		
Reward Magnitude x Display Duration	1	8.052*	0.535	0.025
Error	7	(0.003)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$. **$p < 0.01$.

Table B12

Bonferroni Pairwise Comparisons for Accuracy on the Significant Target Reward Magnitude x Display Duration Interaction in Experiment 3A

	Target Reward Magnitude			
	LRm		HRm	
Comparison	Mean Difference$^{(i-j)}$	*p*	Mean Difference$^{(i-j)}$	*p*
0.150s^{i} *versus* 0.035s^{j}	22.5** (3.0)	0.000	9.6* (3.0)	0.016

Note. Standard Errors appear in parentheses below means.

*p < 0.05. **p < 0.01.

Table B13

Repeated Measures Analysis of Variance for Inverse Efficiency in Experiment 3A

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Magnitude	1	13.970**	0.666	0.007
Error	7	(0.003)		
Display Duration	1	59.023**	0.894	0.000
Error	7	(0.003)		
Reward Magnitude x Display Duration	1	5.417*	0.436	0.053
Error	7	(0.004)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$. **$p < 0.01$.

Table B14

Bonferroni Pairwise Comparisons for Inverse Efficiency on the Significant Target Reward Magnitude x Display Duration Interaction in Experiment 3A

	Target Reward Magnitude			
	LRm		HRm	
Comparison	Mean Difference$^{(i-j)}$	*p*	Mean Difference$^{(i-j)}$	*p*
0.150s^{i} *versus* 0.035s^{j}	-0.205** (0.034)	0.001	-0.107** (0.024)	0.003

Note. Standard Errors appear in parentheses below means.

**p < 0.01.

Table B15

Repeated Measures Analysis of Variance for Sensitivity in Experiment 3A

Source	df	*F*	η^2	*p*
		Within Subjects		
Reward Magnitude	1	5.424*	0.437	0.053
Error	7	(0.471)		
Display Duration	1	8.836*	0.558	0.021
Error	7	(0.687)		
Reward Magnitude x Display Duration	1	8.732*	0.555	0.021
Error	7	(0.013)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$.

Table B16

Bonferroni Pairwise Comparisons for Sensitivity on the Significant Target Reward Magnitude x Display Duration Interaction in Experiment 3A

	Target Reward Magnitude			
	LRm		HRm	
Comparison	Mean Difference(i-j)	*p*	Mean Difference(i-j)	*p*
0.150s[i] *versus* 0.035s[j]	0.992** (0.291)	0.011	0.750* (0.301)	0.041

Note. Standard Errors appear in parentheses below means.

*p < 0.05. **p < 0.01.

Table B17

Repeated Measures Analysis of Variance for Response Time in Experiment 3B

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Probability	1	2.620	0.272	0.150
Error	7	(0.000)		
Display Duration	1	10.377*	0.597	0.015
Error	7	(0.001)		
Reward Probability x Display Duration	1	0.065	0.009	0.806
Error	7	(0.001)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$.

Table B18

Repeated Measures Analysis of Variance for Accuracy in Experiment 3B

Source	df	*F*	η^2	*p*
	Within Subjects			
Reward Probability	1	4.125	0.371	0.082
Error	7	(0.004)		
Display Duration	1	82.867**	0.922	0.000
Error	7	(0.002)		
Reward Probability x Display Duration	1	3.736	0.348	0.095
Error	7	(0.004)		

Note. Mean Square Errors appear in parentheses below means.

**p < 0.01.

Table B19

Repeated Measures Analysis of Variance for Inverse Efficiency in Experiment 3B

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Probability	1	9.926*	0.586	0.016
Error	7	(0.003)		
Display Duration	1	40.459**	0.853	0.000
Error	7	(0.003)		
Reward Probability x Display Duration	1	3.105	0.307	0.121
Error	7	(0.004)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$. **$p < 0.01$.

Table B20

Repeated Measures Analysis of Variance for Sensitivity in Experiment 3B

Source	df	*F*	η^2	*p*
		Within Subjects		
Reward Probability	1	2.316	0.249	0.172
Error	7	(0.438)		
Display Duration	1	6.725*	0.490	0.036
Error	7	(0.638)		
Reward Probability x Display Duration	1	0.023	0.003	0.884
Error	7	(0.054)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$.

Table B21

Independent Samples t-tests in Experiment 3

	Reward Dimension				
	m	p	*t*	*df*	*p*
	(*n* = 8)				
Response Time	0.017 (0.007)	0.012 (0.008)	0.579	14	0.581
Accuracy	-6.4 (1.9)	-4.4 (2.2)	-3.433*	14	0.011
Inverse Efficiency	0.068 (0.018)	0.049 (0.015)	2.673*	14	0.032
Sensitivity (d’)	-0.565 (0.243)	-0.356 (0.234)	-2.294*	14	0.056

Note. Standard Errors appear in parentheses below means.

*$p < 0.05$.

Table B22

Repeated Measures Analysis of Variance for Response Time in Experiment 4A

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Magnitude	1	2.628	0.273	0.149
Error	7	(0.000)		
Display Duration	1	7.682*	0.523	0.028
Error	7	(0.002)		
Reward Magnitude x Display Duration	1	0.028	0.004	0.873
Error	7	(0.001)		

Note. Mean Square Errors appear in parentheses below means.

**$p < 0.05$.

Table B23

Repeated Measures Analysis of Variance for Accuracy in Experiment 4A

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Magnitude	1	1.656	0.191	0.239
Error	7	(0.004)		
Display Duration	1	159.609**	0.958	0.000
Error	7	(0.002)		
Reward Magnitude x Display Duration	1	2.655	0.275	0.147
Error	7	(0.004)		

Note. Mean Square Errors appear in parentheses below means.

**$p < 0.01$.

Table B24

Repeated Measures Analysis of Variance for Inverse Efficiency in Experiment 4A

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Magnitude	1	5.029	0.418	0.060
Error	7	(0.003)		
Display Duration	1	48.181**	0.873	0.000
Error	7	(0.004)		
Reward Magnitude x Display Duration	1	2.246	0.243	0.178
Error	7	(0.003)		

Note. Mean Square Errors appear in parentheses below means.

**$p < 0.01$.

Table B25

Repeated Measures Analysis of Variance for Sensitivity in Experiment 4A

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Magnitude	1	2.202	0.239	0.181
Error	7	(0.445)		
Display Duration	1	6.691*	0.489	0.036
Error	7	(0.631)		
Reward Magnitude x Display Duration	1	0.006	0.001	0.941
Error	7	(0.053)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$.

Table B26

Repeated Measures Analysis of Variance for Response Time in Experiment 4B

Source	df	*F*	η^2	*p*
		Within Subjects		
Reward Probability	1	5.098	0.421	0.059
Error	7	(0.001)		
Display Duration	1	14.225**	0.670	0.007
Error	7	(0.001)		
Reward Probability x Display Duration	1	0.004	0.001	0.951
Error	7	(0.001)		

Note. Mean Square Errors appear in parentheses below means.

**$p < 0.01$.

Table B27

Repeated Measures Analysis of Variance for Accuracy in Experiment 4B

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Probability	1	23.038**	0.767	0.002
Error	7	(0.002)		
Display Duration	1	68.332**	0.907	0.000
Error	7	(0.003)		
Reward Probability x Display Duration	1	19.785**	0.739	0.003
Error	7	(0.002)		

Note. Mean Square Errors appear in parentheses below means.

**$p < 0.01$.

Table B28

Bonferroni Pairwise Comparisons for Accuracy on the Significant Target Reward Probability x Display Duration Interaction in Experiment 4B

	Target Reward Probability			
	LRp		HRp	
Comparison	Mean Difference$^{(i-j)}$	*p*	Mean Difference$^{(i-j)}$	*p*
0.150s^{i} *versus* 0.035s^{j}	24.6** (2.4)	0.000	9.1* (2.9)	0.016

Note. Standard Errors appear in parentheses below means.

*$p < 0.05$. **$p < 0.01$.

Table B29

Repeated Measures Analysis of Variance for Inverse Efficiency in Experiment 4B

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Probability	1	25.492**	0.785	0.001
Error	7	(0.002)		
Display Duration	1	58.178**	0.893	0.000
Error	7	(0.004)		
Reward Probability x Display Duration	1	10.370*	0.597	0.015
Error	7	(0.003)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$. **$p < 0.01$.

Table B30

Bonferroni Pairwise Comparisons for Inverse Efficiency on the Significant Target Reward Probability x Display Duration Interaction in Experiment 4B

	Target Reward Probability			
	LRp		HRp	
Comparison	Mean Difference$^{(i-j)}$	*p*	Mean Difference$^{(i-j)}$	*p*
0.150s^{i} *versus* 0.035s^{j}	-0.233** (0.033)	0.000	-0.106** (0.025)	0.004

Note. Standard Errors appear in parentheses below means.

***p* < 0.01.

Table B31

Repeated Measures Analysis of Variance for Sensitivity in Experiment 4B

Source	df	*F*	η^2	*p*
Within Subjects				
Reward Probability	1	5.852*	0.455	0.046
Error	7	(0.456)		
Display Duration	1	9.102*	0.565	0.019
Error	7	(0.686)		
Reward Probability x Display Duration	1	10.141*	0.592	0.015
Error	7	(0.014)		

Note. Mean Square Errors appear in parentheses below means.

*$p < 0.05$.

Table B32

Bonferroni Pairwise Comparisons for Sensitivity on the Significant Target Reward Probability x Display Duration Interaction in Experiment 4B

	Target Reward Probability			
	LRp		HRp	
Comparison	Mean Difference$^{(i-j)}$	*p*	Mean Difference$^{(i-j)}$	*p*
0.150s^{i} *versus* 0.035s^{j}	1.017* (0.291)	0.010	0.750* (0.301)	0.041

Note. Standard Errors appear in parentheses below means.

*$p < 0.05$.

Table B33

Independent Samples t-tests in Experiment 4

	Reward Dimension				
	m	p	*t*	*df*	*p*
	(*n* = 8)				
Response Time	0.012 (0.007)	0.018 (0.008)	-0.742	14	0.482
Accuracy	-2.9 (2.3)	-15.5 (3.2)	8.469**	14	0.000
Inverse Efficiency	0.040 (0.018)	0.083 (0.016)	-4.560**	14	0.003
Sensitivity (d')	-0.350 (0.236)	-0.578 (0.239)	2.599*	14	0.035

Note. Standard Errors appear in parentheses below means.

**p* < 0.05. ***p* < 0.01.

Appendix C

Probability Discounting Questionnaires

(Experiment 2 and Experiment 4B-discounting procedure component)

Discounting task used in Experiment 2

Questionnaire: Part 1

Question 1: Do you prefer ***$1 for sure*** or ***$10 with a 10% chance*** ?

Question 2: Do you prefer ***$2 for sure*** or ***$10 with a 10% chance*** ?

Question 3: Do you prefer ***$3 for sure*** or ***$10 with a 10% chance*** ?

Question 4: Do you prefer ***$4 for sure*** or ***$10 with a 10% chance*** ?

Question 5: Do you prefer ***$5 for sure*** or ***$10 with a 10% chance*** ?

Question 6: Do you prefer ***$6 for sure*** or ***$10 with a 10% chance*** ?

Question 7: Do you prefer ***$7 for sure*** or ***$10 with a 10% chance*** ?

Question 8: Do you prefer ***$8 for sure*** or ***$10 with a 10% chance*** ?

Question 9: Do you prefer ***$9 for sure*** or ***$10 with a 10% chance*** ?

Question 10: Do you prefer ***$10 for sure*** or ***$10 with a 10% chance*** ?

Questionnaire: Part 2

Question 1: Do you prefer ***$10 for sure*** or ***$10 with a 10% chance*** ?

Question 2: Do you prefer ***$9 for sure*** or ***$10 with a 10% chance*** ?

Question 3: Do you prefer ***$8 for sure*** or ***$10 with a 10% chance*** ?

Question 4: Do you prefer ***$7 for sure*** or ***$10 with a 10% chance*** ?

Question 5: Do you prefer ***$6 for sure*** or ***$10 with a 10% chance*** ?

Question 6: Do you prefer ***$5 for sure*** or ***$10 with a 10% chance*** ?

Question 7: Do you prefer ***$4 for sure*** or ***$10 with a 10% chance*** ?

Question 8: Do you prefer ***$3 for sure*** or ***$10 with a 10% chance*** ?

Question 9: Do you prefer ***$2 for sure*** or ***$10 with a 10% chance*** ?

Question 10: Do you prefer ***$1 for sure*** or ***$10 with a 10% chance*** ?

Discounting task used in Experiment 4B

Questionnaire: Part 1

Question 1: Do you prefer ***$1 for sure*** or ***$10 with a 1% chance*** ?

Question 2: Do you prefer ***$2 for sure*** or ***$10 with a 1% chance*** ?

Question 3: Do you prefer ***$3 for sure*** or ***$10 with a 1% chance*** ?

Question 4: Do you prefer ***$4 for sure*** or ***$10 with a 1% chance*** ?

Question 5: Do you prefer ***$5 for sure*** or ***$10 with a 1% chance*** ?

Question 6: Do you prefer ***$6 for sure*** or ***$10 with a 1% chance*** ?

Question 7: Do you prefer ***$7 for sure*** or ***$10 with a 1% chance*** ?

Question 8: Do you prefer ***$8 for sure*** or ***$10 with a 1% chance*** ?

Question 9: Do you prefer ***$9 for sure*** or ***$10 with a 1% chance*** ?

Question 10: Do you prefer ***$10 for sure*** or ***$10 with a 1% chance*** ?

Questionnaire: Part 2

Question 1: Do you prefer ***$10 for sure*** or ***$10 with a 1% chance*** ?

Question 2: Do you prefer ***$9 for sure*** or ***$10 with a 1% chance*** ?

Question 3: Do you prefer ***$8 for sure*** or ***$10 with a 1% chance*** ?

Question 4: Do you prefer ***$7 for sure*** or ***$10 with a 1% chance*** ?

Question 5: Do you prefer ***$6 for sure*** or ***$10 with a 1% chance*** ?

Question 6: Do you prefer ***$5 for sure*** or ***$10 with a 1% chance*** ?

Question 7: Do you prefer ***$4 for sure*** or ***$10 with a 1% chance*** ?

Question 8: Do you prefer ***$3 for sure*** or ***$10 with a 1% chance*** ?

Question 9: Do you prefer ***$2 for sure*** or ***$10 with a 1% chance*** ?

Question 10: Do you prefer ***$1 for sure*** or ***$10 with a 1% chance*** ?