The Temporal Dynamics of Social Cue Processing

by

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B.Sc, East China Normal University, 2007

M.Ed, East China Normal University, 2010

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ABSTRACT

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Social cues, such as eye gaze and head-turns, can orient attention automatically. Social cue processing includes three sequential stages, namely cue selection, cue following and object recognition. In a typical social cueing task, a central face is presented and then attention is directed to potential target location by an eye gaze or head turn. In these paradigms, the standard finding is that despite the non-predictive nature of the cue (i.e., the target is as likely to appear at the validly cued location as the invalidly cued location), targets appearing at the validly cued location are detected and identified faster than targets presented at the invalidly cued location. The cueing effect starts to emerge at short cue-target stimulus onset asynchronies (SOA) (e.g., 105 ms) and diminishes at the long SOA (e.g., 1005 ms). However, because only one object was presented on one side of the center gaze cue in these paradigms, the social cueing effect could be interfered or abolished by the peripheral onset effect (i.e., the automatic orienting of attention by the abrupt appearance of a single object event).

The goal of this dissertation was to develop a modified social cueing task to measure the temporal dynamics of social cue processing while eliminating the potential confounds from the peripheral onset effect. In the Cued Recognition Task, the peripheral onset effect is removed by simultaneously presenting a target and a distractor object following a non-predictive head-turn cue. Results from a series of experiments using the Cued Recognition Task showed that: (a) if the distractor was not presented on the opposite side of the target, the peripheral onset effect elicited by the target onset interfered with the social cueing effect elicited by the head-turn; (b) in the cued recognition paradigm, the reflexive attention orientation effect elicited by social cues could be inhibited at 0 ms of SOA, started to emerge at 105 ms of SOA, became stable at 300 and 600 ms of SOA and sustained at 1005 ms of SOA; (c) children with ASD showed equivalent magnitude of social cueing effect as TD controls, but they were slower across all conditions despite the fact that they were as fast as TD controls in object recognition. The Cued Recognition Model developed based on all the findings in this dissertation was described in order to provide an explicit explanation of how social cues influence everyday object recognition.

Table of Contents

List of Figures

List of Tables

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Dedication

To my parents: it is your dream for my dream to come true...

Eye Gaze Head-turn

Two different types of social cues: eye gaze and head-turn. Both pictures were taken by the author.

General Introduction

A Brief History of Visual Attention Cueing Studies

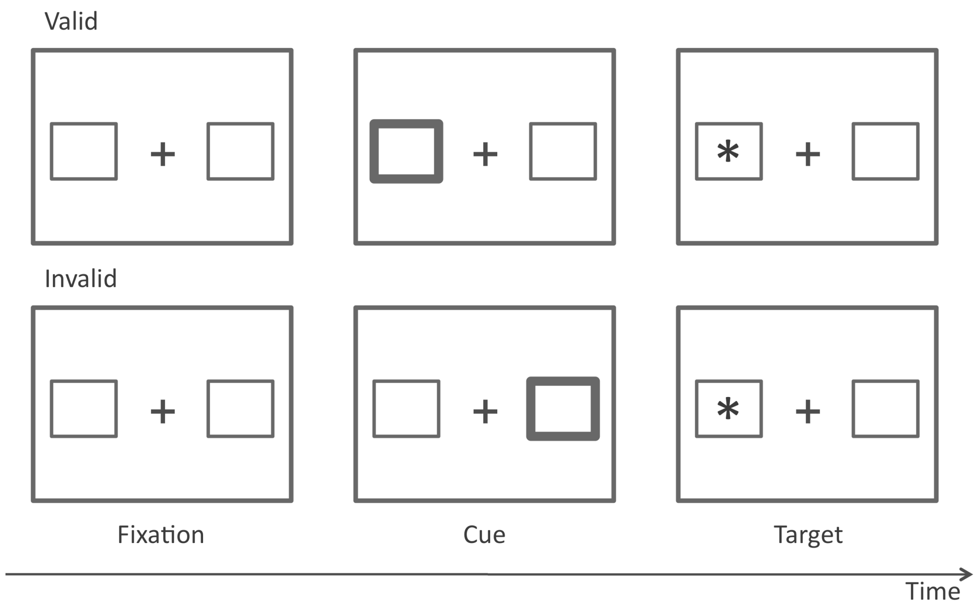
As long as our eyes are open, a great amount of information can be received by our visual system. However, part of the input may be regarded as redundant or uninformative because it is not relevant to the behavioral tasks that we are performing at the moment. Fortunately, with a highly developed visual attention system, we are able to voluntarily select input for further processing by orienting our attention to the relevant aspects of the environment, while selectively ignoring irrelevant visual information. This ability helps us with our daily activities, such as focusing on reading our book in a café without being distracted by the busy street view from the window, etc. However, sometimes we cannot help but get distracted. Imagine that you are reading a paper on your computer screen, and the pop-out window of email notification in your peripheral visual field usually automatically captures your attention. Traditionally, it is suggested that two important visual attention orientation systems interact with each other when performing cognitive tasks. While one system enables the selection and orienting of attention according to internal task goals or expectations, the other system is vigilant of the surrounding environment to detect salient and behaviorally relevant stimulus (for a review, see Corbetta, Patel, & Shulman, 2008; Frischen, Bayliss, & Tipper, 2007). Those two types of attention orientation systems are usually categorized as goal driven or stimulus driven, endogenous or exogenous, voluntary or reflexive, top-down or bottom-up, etc. Regardless of the differences in taxonomy, majority of the researchers agree upon the different functions of those two types of attention orienting.

For well-controlled laboratory studies, the seminal works by Posner (1980) and Jonides (1981) have established two standard paradigms for testing the orienting of visual attention: the exogenous cueing paradigm and the endogenous cueing paradigm. This dichotomy of attention orienting, as well as how they are measured have been widely accepted for decades.

The exogenous cueing task is often used to measure the reflexive orienting of visual attention elicited by abrupt stimulus onset in the peripheral visual field. In a standard exogenous cueing task (Figure 1a), two empty boxes are presented on both the left and right side of the central fixation cross. Participants are required to detect or identify a pre-defined target object presented in either of the boxes. Prior to the onset of the target, the cue is presented in the form of changing the outline (e.g. brightened, bold, etc.) of one of the boxes. After the cue-target stimulus onset asynchronies (SOA), target object is presented at the validly cued location in 50% of the trials, and at the invalidly cued location in the other 50% of the trials. Studies using this paradigm showed that (Posner, 1980, Posner & Cohen, 1984; Posner, Cohen, & Rafal, 1982), despite the instructions to ignore the non-predictive cue, response time was faster when the target was presented at the validly cued location than when presented at the invalidly cued location. This effect is still present even if the peripheral cue is counter-predictive so that the target is more likely to be presented at the invalidly cued location (e.g., 75%) than at the validly cued location (e.g., 25%) (Jonides, 1981; Remington, Johnston, & Yantis, 1992). It indicates that, the abrupt change of the outline of the peripheral box triggers a reflexive attention orientation to this location and facilitates the processing of the stimulus presented at this location. However, despite its robustness with non-predictive and even counter-predictive cues, this reflexive cueing effect is short-lived. The reflexive cueing effect by non-predictive peripheral cues declines between 150 ms and 300 ms after cue onset (Müller & Findlay, 1988) and eventually diminishes if the SOA is longer than

300 ms (Klein, Kingstone, & Pontefract, 1992). After that, the cueing effect is replaced by the Inhibition of Return (IOR) effect at longer SOAs (Klein, 2000; Maylor, 1985; Maylor & Hockey, 1985; Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985) in which target presented at the validly cued location is detected slower than the target presented at the invalidly cued location. It was believed that the IOR effect was attributable to the removal of attention from a previously attended location. The IOR effect encouraged the attention to orient towards novel locations, but discouraged attention from reorienting back to the originally attended location (Klein, 2000; Posner et al., 1985; Taylor & Klein, 1998).

(a). The Exogenous Cueing Task



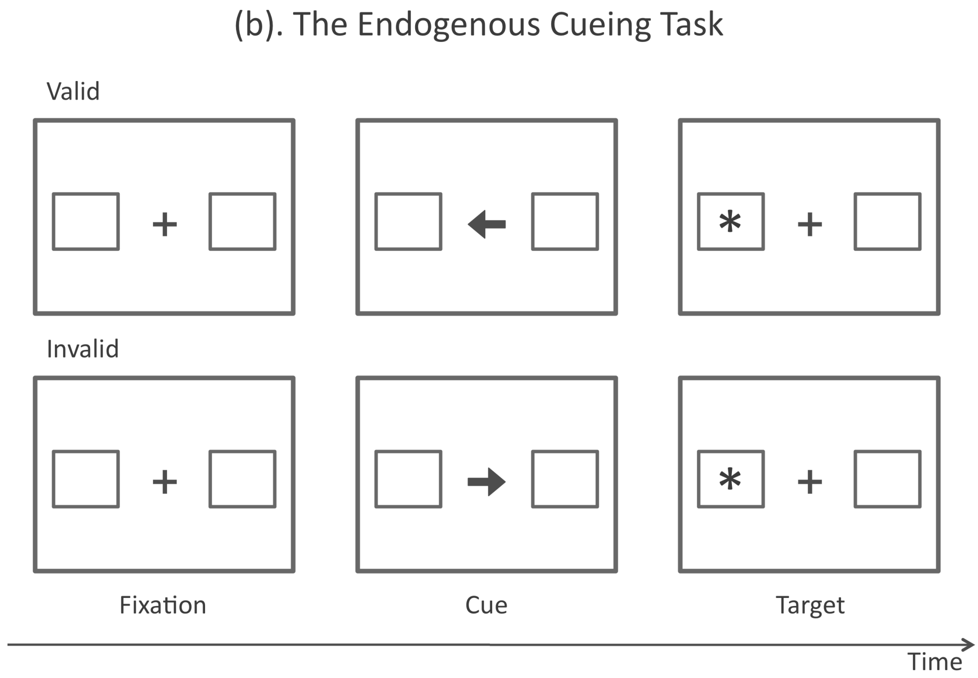


Figure 1. **The illustration of the exogenous and endogenous attention cueing paradigms. (a). The exogenous cueing paradigm. Top panel shows the valid cueing condition and bottom panel shows the invalid cueing condition. (b). The endogenous cueing paradigm. Top panel shows the valid cueing condition and bottom panel shows the invalid cueing condition.**

Different from the exogenous cueing task, the endogenous cueing task (Figure 1b) was originally used to test the orienting of attention elicited by symbolic cues presented in the central visual field. Similar to the exogenous cueing task, the endogenous cueing task also requires participants to detect a target object at peripheral locations (e.g. either to the left or right of the center fixation). However, the cue is presented at the center location in a symbolic form (e.g. an arrow pointing to the left or right) that needs interpretations. The predictability of the cue is also an important manipulation in this paradigm. Not surprisingly, studies using predictive center arrow cues (e.g., Posner, Snyder, & Davidson, 1980) have found significant cueing effects, indicating that center arrow cues are able to orient attention if they were informative. More importantly, although Jonides did not find a cueing effect using non-predictive center arrow cues in his seminal work (Experiment 2 in Jonides, 1981), most of the subsequent studies obtained significant cueing effects by the non-predictive center arrow cues (e.g., Eimer, 1997; Hommel, Pratt, Colzato, & Godijn, 2001; Pratt & Hommel, 2003; Ristic, Friesen, & Kingstone, 2002; Shepherd, Findlay, & Hockey, 1986; Tipples, 2002), raising the question if attention orientation in response to arrow cues was simply voluntary or not. However, it might be true that center arrow cues orient attention less reflexively than peripheral cues do, because when the center arrow cues are counter-predictive, the processing of the arrow cue can be suppressed and thus, no significant cueing effect will be found (Friesen, Ristic, & Kingstone, 2004; Jonides, 1981). Moreover, the temporal dynamics of the cueing effect triggered by the non-predictive center cues and peripheral cues are different. Compared to the relatively early and short-lived exogenous cueing effect elicited by peripheral cues, center arrow cues produce a relatively later onset of the endogenous cueing effect, which can last for a longer period of time. To be specific, the non-predictive endogenous cueing effect builds up more slowly, achieves the peak at the SOA of about 300 ms and will not be replaced by the IOR effect like the peripheral cues do (Cheal & Lyon, 1991; Müller & Rabbitt, 1989; Taylor & Klein, 1998).

Although recent studies have raised issues over solely categorizing center arrows as endogenous or voluntary cues (see Ristic & Kingstone, 2006; Ristic & Kingstone, 2012; Ristic, Landry, & Kingstone, 2012), it is evident that the cueing effect produced by peripheral and center cues are independent from each other according to their different levels of reflexivity and different temporal dynamics.

The Social Cueing of Attention

In our everyday world, there are other types of cues that are important to our social survival. Infants start to respond to social cues such as eye gaze and head turns since early period of their lives. Neonates 2 to 5-days-old are able to discriminate between direct and averted gaze (Farroni, Massaccesi, Pividori, & Johnson, 2004) and infants as young as 3 months old are able to follow eye gaze cues of others (Hood, Willen, & Driver, 1998). Moreover, infants can orient attention to an object being looked at by another person if the object is in the infant's visual field by the age of 6 months (Morales, Mundy, & Rojas, 1998), and attend to that object even if it is not in their visual field by the age of 9 to10 months (Butterworth & Jarrett, 1991; Corkum & Moore, 1998; Scaife & Bruner, 1975). Thus, at a very early point in life, infants understand the intentions of others as conveyed by their eye gaze and body gestures. This ability ensures the typical cognitive and social development of the infant. For example, studies showed that social cue following was crucial for the development of language acquisition (Baldwin, 1995; Morales, Mundy, & Rojas, 1998; Morales et al., 2000). Specifically, orienting to the object of a caregiver's attention might allow the speedy acquisition of nouns, through the pairing of an observed object and its vocalized name (Baldwin, 1995; Reid & Striano, 2005). Therefore, it is not surprising that gaze following ability at an early age is positively correlated with the development of the vocabulary size (Morales et al, 2000).

Are social cues really special? There seemed to be unique neural mechanisms for the processing of eye gaze information. Using single neuron recording, Perrett et al. (1985) showed that one of the important functions of the superior temporal sulcus (STS) of macaque monkeys was to process gaze direction. Subsequent lesion studies showed that, the performance of gaze discrimination in macaque monkeys dropped significantly after the ablation of the STS region (Campbell, Heywood, & Cowey et al., 1990), while their face processing performance remained unaffected (Heywood, Cowey, & Rolls, 1992). For human beings, impairment in gaze discrimination was found in patients with right superior temporal gyrus (STG) lesion (Akiyama, Kato, Muramatsu, Saito, Umeda, & Kashima, 2006) as well as healthy adults with their posterior STS temporarily disrupted by transcranial magnetic stimulation (TMS) (Pourtois et al., 2004). Neuroimaging studies using healthy human subjects showed consistent results that STS has a unique function in processing gaze directions (Calder, et al., 2007; Hoffman & Haxby, 2000).

However, social cues do not always provide useful information. As human beings, we are inherently curious of what the other individuals are interested in, and sometimes this curiosity enables other individuals to manipulate our attention for their own purposes. One of the examples could be found in magic shows. Magicians often provide us with misleading visual attentional cues to some irrelevant locations, so that they can do the tricks in the locations that we are not attending to at the crucial moments (Lamont & Wiseman, 1999). For example, in the vanishing ball illusion, while the audience thinks the ball has been tossed away from the magician's hand and disappeared in the mid air, it is actually still secretly palmed in the performer's hand. Kuhn and Land (2006) found that, during the fake toss in the vanished ball illusion, the most important showmanship was that the performer should make an upward head-turn to look at where the ball was believed to be, instead of looking at his/her hand. In the condition where the performer looked up, 68% of the viewers experienced the illusion. However, in the condition where the performer looked at his/her hand, only 32% of the viewers experienced the illusion. This finding demonstrated that the viewer's visual attention was biased by the social cue elicited by the head-turn of the performer, and this attention manipulation was crucial for the success of the performance of the vanished ball illusion.

The example of vanished ball illusion seems to indicate that the following of social cues is a reflexive process. This was consistent with previous finding from laboratory studies of social cueing of attention. Friesen and Kingstone (1998) modified the endogenous cueing task by replacing the center arrow cue with the eye gaze cue. In the social cueing task, the eye gaze of a schematic face was directed to either the left or right side of the visual field (Figure 2). In conditions where the eye gaze had no predictive validity (i.e., on 50% of trials, the eye gaze cued the correct location and on 50% of the trials, eye gaze cued the opposite location), participants exhibited a strong cueing effect such that targets appeared in the validly cued location were detected faster than targets in the invalidly cued location (also see Driver, Davis, Ricciardelli, Kidd, Maxwell & Baron-Cohen, 1999). Moreover, despite knowing that the eye gaze cue was counter-predictive (i.e., on 80% of the trials, the target appeared at a location opposite to location cued by eye gaze), participants were faster to detect the target when it appeared at the location cued by the counter-predictive eye gaze (Driver et al., 1999; Friesen, Ristic, & Kingstone, 2004). Head-turns, like eye gaze, are important social cues that signal the location of a person's attention (Anstis, Mayhew, & Morley, 1969; Kluttz, Mayes, West, & Kerby, 2009; Langton, Honeyman, & Tessler, 2004; Symons, Lee, Cedrone, & Nishimura, 2004). Targets cued by a left or right head-turn were detected faster than targets appeared at the location opposite to the head-turn, even when participants were informed that the head-turn was counter-predictive (Langton & Bruce, 1999). The robust effects of eye gaze and head-turns under conditions when they were counter-predictive suggest that the tendency to follow social cues is driven by automatic, reflexive processes.

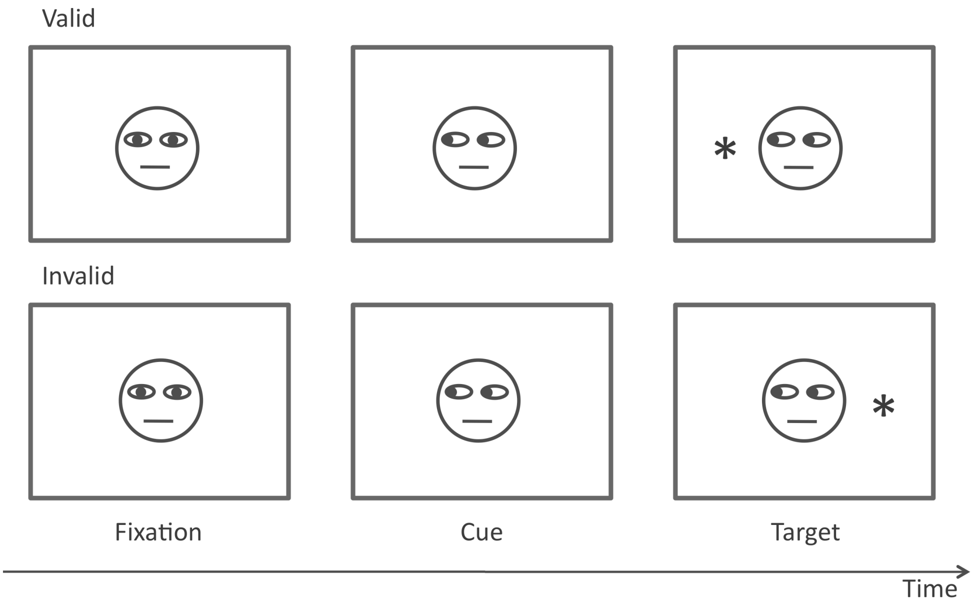


Figure 2. **The illustration of the social cueing paradigm. Top panel shows the valid cueing condition and bottom panel shows the invalid cueing condition.**

However, the social cueing paradigm does not fit neatly into either the exogenous or endogenous cueing paradigms for several reasons. First, in contrast to the center arrow cues results, social cues are able to trigger cueing effect even if they are counter-predictive (Driver et al., 1999; Friesen, Ristic, & Kingstone, 2004; Langton & Bruce, 1999). While some studies found that counter-predictive center arrow cues oriented attention reflexively as social cues did (Hommel, Pratt, Colzato, & Godijn, 2001; Tipples, 2008), others failed to find reflexive attention orientation following counter-predictive arrow cues (Friesen et al., 2004; Jonides, 1981). Moreover, the temporal dynamics of the cueing effect in the social cueing task differ from the cueing effect in the exogenous cueing task. Whereas the cueing effect in the exogenous cueing task diminishes around 300 ms after onset (Klein, Kingstone, & Pontefract, 1992; Müller & Findlay, 1988), the cueing effect in social cueing task disappears with longer SOAs (e.g., 1000 ms) (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). This raises the question of the traditional dichotomy of attention orienting, because social cue should be a unique type of reflexive attentional cue that differs from center endogenous cue on the reflexivity dimension, and varies from the peripheral exogenous cue in temporal dynamics.

Moreover, it was not clear whether different neural mechanisms were activated in the social cueing task compared to the center arrow cueing task. For example, Hietanen et al. (2006) found that arrow cues activated a much more extensive network than gaze cues, suggesting that gaze and arrow cues were not supported by the same cortical network. In addition, Kingstone et al. (2004) used functional magnetic resonance imaging (fMRI) to investigate brain activation during an attention orientation task in which the cue was an ambiguous figure (i.e., either as a car with averted wheels or a face with averted eyes). The STS activity was increased when the cue was perceived as a face with averted eyes as compared to when it was perceived as a car. However, following the same logic, Tipper et al. (2008) studied gaze and arrow cuing using an ambiguous stimulus that could be perceived as either an eye or an arrow. Results showed that both types of cues engaged extensive dorsal and ventral fronto- parietal networks and few differences were found between the neural mechanisms activated in those two conditions. In short, whether eye gaze is a unique attentional cue is still unclear due to the mixed findings from literatures.

One of the issues in well-controlled laboratory studies was that the ecological validity might have been compromised. As mentioned earlier, the standard task to study social cueing of attention is the social cueing task, in which social cues are presented as either a real or schematic face at the center of the screen with pupils moved to the left or right side of the eyes, indicating gaze shifts to the left or right side of the cue. Participants are required to detect or identify the target presented at either the validly or invalidly cued location. However, in real life, social cues are not processed in this over-simplified ways. Recent studies addressed this issue by testing the social cue processing using more naturalistic stimulus, usually employing the eye-tracking technologies. When viewing a naturalistic image, the allocation of attention could be influenced by social cues presented in the image. Using behavioral measurement, Langton, O'donnell, Riby, and Ballantyne (2006) found that participants were able to detect changes sooner when this changed item was attended to by a person in the image than when it was not attended to by anyone in the image. It suggested that one’s attention was preferentially allocated to the location of another individual’s attention when viewing static naturalistic scenes. Moreover, using eye-tracking technologies, Castelhano, Wieth, and Henderson (2008) investigated the gaze-following behavior by recording eye movements of their participants while they were viewing a slide show about a janitor cleaning the office. They found that, after looking at the head region of the janitor, participants moved their gaze away from that region, and re-orient their gaze to the location indicated by the gaze direction of the janitor. Zwickeln and Võ (2010) did a similar study, but with better controls over the low-level visual saliency of the person presented in the scene. They found that, objects that were attended to by a person in the scene were visited earlier, more often, and longer than when they were not attended to. In addition, this effect could be generalized to the gaze behavior when viewing dynamic scenes in special occasions, such as a magic presentation. Kuhn, Tatler, and Cole (2009) studied gaze following when participants were watching the performance of a magic trick. They found that observers directed their gaze toward the same locations that the magician was looking at. Furthermore, also using eye-tracking technologies, studies have been conducted to test how gaze cue influences real-life social interactions. For example, during collaborative tasks, such as building LEGO structures, gaze cues appear to be a useful communicative tool. Using the gaze cues of the partner, one can more accurately select the target object (Macdonald & Tatler, 2013), attend to the object that being referred to even before the verbal disambiguation occurs (Hanna & Brennan, 2007), and alter the content of the verbal communication if a different object is attended to by the partner (Clark & Krych, 2004). Moreover, within verbal communication settings, gaze cue contributes to the understanding of the narratives. We tend to look at the actor's eyes and then to the object that the actor is looking at when they try to understand the descriptions delivered by the actor (Castelhano, Wieth, & Henderson, 2007). We also make use of the eye gaze of the other individual in order to make inferences from their descriptions (Staudte & Crocker, 2011). Last but not least, gaze cues from others are used when we are walking on the street. We tend to shift our gaze in the same direction as the gaze direction of the person walking in front of us, but in the opposite direction as the gaze direction of the person walking toward us (Gallup, Chong & Couzin, 2012; Nummenmaa, Hyona & Hietanen, 2009). In short less well controlled than laboratory experiments, studies using naturalistic stimulus, or tested in naturalistic testing environment showed the importance of social cue processing in our everyday life.

The Other Side of the Spectrum

The most recent statistics showed that Autism Spectrum Disorder (ASD) has an estimated prevalence of 1/50 among children from 6-17 years old in U.S.A. (Blumberg et al., 2013). People with ASD display challenges in social interaction and communication, and show restricted, repetitive, and stereotyped patterns of behaviors, interests, and activities (APA, 2000). Although the process of social cue is proved to be automatic and effortless in typically developed population, it is believed that people with ASD do not automatically follow social cues (e.g. Baron-Cohen et al. 1995; Dawson et al. 1998). Studying the social cue processing of children with ASD is important because social attention issue is among the earliest, most salient and specific features of autism (Mundy, 1995; Swettenham et al., 1998; Zwaigenbaum et al., 2005). A better understanding of social cue processing in children with ASD will help with the early identification of ASD, which is a vital endeavor for the interventions (Howlin et al., 2009; Reichow & Wolery, 2009).

Studies of social cue following in non-laboratory situations, such as interview, observation, etc. show that children with ASD engage in less mutual gaze (e.g., Sigman, Mundy, Sherman, & Ungerer, 1986; Volkmar & Mayes, 1990), and have delayed spontaneous gaze following behaviors (e.g., Leekam et al., 1997; Leekam, Hunnisett, & Moore, 1998; Leekam, López, & Moore, 2000) than typically developed (TD) controls. In addition, laboratory studies using naturalistic stimulus (Freeth, Ropar, Chapman & Mitchell, 2010) found that, for both adolescents with and without ASD, the gaze direction of the person in the scenes spontaneously cued the participants' attention to the direction of their gazes, affected their judgments of preference, caused memory biases and improved their visual search accuracy. However, in another study conducted by the same group of authors (Freeth, Chapman, Ropar & Mitchell, 2010) using eye-tracking technologies, a different time-course of gaze processing was found between adolescents with and without ASD. They found that ASD participants spent similar proportion of time looking at the person's face as TD participants did, and they also re-oriented their attention following the direction of the person's gaze. However, they were slower in orienting their attention to the face, as well as to the location being cued than TD participants. A later study by this group of authors (Freeth, Ropar, Mitchell, Chapman, & Loher, 2011) using eye-tracking found that ASD participants showed less interest in the person presented in the scene than the TD participants did, and this difference can also be reflected from the verbal description of the scene from the two groups of participants. In short, the majority of the studies conducted in non-laboratory environment or using naturalistic stimulus found that people with ASD process social cues differently than TD controls.

However, studies using the social cueing paradigm yielded mixed results. Among the 13 studies that used the social cueing task to investigate if children with ASD showed similar social cueing effects as TD controls, only 5 of them found that children with ASD showed a smaller or no social cueing effect compared to the TD controls (Goldberg et al., 2008; Johnson et al., 2005; Ristic et al., 2005; Senju et al., 2004; Vlamings et al., 2005). The majority of studies found comparable cueing effects between the ASD and TD groups (Charwarsaka et al., 2003; Greene, Colich, Iacoboni, Zaidel, Bookheimer & Dapretto, 2011; Kuhn, Benson, Fletcher-Watson, Kovshoff, McCormick, Kirkby, & Leekam, 2010; Kylliäinen & Hietanen, 2004; Pruett et al., 2011; Rombough & Iarocci, 2012; Stauder, Bosch & Nuij, 2011; Swettenham et al., 2003). The mixed findings might be due to differences in experimental paradigms (e.g., stimulus for gaze cues, SOA, task length, etc.) as well as the heterogeneity of the autism spectrum (Frischen, Bayliss & Tipper, 2007, Nation & Penny, 2008) especially when the sample sizes were relatively small.

However, recent neural imaging studies investigated the neural activities during real face-to-face interactions and found different neural mechanisms between ADS and TD groups were activated during activities that required the processing of social cues. For example, in a recent study by Redcay et al. (2012), both ASD and TD participants performed an interactive face-to-face game with an experimenter. They were required to process and follow the eye gaze of the other's during an fMRI scan. The results showed that less activation was found in the dorsal medial prefrontal cortex (dMPFC) and right posterior superior temporal sulcus (pSTS) of ASD participants than TD participants, suggesting that those two regions might be responsible for the atypical social cue processing in people with ASD. Tanabe et al. (2012) paired ASD and TD participants (and TD and TD participants, as controls) in a one-on-one gaze shifting task in which they were required to shift their gaze according to the gaze direction of their partners. During this task, fMRI data was acquired from both participants. The results showed that, on the behavior level, the ASD-TD pair did not perform as well as the TD-TD pair, and more interestingly, the performance was impaired not only for the ASD participant, but also for the TD participant in the ASD-TD pair. Neural imaging data was consistent with behavior findings that, compared to TD participants in TD-TD pair, ASD participants in the ASD-TD pair showed less activation in left occipital pole (OP) and TD participants in the ASD-TD pair showed hyper activity in the bilateral occipital cortex and right prefrontal area, but less connectivity between the right inferior frontal gyrus (IFG) and STS.

In conclusion, although studies using the social cueing paradigm yielded mixed results on whether people with ASD could process and follow social cues the same way as TD people did, studies using naturalistic stimuli, or conducted in the naturalistic setting found differences between the two groups. Moreover, neural imaging studies also found different brain activation patterns between ASD and TD groups during tasks that required social cue processing.

The Three Stages of Social Cue Processing

Studies using the social cueing task, as one of the most widely used methods in testing social cue processing, have made immense contributions to the understanding of the temporal dynamics of how social cues are processed and followed. Indeed, the strict laboratory control excludes confounds from irrelevant factors, and enables the better measurement of the cueing effects. However, social cues are usually processed in social situations, which are more sophisticated than the scenes presented in the laboratory. For example, when you are hiking on a trial, the person walking toward you suddenly turns her head to her right. After you see her head-turn, you also look at the location that she is looking at, and find a snake at that location. From this example, three basic and necessary sequential stages can be specified, namely *cue selection* (i.e., you see the head turn), *cue following* (i.e., you look at where she is looking at), and *object recognition* (i.e., you find a snake). The following part will be devoted to the discussion of how these three stages work in social cue processing, how they are tested in the social cueing task and if any modifications can be made to the social cueing task in terms of the testing validity.

Cue Selection

Cue selection is the very first step in this chain of process in real life situations. However, cue selection is bypassed in the social cueing paradigm, because cues are pre-selected and placed at fixation of the participants (Birmingham & Kingstone, 2009; Gibson & Kingstone 2006). The clue of where the other individuals are attending to usually comes from the face region. As salient objects in our environment, research has shown that faces more readily capture our attention than other non-face objects (Farroni et al., 2005; Morton & Johnson, 1991) and once attended to, are more efficiently processed by our visual system (Lewis & Edmonds, 2003). This selection and processing bias of faces enables the efficient extraction of social cues from the faces, such as the gaze direction and head-turn, which provide guidance of where we should orient our attention. However, this is not always the case, especially for clinical population, such as individuals with ASD. Individuals with ASD do not automatically orient to faces. The lack of attention to faces is used as one of the early signs of ASD (e.g., in the checklist by Robins et al., 2001). Numbers of studies showed that individuals with ASD do not have a bias to select faces from other non-face objects from the environment (e.g., Klin et al., 2002; Mars et al., 1998; Osterling & Dawson, 1994; Speer et al., 2007; Swettenham et al., 1998, but see New, Schultz, Wolf, Niehaus, Klin, German & Scholl, 2010). As mentioned in the previous part, despite the converging evidence that children with ASD could not follow social cues in real life situations, laboratory tasks using the social cueing paradigm failed to find consistent results on this topic. One of the possible reasons for these inconsistencies can be that, children with ASD may have intact functioning in *cue following,* but have difficulties in *cue selection* because of their lack of understanding of the significance of social cues compared to other competing stimulus (Rombough & Iarocci, 2012). As a result, because the social cueing task is not sensitive to the differences in *cue selection*, it is therefore not sensitive to the difference between the ASD and TD group when studying social cue processing. In conclusion, testing the *cue selection* process in social cueing tasks should not be considered as redundant. Instead, it could be informative especially when studying social cue processing in clinical populations.

Cue Following

The social cueing paradigm focused on *cue following* and *object recognition* (sometimes object detection or localization). In most social cueing studies, cueing is achieved by the movement of both pupils from the center location to either the left or right side of the eyes. This is a reasonable way to present social cues, because the social cue information is usually extracted from some specific body parts, especially the eye region. The specific anatomical properties of the eyes make the social cue selection and processing easier. Among primates, the contrast between the sclera and iris is high (Kobayashi & Kohshima, 1997; Ricciardelli, Baylis, & Driver, 2000). The large eye width to iris diameter ratio of human beings (approximately 1.8) does enable the possibility to express attention status solely from the movement of pupil. However, information from the eye region is not all the information that being used to understand the attention status of another individual. The same pupil location can provide distinct information under different conditions, such as the Wollaston Effect illustrated in Figure 3. Although the eyes on the two faces are identical, the person in the image to the left seems to be making eye contact with the observer, whereas the person in the image to the right appears to be looking to the observer's left (details of the explanation can be found in Todorovic, 2006). Therefore, one's attention status is expressed by the combination of the location of the pupil and the direction of the head (Langton, 2000; Hietanen, 1999; Itier, Villate & Ryan, 2007; Kluttz, Mayes, West & Kerby, 2009). When the eye gaze and head-turn provide congruent attention cues, significant social cueing effects can be yielded (Langton & Bruce, 1999). In short, in order to achieve a better ecological validity for the social cueing task, more complex social cues, such as the combination of congruent head-turn and eye gaze cues, might be employed instead of the simplistic manipulation of pupil locations.

Figure 3. **The illustration of the Wollaston Effect. From Todorovic, 2006.**

Object Recognition

In the *object recognition* stage, an object is presented either at the validly or invalidly cued location, and the cueing effects are usually measured by comparing the response time of object detection or recognition in the valid and invalid cueing condition. The logic behind this method is that, the difference in response time between the valid and invalid cueing condition should only reflect the effect of the social cueing, but nothing else. However, obviously, within the social cueing task, social cuing is not the only process that is undertaking. Therefore, one of the prerequisites for the subtraction method to work is that, all the irrelevant processes activated during the social cueing task should not interact with the social cueing processing, otherwise, the subtraction can only eliminate the main effect of the irrelevant process, but not the interaction between the irrelevant process and the social cueing process. However, is this prerequisite satisfied?

One of the most important irrelevant processes in the social cueing task is detecting the onset of the object. The findings from the exogenous cueing task indicate that, the sudden appearance of the object in the peripheral also works as an attention orientation cue, which produces a reflexive orientation effect (e.g., Posner, 1980). Friesen, Moore and Kingstone (2005) argued that the social cueing effect (i.e. head-turn, eye gaze, arrow) interacts with the abrupt onset of the single target stimulus. In their paper, Friesen et al. argued that:

"…This is a profound concern because it is very possible that gaze direction–target location compatibility is merely modulating the attentional capture produced by the target onset. In other words, it may be that the abrupt onset of the target—and not the gazing face—is responsible for the reflexive nature of the shift of attention being measured. If this were indeed the case, then by the principle of parsimony alone, there would be no reason to invoke the notion of a second reflexive attentional system that is cortically, rather than subcortically, mediated…." (p. 66-67)

To address this issue, Friesen et al. (2005) modified the social cueing task to include the presentation of two peripheral objects (a target and a distracter), one on each side of the cueing stimulus, thus equally distributing low-level information changes across both left and right visual fields. In their go-no-go paradigm, the eye gaze cue appeared prior to the onset of two flanking objects and participants' task was to report the presence of a pre-defined target (e.g., circle). On some trials, the target appeared on one side of the cue and the distracter (e.g., square) on the other side, while on the catch trials, distracters appeared on both sides of the cue. In order to test whether the single abrupt peripheral target onset interfere with the cueing effects from central gaze cues, a one-object (non distractor) condition was tested in comparison to the two-objects condition using a between-subject design. However, no interaction between the number of objects and size of the cueing effect was found, indicating that the reflexivity of attention orienting was due to the gaze cueing, rather than the peripheral onset effect.

Although the Friesen et al. (2005) study did not find interactions between the number of objects and size of the cueing effect, it raised an important question about the entanglement of two different attention orienting processes, namely the reflexive orienting following the center social cues, and the reflexive orienting to the abrupt peripheral object onset. In the social cueing task, the manipulation of the pupil movement is supposed to provide the attention cueing during the *cue following* process only, and the onset of the object after the SOA, is supposed to measure the cueing effect on *object recognition* process only. However, the single-sided peripheral onset can orient attention reflexively as exogenous cues, as suggested by the findings from early works by Posner (1980) and Jonides (1981). Also, Yantis and Jonides (1996) provided evidence that an object appearing abruptly in a previously blank location was efficiently detected even when it is embedded in an array of objects without abrupt onset. Therefore, the social cueing task might have introduced the exogenous cueing effect to the measurement of the social cueing effect. These two types of attention cueing effect – the social cueing effect and exogenous cueing effect – were believed to be very different to each other in temporal dynamics (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Jonides, 1981; Langton & Bruce, 1999; Posner, 1980) and neural substrates (e.g., Corbetta et al., 2008). It is necessary to test if the exogenous cueing effect elicited by the single-sided peripheral object onset interferes with the social cueing effect. This investigation can be conducted by comparing the magnitude of social cueing effects between the distractor and non-distractor condition of the social cueing task. In the distractor condition, a distractor will be presented on the opposite side of the target. The peripheral onset effect of the target can be neutralized by the peripheral onset of the distractor, and therefore, no exogenous cues will be elicited by object onsets. On the other hand, in the non-distractor condition, only the target will be presented and therefore, exogenous cue will be elicited by this single-sided peripheral onset of object. If the social cueing effect in the non-distractor condition is attenuated compared to the distractor condition, the conclusion can be made that the peripheral onset effect does interfere with the social cueing effect. If that is the case, the peripheral onset effect should be controlled by using two objects (i.e., one target and one distractor) as in Friesen et al. (2005).

Investigating the Temporal Dynamics of Social Cue Processing

The purpose of the current dissertation is to investigate the temporal dynamics of social cue processing using a task that is sensitive to differences in the *cue selection*, *cue following* and *object recognition* stages. This task should be developed based on the traditional social cueing task, but some updates should be made in order to improve both the ecological and testing validity, such as increasing the sensitivity of the task to measure *cue selection*, using more complex social cues, and provide better controls over the peripheral onset effects. The merit of developing such a task is at least two-fold. First, we can contribute to the theoretical understanding of the temporal dynamics of social cue processing, such as how early the social cueing onsets, how late this effect diminishes, and if and when the cueing effect could be inhibited. These findings can either consolidate the existing understandings, or provide new insights of how social cues are processed. Second, a better theoretical understanding of the temporal dynamics of social cue processing in TD population provides a norm that could be compared against in the studies on special populations, such as individuals with ASD. The differences, if any, between the TD and ASD participants revealed from the investigation using this task can contribute to the understanding of ASD, and perhaps support the development of intervention programs.

The current project is motivated by these potential benefits. While this chapter provided a general review of the existing literatures on social cue processing, discussed the potentials of the development of an updated task for measuring social cue processing and described the motivation of the current project, later chapters of this dissertation will be devoted to a series of experiments using the Cued Recognition Task to test the temporal dynamics of social cue processing. In Chapter 2, the development of the Cued Recognition Task will be discussed in detail, and the temporal dynamics of social cue processing measured by the Cued Recognition Task will be reported (Experiment 1). Chapter 3 focused on how the peripheral onset effect from the single-sided object presentation interferes with the social cueing effect (Experiment 2). Chapter 4 investigated whether the processing of social cue could be inhibited, by comparing the performance from participants of different ages (i.e., 5-6, 7-8, 9-10, 11-12 and adults) who were believed to have different levels of maturity in inhibitory control (Experiment 3). Chapter 5 used eye tracking technologies to study the temporal dynamics of social cue processing using the Cued Recognition Task, and investigated if the social cueing effect would be eliminated when *cue selection* and *cue following* was prohibited (Experiment 4). In Chapter 6, social cue processing between ASD and TD children will be measured by the Cued Recognition Task. Comparisons will be made and the differences between the two groups will be discussed (Experiment 5). In Chapter 7, all the findings from the 5 experiments will be discussed in detail. A conceptual model will be proposed to explain how social cues are processed based on the findings from all the experiments.

Experiment 1. The Cued Recognition Task

Introduction

As mentioned in the previous chapter, social cue processing consists of three distinct stages, namely *cue selection*, *cue following* and *object recognition*. Focused mainly on the measurement of *cue following* and *object recognition*, the social cueing paradigm did not provide the possibility to measure *cue selection*, and had the potential of mixing two different types of attention orientation effects by only presenting an object at one side of the cue. In order to address these potential issues, the Cued Recognition Task is developed. Figure 4 illustrates the trial sequence of the Cued Recognition Task in relation to the three stages of social cue processing. The trial starts with a center fixation cross. After that, a half-length portrait of a model with outstretched hands will be presented. The onset of the *cue selection* stage coincides with the onset of the picture of the model. It should be noted that the face of the model is always above the location of the center fixation cross. In the next frame of presentation, the head-turn of the model will be presented. This frame will be presented for different lengths of SOAs before the objects are presented in the next frame. The *cue selection* stage can be completed shortly after the onset of the head-turn but before the objects are presented. The *cue following* stage starts right after the completion of *cue selection*. A short period after the objects are presented, *cue following* can be competed and *object recognition* stage will be initiated, until a response is made by the participants. In the Cued Recognition Task, one of the two target objects (either a circle or a square), and the distractor object (a triangle) will be presented in each hand of the model. The head-turn of the model is not predictive of where the target will be presented. The task of the participants is to report whether the target is a square or circle, while ignoring the non-predictive head-turn. In the example presented in Figure 4, the model is looking at the hand that holds the distractor triangle, and the correct response is “square ”. There are three critical differences between the Cued Recognition Task and the standard social cueing task, as will be described in the following paragraphs.

Figure 4. **The illustration of the trial sequence of the Cued Recognition Task in relation to the three stages of social cue processing. In this example, a trial in the invalid cueing condition was presented. The correct response in this trial is “square”.**

First of all, the social cue used in the Cued Recognition Task is head-turn. When measuring social cue processing, the use of head-turns as social cues provides better ecological validity than the use of eye gaze shifts, both in terms of the sender and the receiver of the social cues. To be specific, when attending to different locations in the visual field, eye gaze shift is usually accompanied with head-turns. Studies showed that when looking at visual stimuli in different locations of the visual field, horizontal gaze position changes within 35 visual degrees were usually achieved by the pupil movements, but changes larger than 35 degrees received contributions from both pupil movements and head-turns (Stahl, 1999). The coordination between pupil movements and head-turns is optimized by the cross-communication between independent neural circuits of eye and head controllers (Kardamakis & Moschovakis, 2009). Therefore, when interpreting where an individual is looking, observers make use of both the pupil location and head direction (Hietanen, 2002; Todorovic, 2006; Itier, Villate & Ryan, 2007; Kluttz, Mayes, West& Kerby, 2009). In the Cued Recognition Task, head-turns are employed as the social cues to orient the attention of the viewer.

Second, before the objects are presented, the head-turn will no longer be the only stimulus on the screen, and will not be presented at the location of the center fixation cross (see the example in Figure 4). This manipulation provides the opportunity for *cue selection*. In the social cueing paradigm, gaze cue is usually presented at fixation and is the only stimulus on the screen before the objects are presented. Therefore, there are no competitions between the social cue and other information. In the Cued Recognition Task, the half-length portrait of a model with outstretched hands will be presented. The social cue will be presented in the form of the head-turn of the model, indicating that he/she is looking at either his/her left or right hands, in which the object will be presented after various SOAs. The non-social body parts, including the neck, shoulder, chest and hands cover a larger visual areas than the social body part such as the eyes and face. This manipulation enables the measurement of whether the viewers automatically select the social cue instead of other non-social stimulus, even if this process is orthogonal to the task of object recognition. More importantly, since objects will be presented in the hands of the model, a connection between the model and the objects can be built. This attention orienting from head to hand is very often observed in daily life, and is one of the first joint attention abilities observed in infants around 3-4 months old (Amano, Kezuka, & Yamamoto, 2004).

Last but not least, the task for the participants is to identify which of the two target objects is presented in one hand of the model, while disregarding the distractor presented in the other hand of the model. The purpose of this manipulation is to control for the peripheral onset effect elicited by the single-sided object presentation. As mentioned in the previous chapter, the single-sided peripheral object onset itself serves as reflexive attention cues, and this type of attention orientation cue has different characteristics than center social cues (Corbetta et al., 2008; Driver et al., 1999; Friesen & Kingstone, 1998; Jonides, 1981; Posner, 1980; Yantis & Jonides, 1996). While the purpose of the center cueing task is to measure the temporal dynamics of the cueing effect elicited by social cues, the peripheral onset effect elicited by the object could be a potential confound. The disentanglement of the interaction between the two different types of cueing effects is especially important in the short and long SOA conditions. In the short SOA conditions, the social cueing effect may be relatively small, and may be overwhelmed by the peripheral onset effect. In the long SOA conditions, it is believed that the social cueing effect can be suppressed by voluntary inhibition due to its non-predictive nature (e.g., Friesen & Kingstone, 1998). However, the diminished social cueing effect might not just be a result of voluntary inhibition, it could also partly be a product of the increased cueing effect elicited by the peripheral onset of single-sided object. Early studies measuring simple response time of target detection showed that, response time to detect a signal decreased when a warning signal was presented before the reaction signal, and as the foreperiod (the interval between the warning and reaction signals) increased, response time decreased until some optimal foreperiod was reached, indicating an increasing level of alertness or expectation of the object onset (Bertelson, 1967; Bertelson & Tisseyre, 1968, 1969; Klein & Kerr, 1974; Klemmer, 1956; Posner, Klein, Summers

& Buggie, 1973). In the social cueing task, the onset of the gaze cue can be regarded as a warning signal, and the SOA between the gaze cue onset and object onset is similar to the foreperiod. This foreperiod effect is also present in gaze cueing tasks, as indicated by the main effect of SOA that response time in long SOA is faster than those in the short SOA condition (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). It can be inferred that at long SOA, such as 1005 ms, the peripheral onset effect is larger than that at shorter SOAs because of the increased level of expectation and alertness to the object onset. As a result, the increased alertness of single-sided object onset can elicit a strong exogenous attention orientation, which might have overwhelmed the social cueing effect. In short, it is not fair to draw the conclusion that the social cueing effect is not significant at short and long SOAs, unless the peripheral onset effect is eliminated. In the Cued Recognition Task, because the object will be presented at both side of the social cue, the increased alertness of target onset will be cancelled by the same effect elicited by the distractor on the other side of the social cues. Therefore, the peripheral onset effect should be eliminated.

Because these three modifications were made in the Cued Recognition Task as compared to the standard social cueing task, the main purpose of Experiment 1 is to test if the Cued Recognition Task is able to elicit any significant social cueing effect at all. Moreover, if the cueing effect is significant, another main purpose of this experiment is to investigate the temporal dynamics of the cueing effect. It is expected that, with the elimination of the peripheral onset effect, the results should reflect the true temporal dynamics of social cue processing, and it's possible to test if the social cueing effect still exists at long SOA.

Method

Participants

Participants were a sample of 27 (20 female) undergraduate students at the University of Victoria. The mean age of the participants is 20.22 years old (*SD*=2.35). Participants were recruited through the online Psychology Research Participation System from University of Victoria (SONA Ltd.) and compensated with bonus class points.

Apparatus

Experiments were conducted on a 17-inch VDT monitor. A set distance of 55 cm from the participants' eyes to the surface of the screen was arranged to control for the visual angle of the stimulus. A string attached to the monitor was used to measure this distance and participants were asked to remain relatively still throughout the duration of the experiment in order to maintain this distance.

Stimuli

Pictures of a target object (either a circle or a square) appearing on one outstretched hand of a human model and a distracter object (a triangle) appearing on the other hand were presented (Figure 5). The target and distractor appeared in either blue or orange color, but within each trial, the color of the target was always the same as the color of the distractor. The target and the distracter were of 1 visual degree of span (i.e., the height of the square and the triangle, and the diameter of the circle were all 1 degree) and the centroid of the objects were 2.5 degrees away from the vertical middle line of the screen and 1 degree below the horizontal middle line of the screen. The face of the model spread approximately 2 degrees in width and 2.5 degrees in height and the eyes of the model were at approximately 1 degree above the center of the screen. Two students (one male and one female, all Caucasians) volunteered to be the model.

Figure 5. **An example of the stimulus used in the Cued Recognition Task.**

Design

The with-subject variable of this study was the Cue Validity and Stimulus Onset Asynchronies (SOA). The Cue Validity variable consisted of two conditions, valid and invalid conditions. In the valid condition (50% of the trials), the model looked at the target, and in the invalid condition (the other 50% of the trials), the model looked at the distractor. In general, the head-turn was not predictive of where the target would appear. The SOA, which referred to the delay between the head-turn of the model and the appearance of the objects, consisted of 5 levels, namely 0, 105, 300, 600 and 1005 ms. The experiment consisted of 16 practice trials followed by 2 blocks of 160 trials for a total of 320 trials. Participants were allowed to take a short break after the completion of each block. All the blocks were counter-balanced across Cue Validity (valid and invalid) and SOA (0, 105, 300, 600 and 1005 ms), target type (circle or square), target and distractor color (orange or blue), gender of the model (male or female), and the location of the target (left or right). Therefore, all the conditions were mixed within each block, and the participant didn't know what condition they were in until the objects appeared.

Procedure

Participants were asked to complete a 20-minute computerized task. Once participants had read through the instructions provided on the monitor, the experimenter reiterated the following instructions. Participants were told that a model would appear on the screen with their hands held out to the side, palms facing up. The model's head would turn either to the right or the left and then objects would appear on both hands of the model. On one hand, a circle or a square would be presented, which was the target that the participants were required to respond to. On the other hand, there would always be a triangle, which was a distractor and should be ignored. Participants were told to ignore the head turn of the model, as it would not predict the location of the target. The task was to identify the target (either the circle or the square) by pressing "c" for circle or "s" for square with their left hand (left middle finger on "s" and left pointer finger on "c"). Before the participants began the experiment, the experimenter measured the distance between the participants' eyes and the computer screen according to the string attached to the monitor. Participants were then given 16 practice trials before continuing on to the experiment. The trial started with a center fixation cross presented on the screen for 100 ms, followed by a picture of the model with their left and right hands empty and looking straight at the participants for either 600 ms or 1000 ms on a random basis. The next image presented was the head turn of the model to look either toward their left or right hand. Objects would then appear in both of the model's hands after different SOA levels (selected on a random basis). This image would not disappear until the participant input their response from the keyboard. See Figure 6 for a demonstration of the experiment flow.

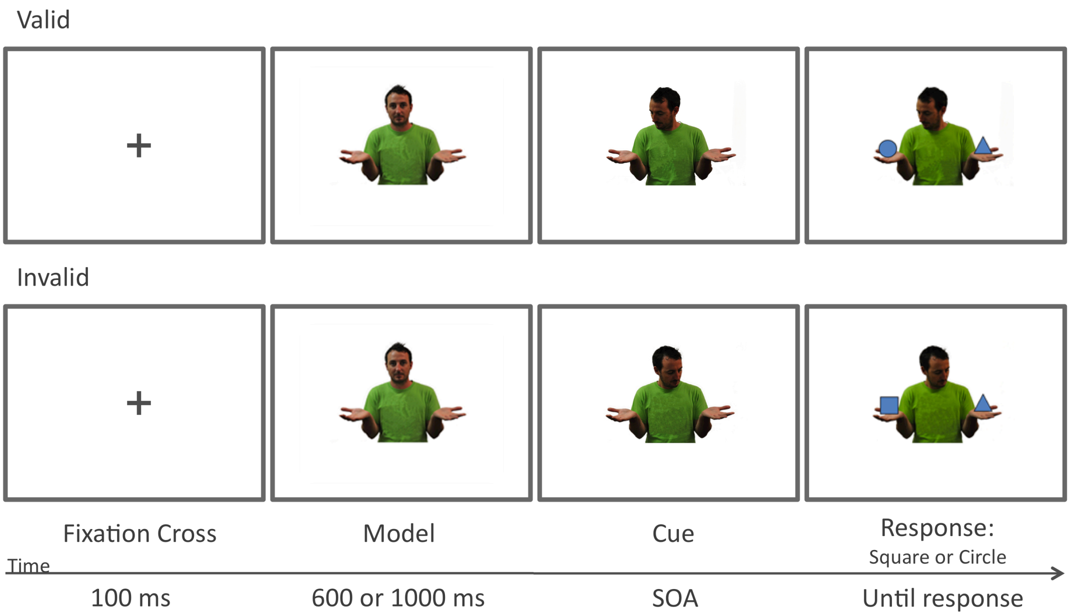


Figure 6. **The illustration of the trial sequence of the Cued Recognition Task. The top panel demonstrates a trial in the valid cueing condition. The correct response is "circle". The bottom panel demonstrated a trial in the invalid cueing condition. The correct response is "square".**

Results

Accuracy

A two-way ANOVA was conducted with Cue Validity (valid, invalid) and SOA (0, 105, 300, 600 and 1005 ms) as within-subject variables (Figure 7). The main effect for Cue Validity was significant ($F_{(1,26)}$ =17.44, p<0.001, η_p^2=0.40, $CI_{95\%}$: 0.19, 0.61), which was driven by the higher accuracy in the valid condition than invalid condition. The two-way interaction between Cue Validity and SOA showed the trend to be significant ($F_{(4,104)}$ =1.98, p=0.10, η_p^2=0.07, $CI_{95\%}$: 0.01, 0.12). Planned multiple comparison analysis for the cueing effect across different level of SOAs (with Bonferroni corrections) showed that, the accuracy in the valid condition was significantly higher than the accuracy in the invalid condition at 0 (p<0.05), 600 (p<0.05) and 1005 (p<0.01) ms of SOA, but not at 105 (p=0.49) and 300 (p=0.36) ms of SOAs.

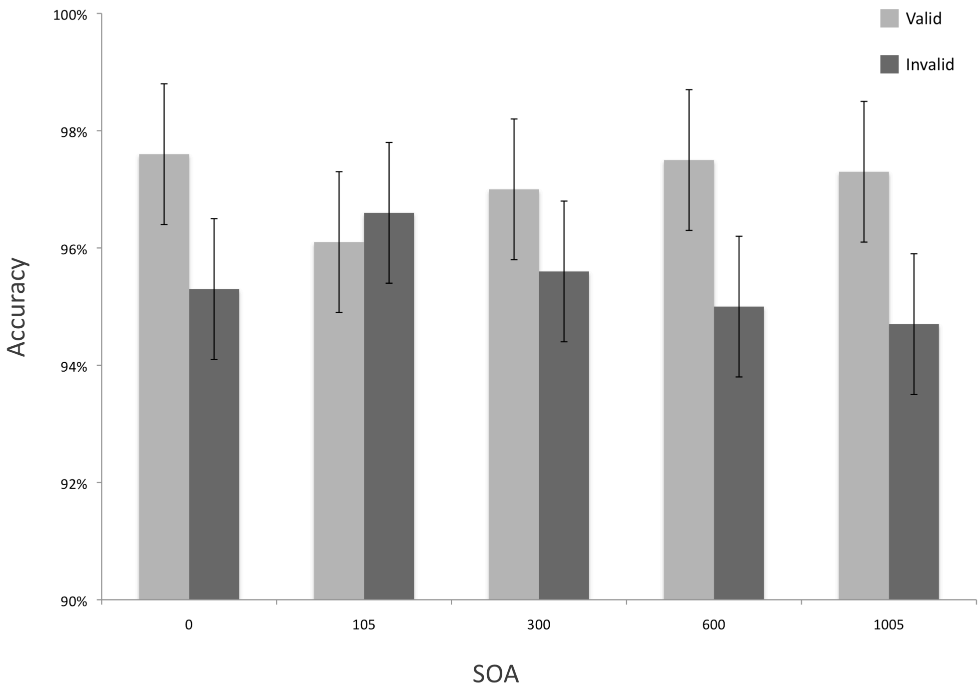


***Figure 7*. Accuracy in the valid and invalid conditions at different levels of SOAs. Error bars refer to 95% within-subject confidence intervals.**

Response time

Only correct trials and trials with response times within the range of 2 standard deviations from the participant's mean response time were included in the analysis. A two-way ANOVA with Cue Validity (valid, invalid) and SOA (0, 105, 300, 600 and 1005 ms) as within-subject variables was conducted (Figure 8). The main effect for SOA ($F_{(4,104)}$ =3.67, p<0.01, η_p^2=0.12, $CI_{95\%}$: 0.02, 0.14) was significant. This main effect was driven by the typical foreperiod effect that responses at 600 ms of SOA were faster than at 0 and 105 ms of SOA (both ps <0.001). The main effect of Cue Validity ($F_{(1,26)}$ =5.86, p<0.05, η_p^2=0.18, $CI_{95\%}$: 0.02, 0.42) was also significant. This main effect was driven by the faster response time in the valid condition than the invalid condition. The two-way interaction between SOA and Cue Validity was also significant ($F_{(4,104)}$ =2.99, p<0.05, η_p^2=0.10, $CI_{95\%}$: 0.01, 0.13). Planned multiple comparisons for the cueing effect across different level of SOAs (with Bonferroni corrections) showed that, response times in the valid condition were significantly faster than the invalid condition at 300 (p<0.01) and 1005 (p<0.05) ms of SOA, and this cueing effect at 105 (p=0.09) and 600 (p=0.10) ms of SOA showed a trend to be significant.

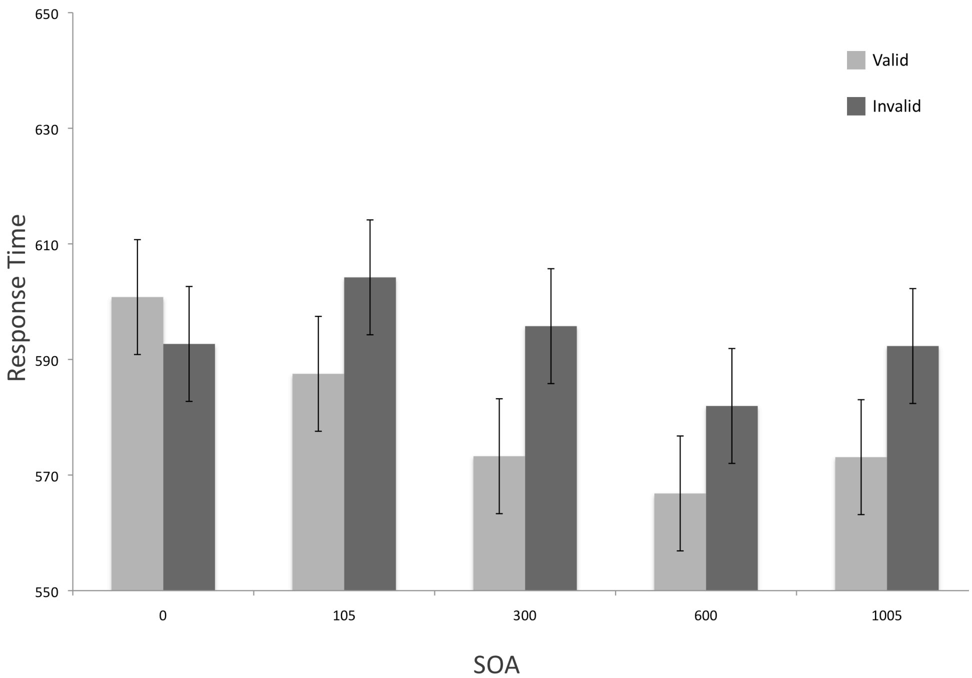


Figure 8. **Response time in the valid and invalid conditions at different levels of SOAs. Error bars refer to 95% within-subject confidence intervals. Only correct trials (excluding response time outliers) were included.**

Discussion

The current experiment used the Cued Recognition Task with non-predictive head-turn cues to measure the temporal dynamics of social cue processing. The results showed that, in general, objects were identified more accurately and faster in the valid cueing condition than the invalid cueing condition. The cueing effect was more pronounced in response time measure, because the accuracies were close to ceilings. The cueing effects reflected in response time were significant at all SOA conditions except for 0 ms.

The main purpose of this experiment was to test if the Cued Recognition Task was able to elicit significant social cueing effects. The results showed that, consistent with the findings using gaze cueing task, significant cueing effects were also found in the Cued Recognition Task using non-predictive head-turn cues. It indicated that, the non-predictive head-turn cues in the Cued Recognition Task were selected and followed automatically despite the instructions to ignore them.

However, the findings from the current experiment differed from the traditional findings using social cueing tasks that the cueing effect usually diminished at long SOAs (Driver et al, 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). One of the reasons for this difference could be that, in the 1005 ms SOA condition of the Cued Recognition Task, despite the increased alertness and expectation of the objects' onset (Bertelson, 1967; Bertelson & Tisseyre, 1968, 1969; Klein & Kerr, 1974; Klemmer, 1956; Posner et al., 1973), no attention orientation effect would be elicited by the objects because such effect at one side of the cue could be cancelled out by the same effect at the opposite side of the cue. Therefore, the significant cueing effect at 1005 ms of SOA showed that non-predictive head-turn cues could still automatically orient attention to the validly cued location even 1005 ms after its onset.

However, except for the employment of the distractor to eliminate the peripheral onset effect, the Cued Recognition Task also used different types of cues (i.e., head-turns) than the social cueing paradigm (i.e., pupil shift). In the next chapter, a control experiment was conducted to exclude the possibility that the prolonged social cueing effect in the current experiment was because of the head-turn cues used in the Cued Recognition Task, rather than the control for the peripheral onset effect. Therefore, in Experiment 2, the performance in the non-distractor version of the Cued Recognition Task without the control for peripheral onset effect (i.e., only targets, but no distractors on the other side of the cue were presented) was used to compare with the performance in the standard Cued Recognition Task. This comparison should provide evidence of whether the control for peripheral onset effect was responsible for the significant cueing effect at 1005 ms of SOA.

Critically, at the 0 ms of SOA when head-turn cues and objects onsets were simultaneous, no cueing effect was found in the response time measurement. It was possible that the simultaneous presentation of the cues and objects did not provide enough time for the *cue selection* process to accrue. Although participants could still orient their attention to the social cues rather than the objects, this process was overwhelmed by the more task relevant process of attending to the objects. It might be the case the *cue selection* process was voluntarily inhibited by the participants, and therefore the *cue following* process was not activated. However, in order to support this hypothesis, a control experiment is necessary. In this control experiment, the 0 ms of SOA condition of the Cued Recognition Task should be used to test participants of difference age groups. If the social cue processing was inhibited at 0 ms of SOA by adult participants in the current experiment, participants of younger age, whose inhibitory control ability is not fully developed, should not be able to fully inhibit the processing of the social cue (Comalli, Wapner & Werner, 1962; Rueda, Fan, McCandliss, Halparin, Gruber, Lercari & Posner, 2004; Wright, Waterman, Prescott & Murdoch-Eaton, 2003).

Moreover, one of the important manipulations of the Cued Recognition Task was the possibility to measure *cue selection*. However, as mentioned in the previous chapter, because social cues are highly salient to our visual system, they more readily capture our attention and can be more efficiently processed than non-social stimuli (Farroni et al., 2005; Lewis & Edmonds, 2003; Morton & Johnson, 1991), such as arrows or word labels. In the Cued Recognition Task, even if the head-turn cues were not pre-selected, participants still automatically processed the cues, regardless of the instructions of not to ignore the social cue and the existence of other non-social body parts. However, if *cue selection* is crucial for social cue processing, the magnitude of the cueing effect should be decreased, or even diminished if *cue selection* is mandatorily disabled. This manipulation could be achieved by restricting the eye movement in the *cue selection* and *cue following* stage and make sure participants do not fixate on the social cues. This control experiment should be able to show evidence of the importance of *cue selection* in social cue processing.

In summary, the current experiment showed that, using the Cued Recognition Task, a prolonged cueing effect at 1005 ms of SOA was found, indicating that social cues elicit attention orientation effect even at 1005 ms after its onset, which was different from the traditional finding that the cueing effect diminished at long SOAs. However, several control experiments were needed to verify (a) if the prolonged cueing effect was due to the control for the peripheral onset effect, (b) if the cue selection and following process were inhibited at 0 ms of SOA, and (c) if the cueing effect could be diminished if *cue selection* and *cue following* were not allowed.

Therefore, in the next chapter, three experiments will be carried out to test the three hypotheses.

Experiment 2. Measuring the Peripheral Onset Effect

Introduction

A surprising result from Experiment 1 was that the attention orientation effect elicited by non-predictive social cues was still present at 1005 ms of SOA using the Cued Recognition Task. This finding differed from the previous results using the social cueing paradigm in which the cueing effect diminished at long SOA such as 1000 ms (Driver et al, 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). One of the possible explanations of this difference might be the elimination of the peripheral onset effect in the Cued Recognition Task. As mentioned in the previous chapters, the single-sided object onset elicits exogenous attention orientation. This reflexive attention orientation effect might interfere with the social cueing effect that being measured. In standard social cueing tasks, the peripheral onset effect cannot be eliminated because of the single-sided object presentation. At 1005 ms of SOA, the peripheral onset effect is relatively strong due to the foreperiod effect (Bertelson, 1967; Bertelson & Tisseyre, 1968, 1969; Klein & Kerr, 1974; Klemmer, 1956; Posner et al., 1973) and therefore, the social cueing effect can be overwhelmed by the peripheral onset effect. In the Cued Recognition Task, no cueing effect is elicited by the objects because such effect at one side of the cue can be neutralized by the same effect at the opposite side of the cue. Therefore, the social cueing effect is not interfered by the peripheral onset effect. However, there was still a pending question whether this difference was due to the better control for the peripheral onset effect, or other differences between the Cued Recognition Task and the social cueing task. In Experiment 2, the performance from the non-distractor version of the Cued Recognition Task*,* in which the distractor was not presented on the opposite side of the target, was measured to compare with the performance of the original version of the Cued Recognition Task (the distractor condition). The non-distractor version of the Cued Recognition Task did not control for the peripheral onset effect because of the single-sided target onset. If the prolonged social cueing effect was indeed due to the better experiment control of the peripheral onset effect, the following hypotheses should be supported, and vice versa.

First, the social cueing effect in the distractor and non-distractor conditions should have different temporal dynamics. On the one hand, the temporal dynamics of the social cueing effect in the distractor condition should replicate the findings from Experiment 1. On the other hand, the temporal dynamics of the social cueing effect in the non-distractor condition should replicate the findings from the previous studies using the social cueing paradigm that the social cueing effect was not significant at 105 and 1005 ms of SOA (Friesen & Kingstone, 1998, Experiment 3).

Second, in the non-distractor condition, because the single-sided object onset provides attention orientation cues (Posner, 1980; Yantis & Jonides, 1996), the attention orientation effect elicited by head-turn cues will be interfered by the peripheral object onset effect. This effect can be reflected by the suppression of the processing of head-turn cues, which can be illustrated by delta plots. Delta plots are used to plot the size of interference effects as a function of response speed in conflict tasks, such as Simon task, Stroop task, Flanker task, etc., in which participants are required to perform a central task while suppress the more dominant and automatic processing of task-irrelevant information (e.g., Bub, Masson & Lalonde, 2006; de Jong, Liang & Lauber, 1994; Ridderinkhof, Scheres, Oosterlaan & Sergeant, 2005). According to the activation-suppression hypothesis (Ridderinkhof, 2002), when performing conflict tasks, activation from irrelevant stimulus will be selectively suppressed, but this selective suppression process takes some time to build up.

Therefore, the influence of this suppression process should be presented in trials with slow response times. In these trials, more time will be provided for the suppression process to accrue. The Cued Recognition Task, as well as the social cueing task, shares characteristics with conflict tasks. Participants are required to perform a central task (e.g., object detection or identification) while inhibit the more automatic processing of task-irrelevant stimulus (e.g., gaze shifts, head-turns, etc.). Therefore, delta plots can be appropriately used in investigating the relationship between the size of the social cueing effect and the speed of response. All trials in either the valid or invalid cueing condition can be further categorized into different speed groups in terms of response time independently. Cueing effect can be calculated by subtracting the mean response time in valid cueing condition from that of the invalid cueing condition, and should be calculated for each speed group independently. Consequently, the magnitude of the cueing effect in each speed group can be obtained. The magnitude of the cueing effects as a function of response speed can then be visualized in delta plots, with the horizontal axis as response time and the vertical axis as the magnitude of the cueing effect. In non-distractor condition, especially when head-turn cues are invalid, the attention orientation effect provided by the head-turn cues will be suppressed by the peripheral onset effect. As a result, a negative slope of the delta plot should be presented that the head-turn cueing effect should only be presented in trials with fast response time, in which the suppression process does not have enough time to accrue, but can be suppressed by the peripheral onset effect in trials with slow response time. This suppression effect will be presented in conditions where the magnitude of the peripheral onset effect is larger than the magnitude of the social cueing effect. At short SOA (i.e., 105 ms), the peripheral onset effect might be dominating because the head-turn cueing effect has not fully built up yet. As a result, the peripheral onset effect can overwhelm the social cueing effect. The suppression effect should also be pronounced at long SOA (i.e., 1005 ms) when the head-turn cueing effect is significant but the magnitude of the peripheral onset effect is relatively strong because of the foreperiod effect (Bertelson, 1967; Bertelson & Tisseyre, 1968, 1969; Klein & Kerr, 1974; Klemmer, 1956; Posner et al., 1973). However, no such suppression effect will be found in the distractor condition, because no attention orientation effect will be activated by the object onset.

Method

Participants

Participants were a sample of 35 (29 female) undergraduate students at the University of Victoria. The mean age of the participants is 19.80 years old (*SD*=2.01). Participants were recruited through the online Psychology Research Participation System from University of Victoria (SONA Ltd.), and were compensated with bonus class points.

Apparatus

The apparatus used in this experiment was exactly the same as Experiment 1.

Stimuli

Half of the stimuli used in this experiment were exactly the same as Experiment 1. The only difference between the rest of the stimuli and the stimuli used in Experiment 1 was that, only one of the targets (i.e., square or circle) was presented in one of the model's hand, but no distractor (i.e., triangle) was presented in other hand of the model (Figure 9).

Figure 9. **An example of the stimulus used in the non-distractor version of the Cued Recognition Task.**

Design

There were three with-subject variables in this study, namely the Cue Validity, Stimulus Onset Asynchronies (SOA) and Object Distraction. The Cue Validity was non-predictive (i.e., valid in 50% of the trials), and the same levels of SOA (0, 105, 300, 600 and 1005 ms) were used. The Object Distraction variable consisted of two conditions, namely the non-distractor condition and the distractor condition. In the non-distractor condition (50% of the trials), only the target (either a circle or a square) appeared on the left or right hand of the model. In the distractor condition (the other 50% of the trials), both the target and the distractor (a triangle) appeared on opposite hands of the model. The experiment consisted of 16 practice trials followed by 4 blocks of 160 trials, for a total of 640 trials. Participants were allowed to take a short break after the completion of each block. All the blocks were counter-balanced across Object Distraction (distractor and non-distractor), Cue Validity (valid and invalid) and SOA (0, 105, 300, 600 and 1005 ms), target type (circle or square), target and distractor color (orange or blue), gender of the model (male or female), and the location of the target (left or right). Therefore, all conditions were mixed within each block and the participant didn't know which condition they were in until the objects appeared.

Procedure

Participants were asked to complete a 40-minute computer task. The procedure was exactly the same as in Experiment 1, except that participants were told that the distractor triangle might or might not be presented. See Figure 10 for a demonstration of the flow of Experiment 2.

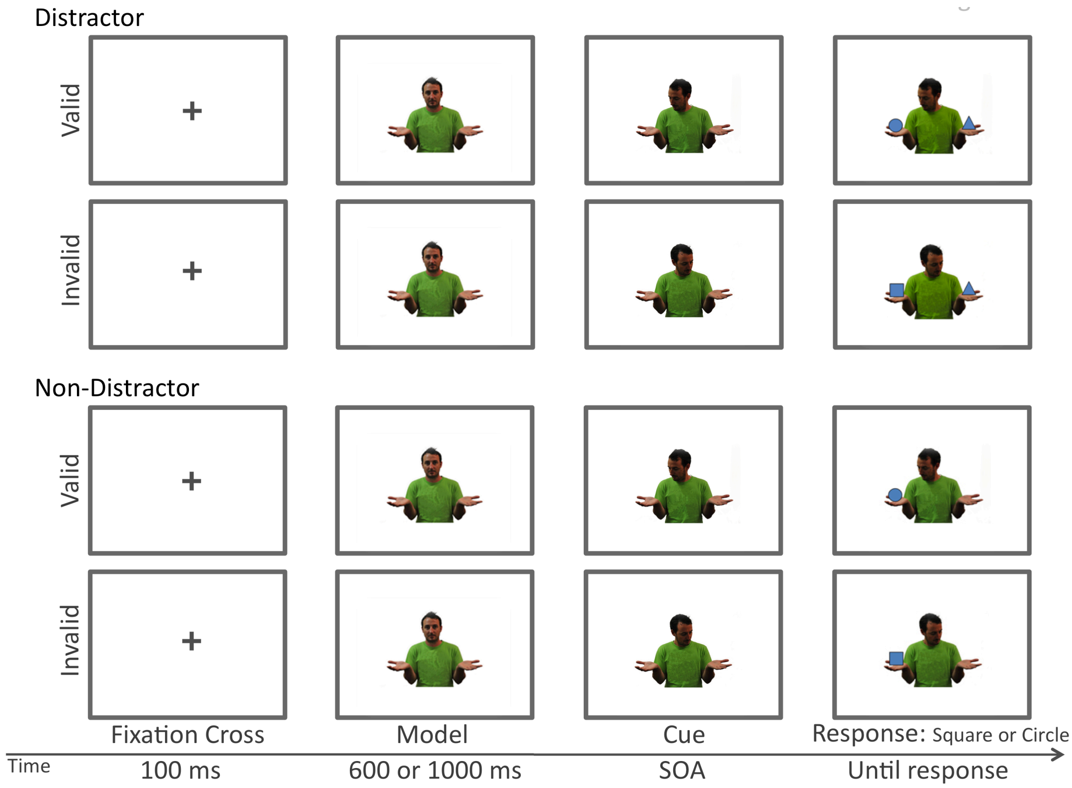


Figure 10. **Illustration of the flow of the non-distractor and distractor version of the Cued Recognition Task. In both conditions, the top panel demonstrates a trial in the valid cueing condition. The bottom panel demonstrated a trial in the invalid cueing condition.**

Results

Accuracy

A three-way ANOVA was conducted with Object Distraction (distractor, non-distractor), Cue Validity (valid, invalid) and SOA (0, 105, 300, 600 and 1005 ms) as within-subject variables (Figure 11a). The main effect for Cue Validity was significant ($F_{(1,34)}$ =21.69, p<0.001, η_p^2=0.39, $CI_{95\%}$: 0.20, 0.58), which was driven by the higher accuracy in valid condition than invalid condition. The main effect for Object Distractor was also significant ($F_{(1,34)}$ =10.01, p<0.001, η_p^2=0.23, $CI_{95\%}$: 0.06, 0.44), which was driven by the higher accuracy in the non-distractor condition than the distractor condition. Moreover, there was a significant two-way interaction between Object Distraction and Cue Validity ($F_{(1,34)}$ =6.94, p<0.05, η_p^2=0.17, $CI_{95\%}$: 0.03, 0.38). Planned comparisons for the cueing effect in between the distractor and non-distractor conditions showed that, accuracy in the valid condition was significantly higher (p<0.05) than the invalid condition in non-distractor conditions, but this effect was much larger in distractor condition (p<0.001) (Figure 11b). Furthermore, this two-way interaction could be further interpreted by the significant three-way interaction among Cue Validity, Object Distraction and SOA ($F_{(4,136)}$ =2.64, p<0.05, η_p^2=0.07, $CI_{95\%}$: 0.01, 0.10). Planned multiple comparisons (Bonferroni corrected) for the cueing effect in both distractor and non-distractor conditions at all levels of SOAs showed that, in the non-distractor condition, the cueing effect was only marginally significant at 105 (p=0.09) and 300 (p=0.06) ms of SOA. However, in the distractor condition, the cueing effect was significant at 300 (p<0.01) and 1005 (p<0.001) ms of SOA, and marginally significant at 600 (p=0.07) ms of SOA.

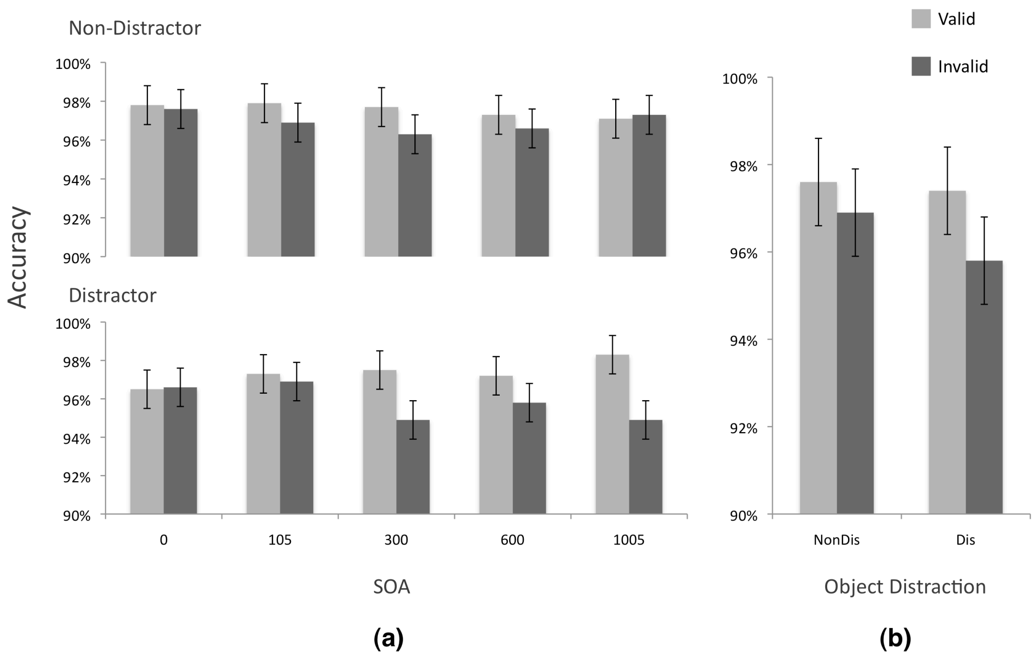
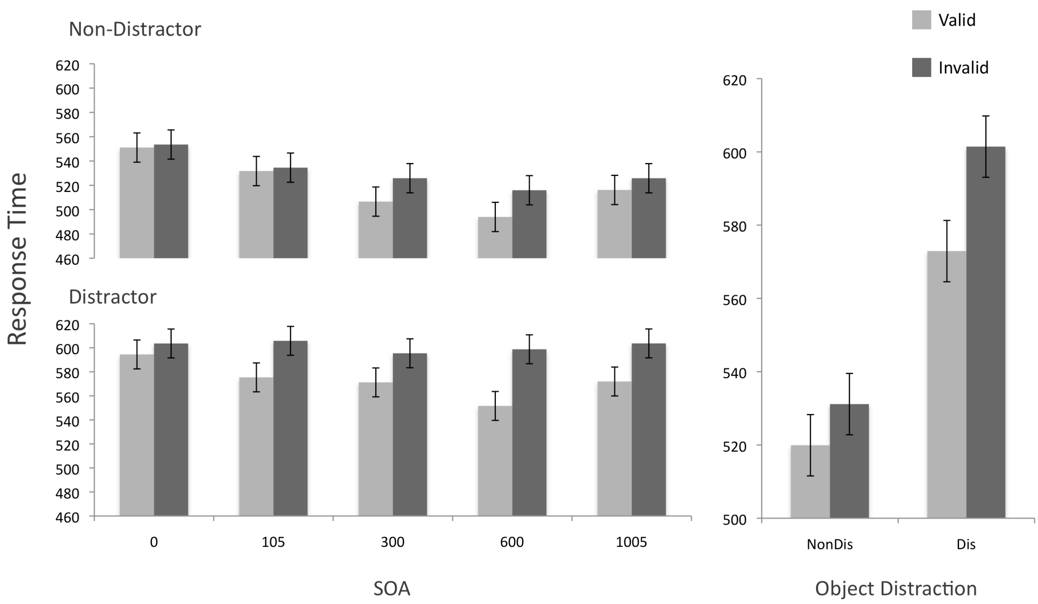


Figure 11. **Accuracy by Cue Validity, Object Distraction and SOA. (a). Accuracy in the valid and invalid conditions at different levels of SOAs for both the distractor and non-distractor condition; (b). Accuracy in the valid and invalid conditions for both the distractor and non-distractor condition, collapsed across different SOAs. Error bars refer to 95% within-subject confidence intervals.**

Response time

Only correct trials and trials with response times within the range of 2 standard deviations from the participant's mean response time were included in the analysis. A three-way ANOVA with Object Distraction (distractor, non-distractor), Cue Validity (valid, invalid) and SOA (0, 105, 300, 600 and 1005 ms) as within-subject variables was conducted (Figure 12a). The main effects for SOA ($F_{(4,136)}$ =23.34, p<0.001, η_p^2=0.40, $CI_{95\%}$: 0.08, 0.26), Object Distraction ($F_{(1,34)}$ =91.09, p<0.001, η_p^2=0.73, $CI_{95\%}$: 0.61, 0.83) and Cue Validity ($F_{(1,34)}$ =50.23, p<0.001, η_p^2=0.60, $CI_{95\%}$: 0.44, 0.73) were all significant. The main effect of SOA was driven by the foreperiod effect that responses at longer SOAs (i.e., 600 and 1005 ms) were faster than responses at shorter SOAs (i.e., 0, 105 and 300 ms). The main effect of

Object Distraction showed that it took longer to respond in the distractor condition than the non-distractor condition. The main effect of Cue Validity showed that response time in valid condition was significantly faster than the response time in the invalid condition. Importantly, the two-way interaction between Object Distraction and Cue Validity was significant ($F_{(1,34)}$ =21.30, p<0.001, η_p^2=0.39, $CI_{95\%}$: 0.20, 0.57). This interaction was driven by the larger cueing effect in the distractor (p<0.001) condition than the non-distractor condition (p<0.001) (Figure 12b). Planned comparisons (Bonferroni corrected) were carried out on the cueing effects at all levels of SOAs in both distractor and non-distractor conditions. For the non-distractor condition, the cueing effects were only significant at 300 (p<0.05) and 600 (p<0.01) ms of SOAs. However, for the distractor condition, cueing effects were significant at 105 (p<0.001), 300 (p<0.05), 600 (p<0.001) and 1005 (p<0.001) ms of SOAs. Moreover, the magnitude of cueing effects were larger in the distractor condition than non-distractor condition at all levels of SOAs (all ps<0.05) except for 0 ms.



(a) **(b)**

Figure 12. **Response time by Cue Validity, Object Distraction and SOA. (a). Response time in the valid and invalid conditions at different levels of SOAs for both the distractor and non-distractor condition; (b). Response time in the valid and invalid conditions for both the distractor and non-distractor condition, collapsed across different SOAs. Error bars refer to 95% within-subject confidence intervals. Only correct trials (excluding response time outliers) were included.**

Response Time Distribution

In order to explore the relationship between response speed and the magnitude of cueing effect, response time data for each participant were rank-ordered and further categorized into four successive bins in the valid and invalid condition independently. The 1st quartile represented the fastest 25% of the trials (i.e., bin1); the 2nd quartile represented the second fastest 25% of the trials (i.e., bin2), etc. Mean response time were calculated for the valid and invalid condition independently. Data for error trials and response outliers were excluded from the analysis, and the four successive quartile bins were of equal or nearly equal size, with 7 or 8 trials in each quartile in the majority of the cases. The relationship between the size of the cueing effects and response speed in distractor and non-distractor conditions were visualized in delta plots (Ridderinkhof, 2002). Visually, the slopes of the delta functions of the distractor and non-distractor conditions seemed to be different at 0, 105 and 1005 ms of SOA (Figure 13). Planned comparisons between the response time of valid and invalid conditions were conducted in each bin for both the distractor and non-distractor conditions at each level of SOA. At 0 ms of SOA, different patterns were found between the distractor and non-distractor condition. For the non-distractor condition, there were trends of reversed cueing effect (i.e., response time in invalid trials was faster than valid trials) in bin1 ($p = 0.06$) and bin2 ($p=0.08$), no significant cueing effect in bin3 ($p = 0.87$) and a trend of significant cueing effect in bin4 ($p = 0.10$). However, for the distractor condition, cueing effect in bin1 ($p<0.01$) and bin2 ($p<0.05$) were both significant, but not in bin3 and bin4 (both ps >0.16). Different patterns between the distractor and non-distractor condition were also found at 105 ms of SOA. For the non-distractor condition, cueing effect was significant in both bin1 ($p<0.05$) and bin2 ($p<0.05$), was diminishing in bin3 ($p= 0.11$) and was eliminated in bin4 ($p=0.55$). However, a different pattern was found for the distractor condition, in which cueing effects were significant in all bins (all *p*s < 0.01). Moreover, the cueing effect in bin4 showed trends to be significantly larger than bin 2 ($p=0.09$) and bin 3 ($p=0.10$). At 300 and 600 ms of SOA, similar patterns were found between the distractor and non-distractor condition. At 300 ms of SOA, in both the distractor and non-distractor condition, cueing effects were significant in bin1, bin2 and bin3 (all *p*s<0.05). In bin4, a slight trend was presented in the distractor condition ($p=0.15$), but not in the non-distractor condition ($p= 0.74$). At 600 ms of SOA, cueing effects were significant in all bins for both the distractor and non-distractor conditions (all *p*s<0.05). However, different patterns emerged again at 1005 ms of SOA between the distractor and non-distractor condition. For the non-distractor condition, the cueing effects were significant both in bin1 and bin2 (both *ps*<0.001), but diminished in bin3 and bin4 (both *p*s >0.35). However for distractor condition, the cueing effect was significant in bin1, bin2 and bin3 (both *p*s <0.001) and was diminishing in bin4 ($p=0.15$).

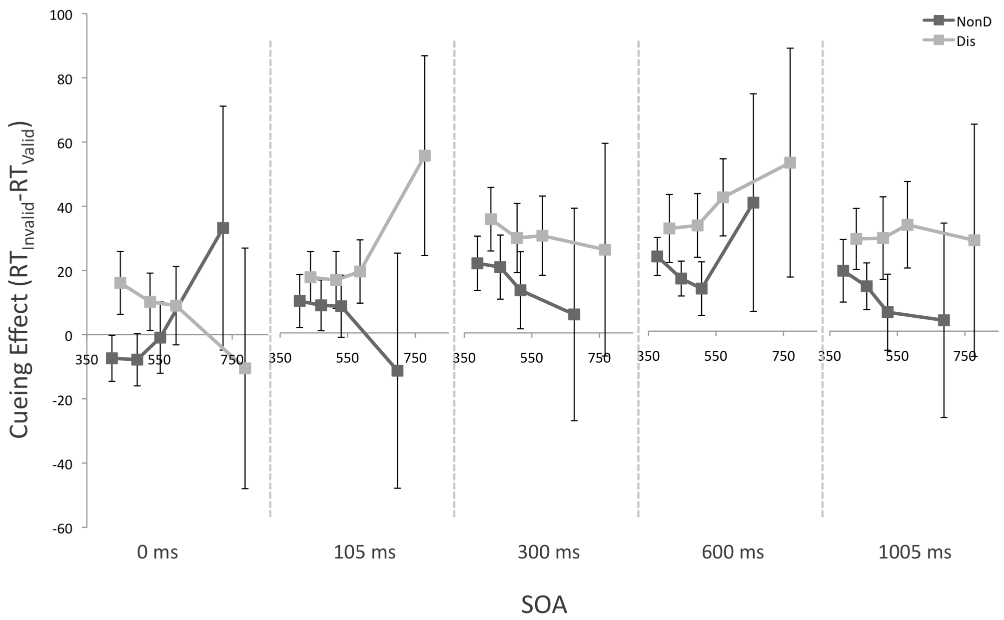


Figure 13. **Delta plots by SOA and Object Distraction. The vertical axis refers to the difference between the mean response time of invalid and valid conditions. The horizontal axis refers to the mean response time of all the trials in this quartile. Error bars refer to 95% within-subject confidence intervals. Only correct trials (excluding response time outliers) were included.**

Discussion

The purpose of the current experiment was to investigate whether the peripheral onset effect interfered with the social cueing effect. The results showed that overall, larger cueing effects were found in the distractor condition than the non-distractor condition. The head-turn cueing effects were significant at both short (i.e., 105 ms) and long (i.e., 1005 ms) SOAs in the distractor condition, but not in the non-distractor condition. Moreover, although the social cueing effects were significant in both the distractor and non-distractor conditions at 300 ms and 600 ms of SOAs, the magnitude of the cueing effects were significantly larger in the distractor condition than the non-distractor condition. In short, compared to the distractor condition, the social cueing effect had a later onset, was shorter-lived and was smaller in magnitude in the non-distractor condition.

Similar to the current study, Friesen et al. (2005) examined the peripheral onset effect by modifying the social cueing task to include the presentation of two peripheral objects (a target and a distracter), one on each side of the center gaze cue. In their task, the eye gaze cue appeared prior to the onset of two flanking objects and participants' task was to report the presence of a pre-defined target (e.g., circle). On some trials, the target appeared on one side of the cue and the distracter (e.g., square) on the other side, while on the catch trials, distracters appeared on both sides of the cue. In order to test whether the peripheral onset effect interfered with the cueing effect from center gaze cues, a one-object (non-distractor) condition was tested in comparison to the two-objects condition using a between-subject design. However, unlike the findings from the current experiment, the results from the study by Friesen et al. showed that the social cueing effect in the two-object paradigm was as large as the social cueing effect in the one-object paradigm, indicating the eye gaze cue was not interfered by the peripheral onset effect. It should be noted, however, there were several major differences between the current experiment and the study by Friesen et al. First, in the current experiment, a within-subject mixed design was employed in which participants were unaware of the distractor or non-distractor condition until the objects were presented. As a result, the differences between the distractor and non-distractor condition were purely due to the distinct bottom-up processing cause by the absence or presence of the distractor. However, in the study by Friesen et al., a between-subject design was used in which half of the participants were assigned to the distractor condition while the other half to the non-distractor condition. In this case, participants were all well informed of whether they were in the distractor or non-distractor condition. Participants might have developed distinct overall strategies to perform the tasks accordingly. Therefore, the discrepancies between the distractor and non-distractor condition reflected not only the differences in bottom-up processing (i.e., the absence or presence of the distractor), but also top-down strategies employed by participants in all stages of processing. In order to investigate whether the peripheral onset effect interfered with the processing of social cues, the within-subject mixed design used in the current experiment seemed to be a more valid choice. Second, different tasks were used. The current experiment required participants to perform an object recognition task, while ignoring the non-predictive social cues. In contrast, Friesen et al. required their participants to perform a go-no-go object detection task in which they had to inhibit both their responses on the catch trials and the non-predictive eye gaze cue. Therefore, a general inhibition mechanism was used to inhibit the response to the catch trials, and a selective inhibition mechanism was used to suppress the process of task-irrelevant social cues. Although these two inhibition mechanisms served different purposes, they could interact with each other (Ridderinkhof, Band & Logan, 1999). Although the general inhibition mechanism was equally activated in both conditions, the level of its interaction with the selective inhibition mechanism might vary across the two conditions. Therefore, the discrepancies between the distractor and non-distractor condition could be the product of not only the different level of selective inhibition, but also the different level of interactions between the general and selective inhibition mechanism. However, if the purpose of the experiment was to investigate the selective inhibition of social cue processing, the presence of the interaction between the general and selective inhibition mechanism might be a potential confound. In conclusion, the inconsistency between the findings from the current study and the study by Friesen et al. might be a result of the differences in the experiment design and task. The experiment design and task used in the current study had better validity in investigating whether the peripheral onset effect interfered with social cue processing.

The findings from the current experiment showed that the social cueing effects had different temporal dynamics and magnitudes in distractor and non-distractor conditions. It should be noted that response time in the non-distractor condition was significantly faster than that in the distractor condition. This extra 60 ms of response time in the distractor condition might have provided longer time for the head-turn cue to be processed. However, response time distribution analysis showed that this should not be the reason why the cueing effects were larger in the distractor condition than non-distractor condition. Although it was the case at 105 ms of SOA in the distractor condition, the magnitude of social cueing effect in both the non-distractor and distractor condition was not a function of respond speed at longer SOAs. Therefore, at least at 300, 600 and 1005 ms of SOAs, slower respond speed did not necessarily lead to larger social cueing effects.

If the pattern of the magnitudes of social cueing effect in the distractor condition reflected the true temporal dynamics of social cue processing, it could be concluded that the social cueing effect was still building up at 105 ms of SOA, peaked at 300 ms and 600 ms, and still existed at 1005 ms of SOA. These conclusions could be supported by the response time distribution analysis. At 105 ms of SOA, cueing effect was larger in trials with slow response times, in which longer exposure time was provided for the social cue to be processed, indicating the build-up of the cueing effect. At 300 ms, 600 ms and 1005 ms of SOA, the magnitudes of cueing effects were generally equivalent in trials with slow and fast responses, indicating that the social cueing effects were relatively stable.

In contrast, the response time difference between the valid and invalid condition in the non-distractor condition was the result of the interaction between the social cueing effect and the peripheral onset effect. Although the response time difference between the valid and invalid condition at 300 and 600 ms of SOA in the non-distractor condition were significant, they were still significantly smaller than their counterparts in the distractor condition. This difference in magnitude indicated that, compared to the distractor condition, the attention orientation effects by social cues were attenuated by the peripheral onset effect in the non-distractor condition at 300 and 600 ms of SOAs. Moreover, this interaction between the peripheral onset effect and the social cueing effect led to the elimination of the social cueing effect at 105 and 1005 ms of SOA. Response time distribution analysis indicated that, at 105 ms and 1005 ms of SOA, the attention orientation effect elicited by the social cues was significant in trials with fast response time, but not slow response time, indicating the activation of the suppression mechanism (Ridderinkhof, 2002). However, the characteristic of this suppression effect at 105 ms of SOA was different than that at 1005 ms of SOA. At 105 ms of SOA, the social cueing effect hadn't reached the peak yet. Therefore, it was overwhelmed by relatively strong peripheral onset effect (this effect was also present, though less well-pronounced at 300 ms of SOA). On the other hand, at 1005 ms of SOA, although the social cueing effect had already been built-up, the peripheral onset effect became even larger due to the increased level of expectation and alertness to the object onset (Bertelson, 1967; Bertelson & Tisseyre, 1968, 1969; Klein & Kerr, 1974; Klemmer, 1956; Posner et al., 1973). As a result, the social cueing effect, again, was overwhelmed by the peripheral onset effect at 1005 ms of SOA.

Although the cueing effects at 0 ms of SOA weren't significant in both the distractor and non-distractor condition, response distribution analysis showed that the relationship between the size of cueing effect and response speed was different under these two conditions. Strikingly, in the non-distractor condition, in trials with fast response time, a reversed cueing effect, with response time in the invalid trials faster than that in the valid trials, was presented. In trials with slow response time, significant cueing effect was presented. Some concepts in the dual-system architecture of conflict resolution (Coulthard, Nachev, & Husain, 2008) might be useful in explaining this seemingly counter-intuitive reversed cueing effect in trials with fast response time. Within the dual-system architecture, a bottom-up conflict resolution system and a top-down conflict resolution system are activated simultaneously, but functions independently. In invalid cueing conditions, the conflict elicited by the head-turn and single-sided object onset are represented in the bottom-up conflict resolution system and compete against each other via mutual inhibition. This conflict can be resolved faster if one source of conflict is much weaker than the other, or slower if the two sources of conflict have equivalent strength. On the other hand, the top-down conflict resolution system monitors and resolves this conflict independently by enhancing the activation of the task-relevant cue (i.e., orient attention to the object) and reducing the activation of task-irrelevant cue (i.e., follow the head-turn cue), regardless of how equivalent the strengths of these two cues are (see Cisek, 2008 for more details). In trials with fast response time, compared to the object cues, head-turn cues were relatively weaker because they were not fully activated yet. However, the top-down conflict resolution system still inhibited the processing of head-turn cues and enhanced the object cues. As a result, after the top-down inhibition, the originally weak social cueing effect elicited by the head-turn was over-inhibited, and thus the reversed cueing effects were presented. On the contrary, in trials with slow response time, as the strength of the head-turn cues were building up, they could no longer be overwhelmed by the inhibition from the top-down conflict resolution system. As a result, in trials with slow response time, significant cueing effects were presented. However, this reversed cueing effect in trials with fast response time was not observed in the distractor condition. One of the possible explanations could be that, in early stage of processing, the target and the distractor were only represented equally as objects and therefore, no attention orientation bias was activated. As a result, in early stage of processing, no conflict was represented by both the bottom-up and top-down conflict resolution system, and the head-turn cueing effect, although not fully built-up yet, still dominated the attention orientation. However, in trials with slow response time, objects were recognized as either a target or distractor, and thus, attention orientation cue toward the target was elicited. As a result, the conflict between the object and the head-turn cue was detected, both in the bottom-up and top-down conflict resolution system. However, because the head-turn cue was relatively stronger than that in the earlier stage of processing, the inhibition from the top-down conflict resolution system only eliminated the head-turn cueing effect, but did not yield a reversed cueing effect. However, this explanation should be treated with caution. This dual-system architecture of conflict resolution was developed based on the findings from studies of motor representation and controls (Coulthard et al., 2008; Bub & Masson, 2012). During motor representation and control, the bottom-up conflict resolution was performed by the parietal lobe and the top-down conflict resolution was carried out by the frontal system. However, in the current study, these two conflict resolution systems were only hypothetical, and required validation in future studies.

In conclusion, the current experiment provided evidence that the peripheral onset effect interfered with the social cueing effect at all levels of SOAs. Therefore, the social cueing effect measured in the non-distractor condition of the Cued Recognition Task did not reflect the true temporal dynamics of social cue processing. Interestingly, at 0 ms of SOA, the social cueing effect was inhibited even in the distractor condition, suggesting the contribution from a top-down conflict resolution system in monitoring and resolving the conflicting information provided by task-irrelevant information. The next experiment was designed to study if this top-down conflict resolution system was similar to the function of the frontal brain system.

Experiment 3. The Inhibition of Social Cue Processing

Introduction

Both the results from Experiment 1 and 2 showed that the social cueing effect could be eliminated if the cue and objects were presented simultaneously (i.e., at 0 ms of SOA). One of the possible explanations for this finding was that, the process of the head-turn cue was inhibited by top-down conflict resolution, presumably performed by the frontal system of the brain. However, further evidence was required to support this hypothesis. If the magnitude of the cueing effect at 0 ms of SOA of the Cued Recognition Task was increased in participants with less well-developed frontal system, it could at least be inferred that the top-down conflict resolution was related to the frontal brain system. The current experiment investigated whether the social cue processing can be inhibited by younger participants, who were believed to have less well-developed frontal system, and thus have difficulty in inhibiting the processing of task irrelevant information (Comalli et al., 1962; Wright et al., 2003; Rueda et al., 2004).

In a study by Ristic, Friesen & Kingstone (2002) using the social cueing task, they found that children (ages 3 to 5) showed a stronger cueing effect than adults under the condition where the cue was non-predictive. However, because they used a single target design with no distractor, it was difficult to disentangle the cueing effects of eye gaze from the peripheral onset effect. More importantly, in their study, the shortest SOA was 195 ms, which provided sufficient time to process the gaze cue. Therefore, adult participants still showed a significant cueing effect at the shortest SOA, indicating that the inhibition mechanism was not fully activated.

According to the findings from Experiment 1 and 2, social cue processing in the Cued Recognition Task can be inhibited at 0 ms of SOA, and therefore, no significant social cueing effect was presented. In the current experiment, we tested the social cueing effects using the 0 ms of SOA condition of the Cued Recognition Task in participants of five age groups (5-6 years old, 7-8 years old, 9-10 years old, 11-12 years old and adults). Participants were asked to verbally report the presence of a circle or square target object, while ignoring the distractor triangle presented on the opposite side of the center non-predictive head-turn cue. Younger participants have been shown to have a slower response time compared to older participants (Kail, 1991; Kail & Ferrer, 2007) and are less able to inhibit the processing of conflicting task-irrelevant information (Comalli et al., 1962; Rueda et al., 2004; Wright et al., 2003). Therefore, it was expected that younger participants should have a slower overall response time and a larger cueing effect than older participants.

Method

Participants

Five age groups were tested in this study. Twenty 5 to 6-year-olds (7 boys, 13 girls, mean age = 6.1), thirty-one 7 to 8-year-olds (18 boys, 13 girls, mean age = 7.9), twenty-eight 9 to 10-year-olds (11 boys, 17 girls, mean age = 10.1), twenty-seven 11 to 12-year-olds (13 boys, 14 girls, mean age = 11.8) and 24 adults (6 males, 18 females, mean age = 19.6) participated in the present experiment. Participants aged 5–12 were tested during a free one-day camp held at the University of Victoria, and adult participants were undergraduate students from the University of Victoria and completed the experiment for course credit.

Stimuli

The same set of stimuli was used as in Experiment 1.

Design

The between-subject variable of this study was the Age of the participants while the within-subject variable was Cue Validity. In the valid condition (50% of the trials), the model looked at the target, and in the invalid condition (the other 50% of the trials), the model looked at the distractor. In general, the head-turn was not predictive of where the target would appear. All the 64 trials were counter balanced across Cue Validity (valid and invalid), Target and Distracter Color (blue or orange), Gender of the Model (male or female) and the Location of the Target (left or right).

Procedure

A full trial started with a 1000 ms center cross fixation, and followed by a picture of the model with both hands empty and looking straight at the participants for either 600 ms or 1000 ms on a random basis. In the image followed by this presentation, the model turned his/her head and looked at either the left or right hand, without moving any other body parts. At the same time, one of the targets appeared on one hand, and the distracter appeared on the opposite hand. Participants were told that the head-turn cues were random, and were asked to ignore them. Participants were asked to tell the experimenter if they saw a circle or a square, and the experimenter would press the button as soon as they heard the complete word of "circle" (press <C>) or "square" (press <S>) spoken by the participants. The trial would be terminated by the key press of the experimenter according to the participants' verbal report. Experimenters were trained not to look at the screen and press the button as soon as the participants made a complete vocal reports. Participants practiced for 16 trials naming the target objects without the presence of the model. The practice could be repeated if the participants still had problems understanding the instructions. After that, participants practiced again for 16 trials with the actual stimulus used in the experiment. Once this was done, the experimenters would measure the distance between the participants' eyes and the screen surface, and made adjustment according to the measurement. A break session was provided after 32 trials. When the experiment was resumed, the same measurement and adjustment procedure was conducted.

Results

Accuracy

A two-way ANOVA was conducted with Cue Validity (valid, invalid) as a within-subject variable and Age (5-6 years old, 7-8 years old, 9-10 years old, 11-12 years old and adults) as a between-subject variable. The main effects for Cue ($F_{(1,125)}$=0.95, p=0.33, η_p^2=0.01, $CI_{95\%}$: 0.00, 0.05) and Age ($F_{(4,125)}$=0.91, p=0.46, η_p^2=0.03, $CI_{95\%}$: 0.00, 0.09) were not significant. The interaction between Age and Cue was significant ($F_{(4,125)}$=3.26, p<0.05, η_p^2=0.10, $CI_{95\%}$: 0.01, 0.12). This effect was driven by the significant difference (p<0.01) between the valid (M=0.992 SE=0.005) and invalid (M=0.973 SE=0.006) condition for the 5-6 years old age group. The differences between the valid and invalid conditions for other age groups were not significant.

Response Time

Only correct trials and trials with response times within the range of 2 standard deviations from the participant's mean response time were included in the analysis. A two-way ANOVA, with Cue Validity (Valid, Invalid) as within-subject variable and Age (5-6, 7-8, 9-10, 11-12 years old and adults) as between-subject variable, was conducted (Figure 14). There was a significant main effect of Cue Validity ($F_{(1,125)}$=20.69, p<0.001, η_p^2=0.14, $CI_{95\%}$: 0.06, 0.24) driven by the faster response time for the valid cueing condition than the invalid cueing condition. The main effect of Age was also significant ($F_{(4,125)}$=32.55, p<0.001, η_p^2=0.51, $CI_{95\%}$: 0.13, 0.33). The post-hoc comparisons (with Bonferroni corrections) showed that, the response time of the 5-6 years old group was significantly slower than all the other age groups (all ps<0.001). The 7-8 years old group was significantly slower (all ps<0.01) than the 11-12 years old and adult group. The adult group was faster than all the other age groups (all ps<0.01) except for the 11-12 years old group. No difference was found between the 9-10 years old group and the 11-12 years old group. Critically, there was a significant interaction between Age and Cue Validity ($F_{(4,125)}$=4.99, p<0.01, η_p^2=0.14, $CI_{95\%}$: 0.02, 0.14). Multiple comparisons (Bonferroni corrected) showed that, for the 5-6 years old group, the response time for the valid cueing condition was significantly faster (p<0.001) than the invalid cueing condition. For the 7-8 years old group, the difference between the response time for the valid cueing condition and the invalid cueing condition was also significant (p<0.01). For the 9-10 years old, 11-12 years old, and the adult groups, the difference between the response time of the valid cueing condition and the invalid cueing condition was not significant (all ps>0.33).

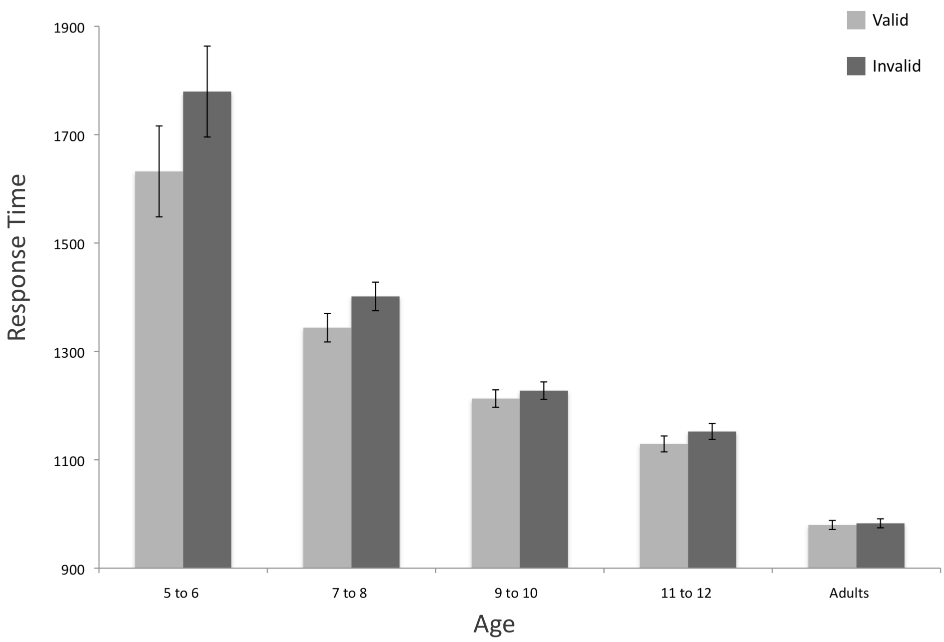


Figure 14. **Response time in valid and invalid cueing conditions across the five age groups. Error bars refer to 95% within-subject confidence intervals. Only correct trials (excluding response time outliers) were included.**

Response Time Distribution

In order to explore the relationship between response speed and cueing effect, response time data for each participant were rank ordered and further categorized into four successive bins in the valid and invalid condition independently. The 1st quartile represents the fastest 25% of the trials, the 2nd quartile represents the second fastest 25% of the trials, etc. Mean response time were calculated for the valid and invalid condition independently. Data for error trials and response outliers were excluded from the analysis, and the four successive quartile bins were of equal or nearly equal size, with 7 or 8 trials in each quartile in the majority of the cases. Moreover, participants were re-categorized into two groups, the younger group (5-8 years old) who showed a significant cueing effect, and the older group (9 years old and above) who did not show a significant cueing effect. A three-way ANOVA, with Cue Validity (valid, invalid) and Quartile (1st, 2nd, 3rd and 4th quartile) as within-subject variable and Age (5-8 years old, 9 years old and above) as between-subject variable, was conducted (Figure 15a). Main effects for Cue, Quartile and Age were all significant (all *p*s <0.001, all η_p^2s>0.18), and two-way interactions between Age and Cue, Age and Quartile and Cue and Quartile were all significant (all *p*s <0.001, all η_p^2s>0.09). The multiple comparison (Bonferroni corrected) between the valid and invalid conditions across all the 4 quartiles showed that, for younger participants, valid trials were significantly faster than invalid trials in all quartiles (all *p*s<0.01), while for older participants, the differences across the 4 quartiles were all not significant. More importantly, the three-way interaction of Age, Cue and Quartile was significant ($F_{(3,126)}$=4.48, p<0.01, η_p^2=0.10, $CI_{95\%}$: 0.01, 0.12). In order to better understand this interaction, cueing effect was calculated by subtracting the response time of valid trials from invalid trials for each age group (Figure 15b). Multiple comparisons with Bonferroni corrections showed that, for 5-8 years old group, while the cueing effect in the bin1 and bin2 did not significantly differ, cueing effect in the bin4 was significantly larger than that in bin1 and bin2 (all *p*s<0.01), and cueing effect in bin4 was significantly larger than all the other bins (all *p*s < 0.05). However, for the group of 9 years old and above, the cueing effects in all bins did not differ from each other (all *p*s>0.05). Those results indicated that cueing effects were larger in slow trials than fast trials in younger, but not older participants.

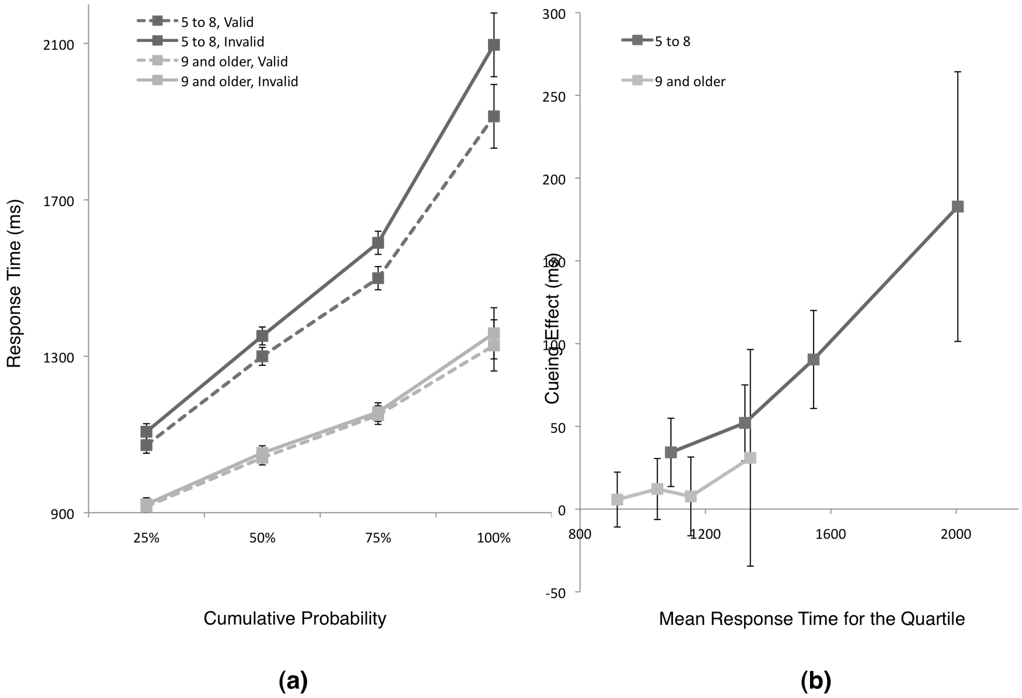


Figure 15. **Response speed and cueing effect by age group. (a). Mean response time for both valid (dotted line) and invalid trials (solid line) in 1st, 2nd, 3rd and 4th quartile for the young and old age groups. (b). Delta plots the young and old age groups. The vertical axis refers to the difference between the mean response time of invalid and valid conditions. The horizontal axis refers to the mean response time of all the trials in this quartile. For both figures, error bars refer to 95% within-subject confidence intervals and only correct trials (excluding response time outliers) were included.**

Discussion

In the current study, participants of 5-6 years old, 7-8 years old, 9-10 years old, 11-12 years old and adult groups performed the Cued Recognition Task at 0 ms of SOA. The main finding of the study was that, despite its lack of predictive value, the head-turn cue produced significant cueing effects of participants in the 5-6 years old and 7-8 years old age groups, but had little influence on the response times of participants in the 9-10 years old, 11-12 years old and adult age groups.

It should be noted that, response time data from adult participants in the current study did not show any cueing effect in trials with fast response time, which was different from the results of Experiment 2. The most plausible explanation was that the current experiment only tested the 0 ms of SOA condition. This design enables the employment of the strategy to always voluntarily inhibit the processing of the head-turn cues because head-turn cues were presented off the initial fixation location and simultaneously with the onset of the more task-relevant objects. Nevertheless, younger participants still showed significant cueing effects, indicating that this strategy was not fully activated in those participants.

The results in the current experiment were similar to the Ristic et al.'s eye gaze findings (2002) where the non-predictive eye gaze cue produced a larger cueing effect in younger participants than older participants. However, whereas the adults in the Ristic et al. study showed a smaller, but significant cueing effect, adults in our study failed to show a significant cueing effect. The divergent results might be explained by important differences between the Ristic et al. study and the current study. First, Ristic et al. employed a detection task in which participants responded to the location of a single target appeared on the left or right side of the central gaze cue. In this paradigm, the influence of the gaze cue might be confounded by the abrupt onset of the exogenous target stimulus. In the cued recognition task, a recognition task was used and the peripheral onset effect was eliminated. The stricter control of the peripheral onset effect enabled a better measurement of the social cueing effect. More importantly, in contrast to the SOA of 195, 600 and 1005 ms employed by Ristic et al., the current study employed the SOA of 0 ms in which the onset of the head-turn cue simultaneously occurred with the onset of the target and distractor objects. Thus, participants did not pre-select the cue prior to the onset of the target and distractor stimuli. Upon the onset of the head-turn cue and the objects, participants had to decide which information to attend to first – the head-turn cue or the objects. Finally, whereas Ristic et al. used horizontal eye gaze cue in their study, the current study used head-turn cues that were not horizontal. Since the head-turn cues were always above the target and distractor, it was possible to selectively allocate attention at where objects might appear, while strategically inhibit the processing of the head-turn cues. Combined with the SOA setting of 0 ms, it would be easier to ignore the head-turn cues in the current study than ignoring the eye gaze cues in the study by Ristic et al., which explains why adult participants in the current study didn't reflexively follow the social cue like the adult participants in the Ristic et al. study did.

Despite these differences, both studies found a stronger cueing effect in younger participants than older participants, even when they were informed of the fact that the cues were not predictive. In both studies, younger participants spent significantly longer time to make responses than older participants, which seemed to be an important factor for the size of the cueing effect because slow responses provided longer time for the head-turn cues to be processed. However, although the relationship between the size of cueing effect and response speed was present in younger participants, this was not the case for older participants. For younger participants, the cueing effect did not differ between the bin1 and bin2, but increased significantly in bin3, and became even larger in bin4. In contrast, for the older participants, the lack of cueing effect was present in both slow and fast response quartiles. More importantly, in the slow response trials (bin3 and bin4) of older participants, the amount of time they spent in those trials were long enough for their younger counterparts to process the social cues, which was reflected by the significant cueing effect in the fast response trials (bin1 and bin2) in younger participants. Therefore, the lack of cueing effect in older participants could not be attributed to their relatively faster response speed. Instead, it was evident that a different mechanism had been employed by older but not younger participants to suppress the processing of the head-turn cues. The most plausible explanation for this difference was that, older participants did not process the cues at all, and in contrast, younger participants failed to inhibit the processing of the cue, and the longer time the cue was exposed, the larger the cueing effect.

The failure of young children to disregard the non-predictive head-turn and eye gaze may be attributable to their lack of inhibitory control mechanisms. According to the findings from Experiment 2, adult participants utilized the frontal system to resolve the conflict between the social cue and target onset cue by inhibiting the processing of the former and enhancing the processing of the latter. However, younger participants didn't seem to make the best use of this frontal system. A great number of studies showed that younger children had issues with the inhibition of task-irrelevant information when performing tasks that involved conflict resolution. For example, in an anti-saccade task where participants are instructed to make a saccade to the opposite side of where the target was presented, younger children were not able to perform the task as efficiently as older children and adults (Fischer, Biscaldi, & Gezeck, 1997; Fukushima, Hatta, & Fukushima, 2000; Klein & Foerster, 2001; Luna et al., 2001; Munoz, Broughton, Goldring, & Armstrong, 1998). Younger children are also more vulnerable to task-irrelevant information than older children and adults, such as in Stroop Task (Comalli et al., 1962; Wright et al., 2003) and Flanker Task (Rueda et al., 2004). Like the anti-saccade task, Stroop Task and Flanker Task, younger participants have difficulty suppressing the automatic response triggered by a head-turn in the cued recognition task. At the level of neural systems, the frontal system, including the dorsal lateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) brain structures have been shown to be strongly activated during the anti-saccade task (e.g. Ford, Goltz, Brown, & Everling, 2005; Munoz &

Everling, 2004), Stroop task (e.g. Adleman, Menon, Blasey, White, Warsofsky, Glover, & Reiss, 2002; Fan, Flombaum, McCandliss, Thomas, & Posner, 2003), and Flanker tasks (e.g. Fan et al., 2003; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). Based on converging evidence from these tasks, the DL-PFC and ACC from the frontal system are believed to play important roles in inhibiting irrelevant task information (for a review, see Nee, Wager & Jonides, 2007). Compared to adults, children showed less activation in the DL-PFC (Konrad, Neufang, Thiel, Specht, Hanisch, Fan, Herpertz-Dahlmann & Fink, 2005) and ACC (Adleman et al., 2002) when they were performing those tasks that required inhibitory controls. This explains why younger children showed weaker ability to inhibit the processing of irrelevant information in the cued recognition task compared to older children and adults.

In conclusion, the current experiment investigated the development trajectory of social cue processing using the 0 ms of SOA condition of the Cued Recognition Task. The results showed that, due to the immaturity of the frontal system (e.g., DL-PFC and ACC), the ability for inhibitory control in younger children was underdeveloped. As a result, unlike older children and adults, younger children failed to inhibit the processing of the task-irrelevant, but prominent social cues.

Experiment 4. Eye Tracking Studies of the Cued Recognition Task

Introduction

One of the important differences between the Cued Recognition Task and the social cueing task was that the Cued Recognition Task did not pre-select the social cues for the participants. Because of the existence of other body parts, such as shoulder, chest, hands, etc., it was possible for the participants to fixate at these non-social body parts but avoid processing the head-turn cues while waiting for the objects to be presented. However, as showed in the previous experiments, even participants were all told not to process the non-predictive head-turn cues, they still selected and followed the head-turn cues. This was a result of the reflexive nature of selecting and processing social cues.

Nevertheless, it was still possible for some participants to utilize this strategy to avoid processing the social cues. For example, individuals with ASD might not select social cues automatically (Klin et al., 2002; Mars et al., 1998; Osterling & Dawson, 1994; Speer et al., 2007; Swettenham et al., 1998). If this was the case, since *cue selection* was not conducted, *cue following* could not be initiated either. The current experiment created a condition that simulated the situation when social cues were not processed. Considering the stimulus used in the Cued Recognition Task, in order to achieve optimal efficiency for performing the task, one should focus at locations closest to where objects might appear, but also as far as possible from the task-irrelevant head-turn cues. Fixating at the location of the red dot on Figure 16 met these criteria. When participants were forced to fixate at this *central* location before the objects were presented, they should be less affected by the head-turn cue, and the social cueing effect should be decreased, or even diminished. In order to achieve the forced fixation, the gaze contingent technology of the eye tracking system was used.

Figure 16. The illustration of the *central* location in the forced fixation condition.

The current experiment compared the magnitude of the social cueing effect between the free viewing condition and the forced fixation condition. In the free viewing condition, participants were allowed to move their eyes freely. In the forced fixation condition, however, participants were required to fixate at the *central* location before the objects were presented, and therefore, both *cue selection* and *cue following* were prohibited. The prediction would be that, the social cueing effect should be significant in the free viewing condition, as suggested by Experiment 1 and 2, but smaller or even diminished in the forced fixation condition because no social cues were processed and followed.

The purpose of the current experiment was two-fold. The first purpose was to investigate the role of *cue selection* and *cue following* in social cue processing by comparing the magnitude of the head-turn cueing effect between the forced fixation and free viewing conditions. Second, the eye movement recorded in the free viewing condition should be informative to reflect the temporal dynamics of social cue processing.

Method

Participants

Participants were a sample of 26 (21 female) undergraduate students at the University of Victoria. The mean age of the participants is 21.28 years old (*SD*=2.80). Participants were recruited through the online Psychology Research Participation System from University of Victoria (SONA Ltd.). Participants were compensated with bonus class points.

Apparatus

Experiments were conducted on a 20-inch CRT monitor. A set distance from the participants' eyes to the surface of the screen was arranged to control for the visual angle of the stimulus. A chin rest was placed 75-centimetres away from the monitor and participants were asked to remain relatively still throughout the duration of the experiment. These instructions were to prevent from having to recalibrate between blocks of trials. Eye movements were recorded at a 1000-Hz sampling rate using the desktop mount configuration of an SR Research EyeLink 1000 system. This configuration provides an average fixation location accuracy between 0.25˚ and 0.50˚. The pupil, using the centroid detection model, and corneal reflection of each subject's dominant eye was tracked under monocular viewing conditions. The participant's head was set on a chin rest, and fixed by a forehead rest.

Stimuli

The sets of stimuli used in the current experiment were the same as in Experiment 1, except that the size of all the stimuli was 78% larger. For example, the face of each model spread approximately 2.6 degrees in width and 3.3 degrees in height. The eyes were approximately 1.3 degrees above the center of the model. The target and the distractor (when present) were 1.3 degrees in span and were either blue or orange in color. The center of the target and the distractor appeared at the eccentricity of 3.3 degrees either to the left or to the right of the fixation cross and 1.3 degrees below the center of the screen.

Design

Three within-subject variables were used in this study, namely Viewing Condition (free viewing and forced fixation), Cue Validity (valid and invalid) and SOA (105, 300, 600 and 1005 ms). The Cue Validity was set to be 50% and distractors were always presented on the opposite side of the targets (the same as in Experiment 1). The Viewing Condition variable was blocked, and counter balanced across participants that half of the participants took the free viewing block first, and the other half took the forced fixation block first. Within each block, the Cue Validity and SOA variables were mixed and counterbalanced. Both the free viewing and forced fixation block consisted of 16 practice trials followed by 128 experiment trials with short breaks after every 32 trials, and each block was only be tested once.

Procedure

Participants were asked to complete a 30-minute computer task. A nine-dot calibration procedure was conducted at the beginning of each block. Afterwards, separate instructions were given in each block. In the free viewing block, participants were told the same instruction as in Experiment 1. Apart from that, they were also told to fixate at a red dot presented randomly at one of four possible locations 10.7 degrees from the center of the screen at the beginning of each trial. The trial could be triggered to start only if a fixation of 200 ms was detected within the area of approximately 1*1 degree centered at the location of the red dot. Participants were also told to place their chin on the chin rest and minimize the head movement during the experiment. Participants were then given 16 practice trials before continuing on to the experiment. The experiment procedure was the same as Experiment 1. For the forced fixation block, the location of the red dot trigger was always at the *central* location, which was on the midpoint of the line segment between the centroid of the distractor and target, and was approximately 3.5 degree below the chin of the model (Figure 16). Participants were told to fixate at the red dot, in order to start the trial. Afterwards, the red dot would disappear and the stimuli of the model would be presented. However, participants were told that they were required to always keep fixating at the location where the red dot had been presented before the objects were presented. During this process, if any eye movement larger than 1 visual degree was detected, the location of the stimulus would be gaze contingent. The purpose of this manipulation was to make sure that the fixation location of the participant was always close enough to the *central* location. Upon the onset of the objects, participants were allowed to freely move their eyes, and the location of the stimulus was no longer gaze contingent.

Results

Preprocessing

In the free viewing condition, fixations with the duration shorter than 50 ms were merged with nearby fixations. The nearby fixation was defined as either the preceding or the following fixation that is less than 0.5° away from the original fixation. In the forced fixation condition, 7.8% of the trials were excluded form the analysis because eye movements of 2 visual degree or larger were detected before the objects were presented.

Eye Movement in the Free Viewing Condition

The locations and durations of all the fixations recorded in the free viewing condition were visualized and analyzed. Heat maps were generated based on the location and duration of each fixation using the iMap 2.0 toolbox (Caldara & Miellet, 2011) within two different periods of each trial.

First, heat maps for fixations within the SOA period, which was after the onset of the head-turn cue, but before the onset of the objects, were generated separately for different SOAs (Figure 17). The coordinates of all fixations in the condition of rightward head-turns were horizontally flipped and then treated as the leftward head-turns conditions when generating heat maps. All trials were grouped only by SOA because the participants did not know whether it would be a valid or invalid trial at this stage yet. Visual inspection of the heat maps suggested that, at 600 and 1005 ms of SOA, more time was spent in looking at the cued location (i.e., the left hand of the model) than the opposite location (i.e., the right hand of the model). However, this difference was less well pronounced at 300 and 105 ms of SOA.

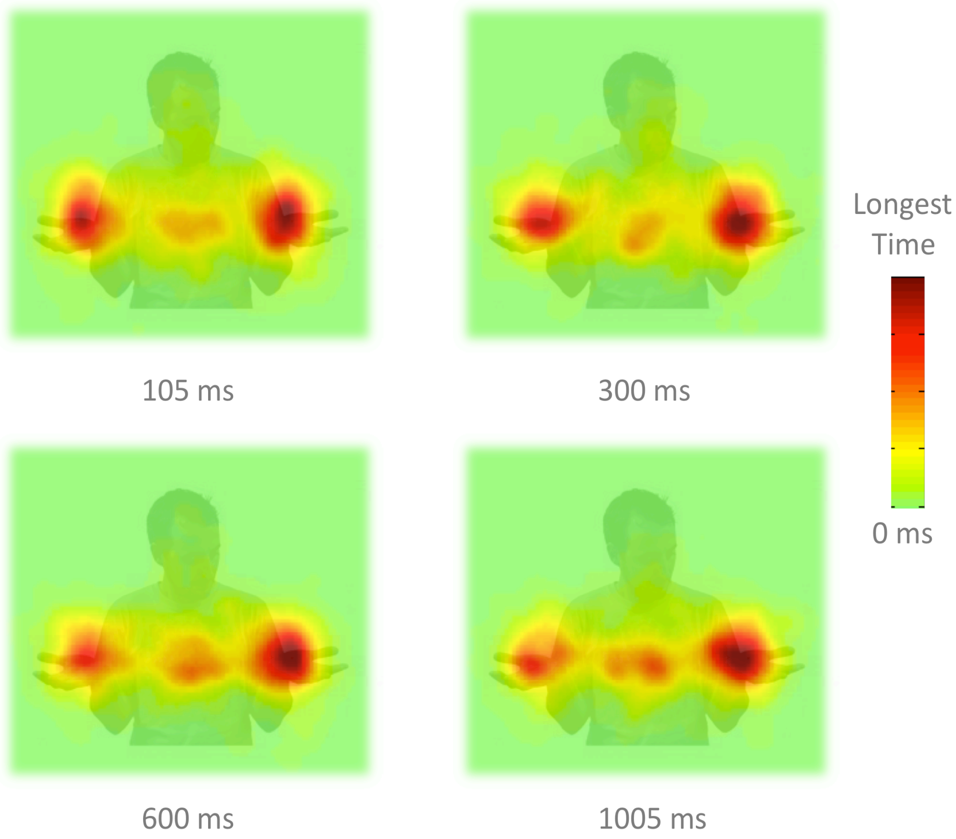


Figure 17. **Heat maps for the SOA period at 105, 300, 600 and 1005 ms of SOAs in the free viewing condition. All heat maps share the same scale ranging from 0 ms to the longest time within a certain condition. Hotter colors mean longer fixating time at this location.**

In order to quantify this effect, four Areas of Interests (AOI), namely the face area (2.5*3.9 degree), cued area (3.0*3.9 degree), uncued area (3.0*3.9 degree) and middle area (2.5*2.4 degree), were created (Figure 18).

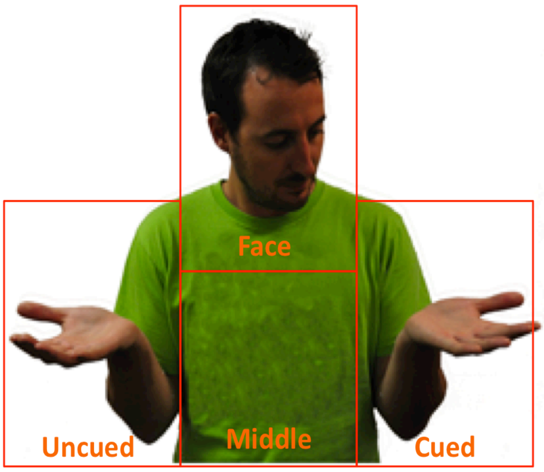


Figure 18. **Areas of Interest for the analysis of the eye movement data in SOA period.**

The proportion of viewing time was computed by dividing the aggregated fixation durations in each AOI by the time of the entire SOA period (i.e., the length of the SOA). A two-way ANOVA of proportion of viewing time was conducted with AOIs (face, validly cued, invalidly cued, middle) and SOA (105, 300, 600 and 1005 ms) as within-subject variables (Figure 19). The significant main effect of AOI ($F_{(3,75)}$ =10.34, p<0.001, η_p^2=0.29, $CI_{95\%}$: 0.05, 0.27) indicated that (all multiple comparisons were Bonferroni corrected) significantly less time was spent in looking at the face areas than all the other areas (all *p*s <0.01) and more importantly, significantly more time was spent in looking at the cued area than uncued area (p<0.001). The interaction between AOI and SOA was also significant ($F_{(9,225)}$ =7.45, p<0.001, η_p^2=0.23, $CI_{95\%}$: 0.03, 0.12). Multiple comparisons with Bonferroni corrections showed that, while the viewing time in the face area was significantly shorter than other areas at all SOAs (all *p*s <0.05), the viewing time in the cued area was only significantly larger than the uncued area at 600 (p<0.01) and 1005 ms (p<0.001) of SOAs. At 300 ms of SOA, this difference was significant before the Bonferroni correction (p=0.03), but not significant after the Bonferroni correction (p=0.14). At 105 ms of SOA, this difference only showed a trend to be significant even before Bonferroni correction (p=0.10). In addition, although the proportion of time spent in the face region was significantly shorter than the time spent in each of the other regions (all ps<0.05), it was significantly larger than 0 (p<0.0001), suggesting that the face region had been processed systematically in the SOA period.

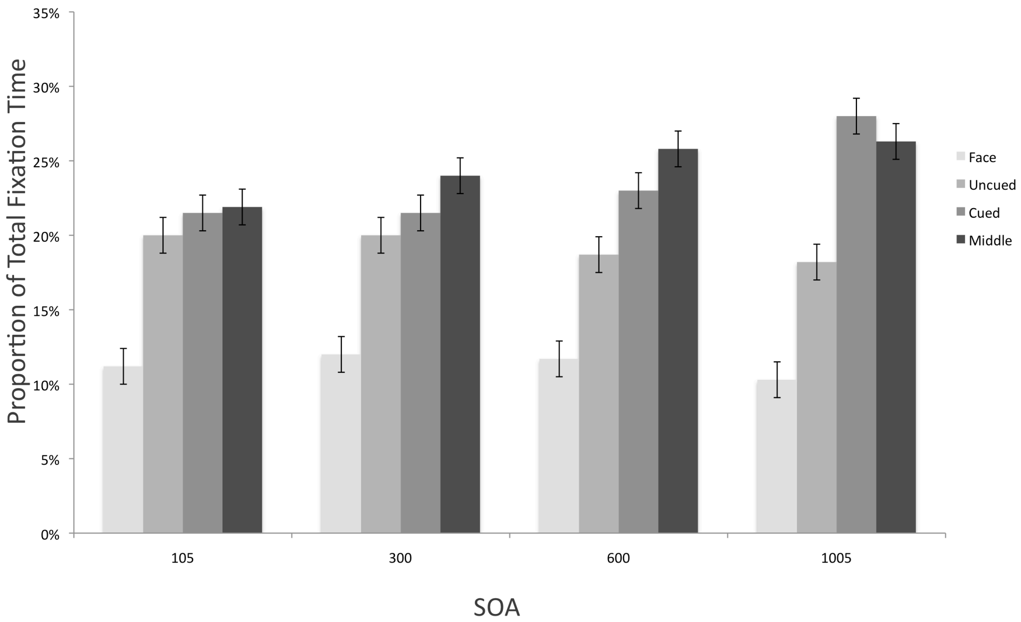


Figure 19. **Proportion of viewing time in all AOIs at 105, 300, 600 and 1005 ms of SOA in the free viewing condition. Error bars refer to 95% within-subject confidence intervals.**

Second, heat maps for fixations of all correct trials within the response period, which was after the onset of the object and before a response was made, were generated (Figure 20). The coordinates of all fixations in trials with the target being presented in the right hand of the model were horizontally flipped and merged with the other condition in the heat maps. Therefore, in all the heat maps, targets were always in the left hand and distractors were always in the right hand of the model, and the model looked at the target in the valid cueing condition, but looked at the distractor in the invalid cueing condition. The difference maps were generated by subtracting the heat maps of the invalid condition from the heat maps of the valid condition. The important comparison was whether the distractor effect, as reflected by the difference between the viewing time on the distractor and the target, was larger in the valid condition than in the invalid condition. Visual inspections of the heat maps and the difference maps indicated that this distractor effect difference was more pronounced at 300, 600 and 1005 ms of SOA than 105 ms of SOA.

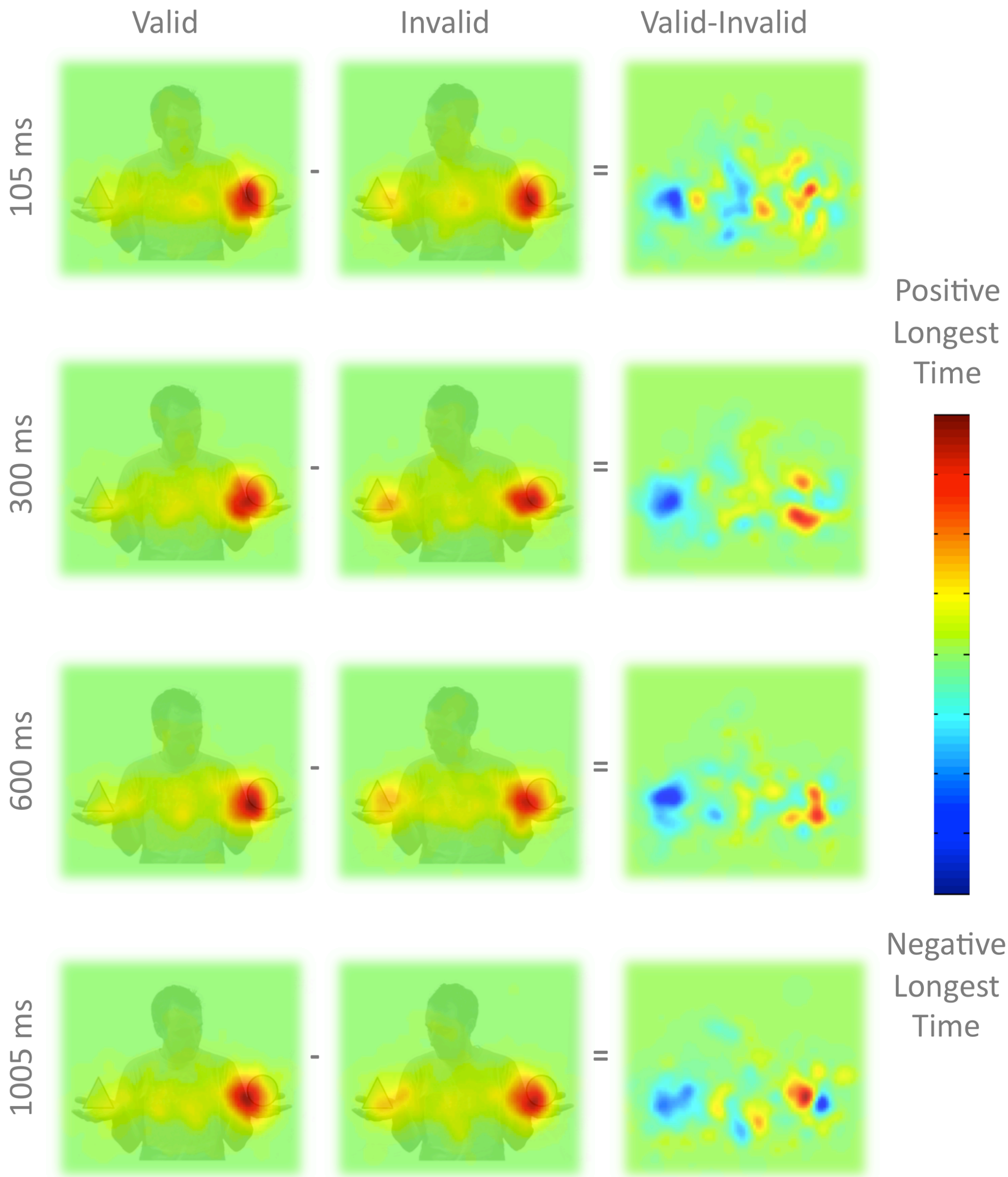


Figure 20. **Heat maps for the valid condition, invalid condition and the difference between the valid and invalid conditions in the response period at 105, 300, 600 and 1005 ms of SOAs in the free viewing condition. All heat maps share the same scale ranging from 0 ms to the longest time within a certain condition. Hotter colors mean longer fixating time at this location. Only data from correct trials are included.**

In order to quantify this effect, two Areas of Interests (AOI), namely the target area (3.0*3.9 degree) and the distractor area (3.0*3.9 degree) were created (Figure 21).

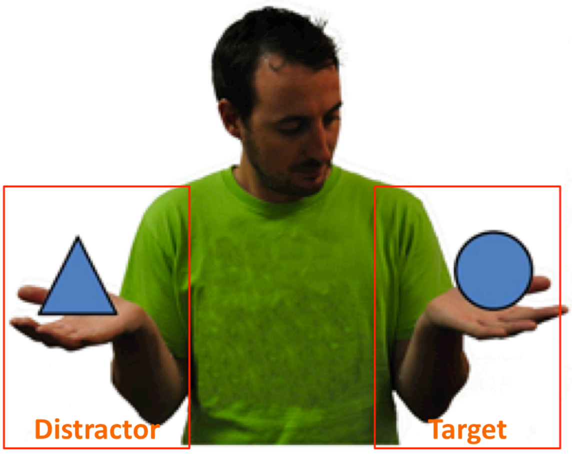


Figure 21. **Areas of Interest for the analysis of the eye movement data in response period.**

The proportion of viewing time was computed by dividing the aggregated fixation durations in each AOI by the time of the entire response period (i.e., the response time or each trial). A three-way ANOVA was conducted with SOA (105, 300, 600 and 1005 ms), Cue Validity (valid, invalid) and AOI (target, distractor) as within-subject variables (Figure 22). The main effect of AOI ($F_{(1,25)}$ =144.70, p<0.001, η_p^2=0.85, $CI_{95\%}$: 0.78, 0.91) was significant, indicating that the proportion of time spent in looking at the target was significantly larger than the time spent in looking at the distractor. The interaction between Cue Validity and AOI was significant ($F_{(1,25)}$ =36.23, p<0.001, η_p^2=0.59, $CI_{95\%}$: 0.41, 0.75). To be specific, although the proportion of time spent in looking at the target was always significantly larger than that of the distractor, this difference was significantly smaller in the invalid condition than the valid condition, indicating that invalid head-turn cues directed the participants to look longer at the distractors. Moreover, this difference between the valid and invalid condition was smaller in shorter SOAs than longer SOAs, as indicated by the trend in the three-way interaction among SOA, Cue Validity and AOI ($F_{(3,75)}$ =2.56, p=0.06, η_p^2=0.09, $CI_{95\%}$: 0.01, 0.16), indicating that invalid head-turn cues were more effective in directing participants' to look at the distractors in conditions with longer SOAs than shorter SOAs.

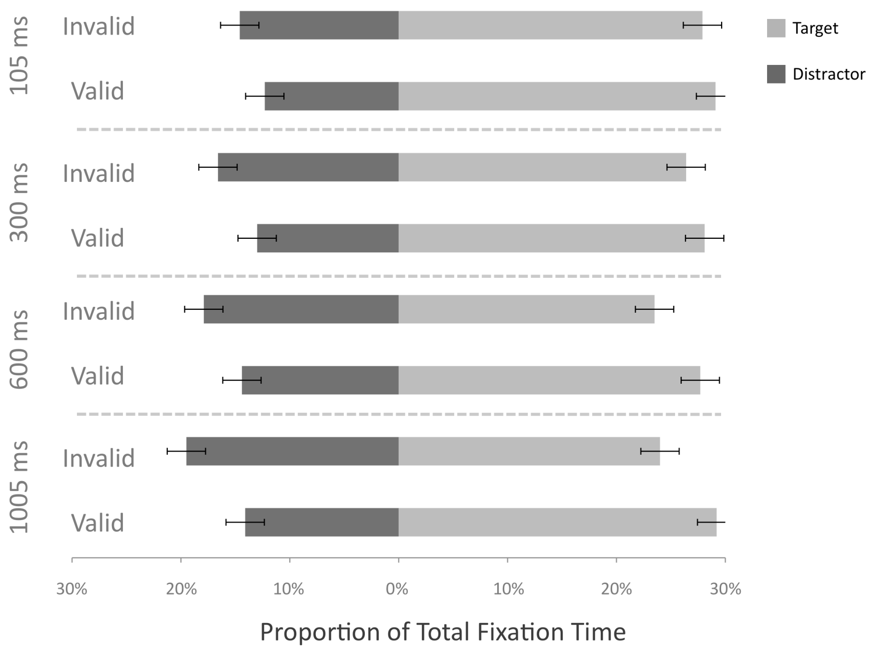


Figure 22. **Proportion of viewing time in the target and distractor region in both valid and invalid conditions at 105, 300, 600 and 1005 ms of SOA in the free viewing condition. The dark bars on the left side refer to the proportion of time spent in looking at the distractor region. The light bars on the right side refer to the proportion of time spent in looking at the target region. Only data from correct trials are included. Error bars refer to 95% within-subject confidence intervals.**

Accuracy

A three-way ANOVA, with Viewing Condition (free viewing, forced fixation), SOA (105, 300, 600 and 1005 ms) and Cue Validity (valid, invalid) as within subject variables was conducted. The main effect of Cue Validity showed a trend to be significant ($F_{(1,25)}$ =3.56, p=0.07, η_p^2=0.13, $CI_{95\%}$: 0.01, 0.36). However, this main effect was mainly driven by the significant difference between the valid and invalid condition in the free viewing condition (p<0.05), but not the forced fixation condition (p=0.7). All other main effects and interactions were not significant (all Fs< 1.4, all ps>0.25 and all η_p^2s<0.05).

Response Time

Only correct trials and trials with response times within the range of 2 standard deviations from the participant's mean response time were included in the analysis. A three-way ANOVA, with Viewing Condition (free viewing, forced fixation), SOA (105, 300, 600 and 1005 ms) and Cue Validity (valid, invalid) as within-subject variables was conducted. Except for the significant main effects of SOA ($F_{(3,75)}$ =3.31, p<0.05, η_p^2=0.12, $CI_{95\%}$: 0.01, 0.17) and Cue Validity ($F_{(1,25)}$ =5.68, p<0.05, η_p^2=0.19, $CI_{95\%}$: 0.02, 0.43), importantly, the interaction between Cue Validity and Viewing Condition was also significant ($F_{(1,25)}$ =10.75, p<0.01, η_p^2=0.30, $CI_{95\%}$: 0.09, 0.54). To be specific, under the free viewing condition, the response time difference between the valid and invalid condition was significant (p<0.01). However, this effect was not significant in the forced fixation condition (p=0.60) (Figure 23). No other main effects or interactions were significant (all Fs<1.17, all ps>0.33 and all η_p^2s<0.05).

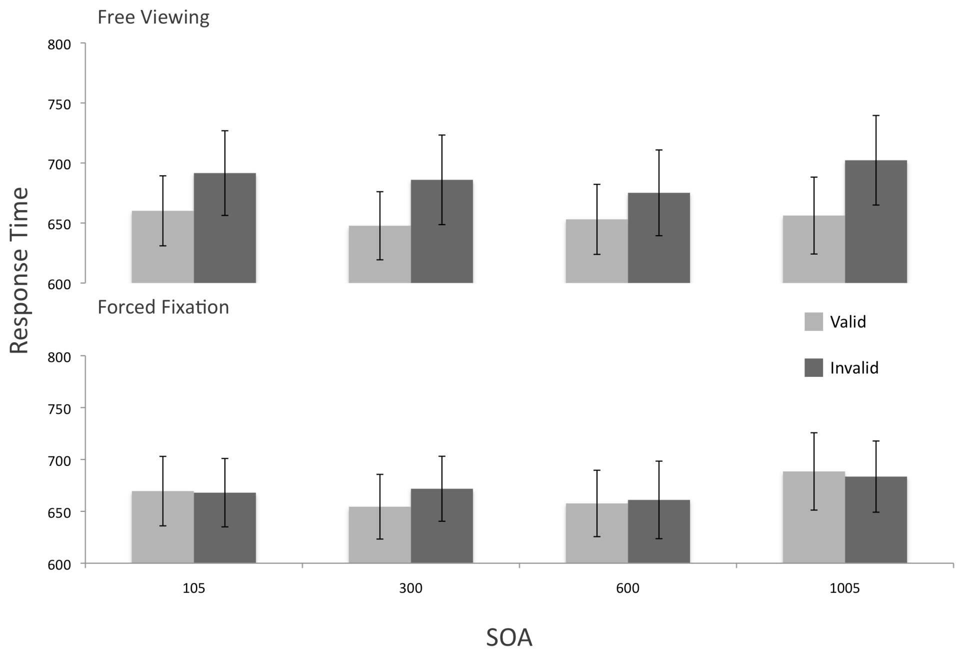


Figure 23. **Response time by Viewing Condition, SOA and Cue Validity. Only correct trials (excluding response time outliers) were included. Error bars refer to 95% within-subject confidence intervals.**

Discussion

There were two major findings in the current experiment. First, in the free viewing condition, eye movement data showed that before the objects were presented, participants' fixation locations were biased by the head-turn cues, and this bias was larger at longer SOAs than shorter SOAs. After the objects were presented, invalid head-turn cues directed fixations toward distractors, and again, this effect grew at longer SOAs than shorter SOAs. Second, when cue selection and following were disabled, the cueing effect was eliminated in the Cued Recognition Task.

Eye movement data both in the SOA and response period from the free viewing condition supported the general finding from Experiment 1 and 2 that the processing of social cue had an early onset, and did not diminish even at 1005 ms of

SOA. Since the temporal dynamics of social cue processing were discussed in length in the discussion session of Experiment 2, it would not be further discussed here.

As expected, when *cue selection* was disabled and *cue following* was impossible to be initiated in the forced fixation condition, no cueing effects were showed. The forced fixation condition was created to simulate the performance of those participants who avoided the processing of the social cues. Admittedly, this situation does not happen very often in TD population because social cues were salient in the environment and the selection of those social cues was effortless (Farroni et al., 2005; Lewis & Edmonds, 2003; Morton & Johnson, 1991). This was supported by the results from the free viewing condition of the current experiment, as well as from Experiment 1 and 2, that, although participants were instructed to ignore the head-turns, they selected and followed the head-turn cues nevertheless. However, for children with ASD, this might not be the case because one of the most important characteristics of ASD was the lack of automatic attention orientations to faces (Klin et al., 2002; Mars et al., 1998; Osterling & Dawson, 1994; Robins et al., 2001; Speer et al., 2007; Swettenham et al., 1998). When social cues were not selected, they could not be followed. The next experiment tested the children with ASD using the Cued Recognition Task. If they did avoid the *cue selection*, they would show reduced or no cueing effect compared to TD controls, and their performance would echo the results in the forced fixation condition. However, if ASD participants showed comparable cueing effect as TD controls, their *cue selection* and *cue following* processes should not be qualitatively different from their TD controls.

Experiment 5. The Other Side of the Spectrum

Introduction

Social attention issues are among the earliest, most salient and specific characteristics of ASD (Mundy, 1995; Swettenham et al., 1998; Zwaigenbaum et al., 2005). It was believed that children with ASD had difficulties with social cue processing. As mentioned in Chapter 1, studies using the social cueing tasks yielded mixed results. Among the 13 studies that used the social cueing task to investigate if children with ASD showed similar social cueing effects as TD controls, only 5 of them found that children with ASD showed a smaller or no social cueing effect compared to the TD controls (Goldberg et al., 2008; Johnson et al., 2005; Ristic et al., 2005; Senju et al., 2004; Vlamings et al., 2005). The majority of studies found comparable cueing effects between the ASD and TD groups (Charwarsaka et al., 2003; Greene, Colich, Iacoboni, Zaidel, Bookheimer & Dapretto, 2011; Kuhn, Benson, Fletcher-Watson, Kovshoff, McCormick, Kirkby, & Leekam, 2010; Kylliäinen & Hietanen, 2004; Pruett et al., 2011; Rombough & Iarocci, 2012; Stauder, Bosch & Nuij, 2011; Swettenham et al., 2003). The inconsistency of findings might be derived from the procedural differences between labs (e.g., stimulus for gaze cues, SOA, task length, etc.) and the heterogeneity of the autism spectrum (Frischen et al., 2007, Nation & Penny, 2008).

As mentioned earlier, the social cueing task might not be sensitive to the most important differences between ASD and TD participants in terms of social cue processing. As mentioned in Chapter 1, studies showed that individuals with ASD had issues in *cue selection* (e.g., Klin et al., 2002; Mars et al., 1998; Osterling & Dawson, 1994; Speer et al., 2007; Swettenham et al., 1998). However, the conventional social cueing task is not sensitive to differences in *cue selection* (Birmingham & Kingstone, 2009; Gibson & Kingstone 2006). Therefore, the social cueing task might not be the best paradigm to investigate the difference between the ASD and TD individuals in social cue processing. On the other hand, the Cue Recognition Task does not pre-select the cues for the participants. According to the findings from Experiment 4, despite the fact that participants select and process the social cues nevertheless in the free viewing condition, if *cue selection* and *cue following* were prohibited through forced fixation, no social cueing effects were presented. If individuals with ASD avoided the processing of social cues, they would show similar results in terms of the social cueing effect as the findings from the forced fixation condition in Experiment 4.

Moreover, unlike the Cued Recognition Task, the social cueing task did not control for the peripheral onset effect. As demonstrated in Experiment 2, the social cueing effect could be attenuated if the interference from the peripheral onset effect was not eliminated. Therefore, the comparison between ASD and TD participants using the social cueing paradigm might only reflect the difference in this attenuated social cueing effect between the two groups of participants. It was unknown if the magnitude of the social cueing effect of the ASD and TD participants would differed when the peripheral onset effect was eliminated in the task.

The current experiment compared the social cue processing of children with ASD and their TD controls using both the original Cued Recognition Task and the non-distractor version of the Cued Recognition Task. The major purpose was to investigate if ASD participants showed equivalent size of social cueing effect as their TD controls. Another purpose was to test if the ASD group was more sensitive to the peripheral onset effect than the TD group.

Method

Participants

Twenty-two children with ASD (3 females) and 22 TD controls (4 females) were recruited from the community. Among the ASD participants, 18 of them had a diagnosis of high-functioning autism, 2 had a diagnosis of Asperger's syndrome and 1 had a diagnosis of Pervasive developmental disorder not otherwise specified (PDD-NOS). The ASD and TD groups were matched on age and verbal, non-verbal and composite IQ, which was measured by Kaufman Brief Intelligence Test—Second Edition (KBIT-2; Kaufman and Kaufman, 2004). Detailed information could be found in Table 1.

Table 1. Average Ages and IQ scores for ASD and TD participants. The figures in the parentheses are standard errors.

Group	Age	Verbal IQ	Non-Verbal IQ	Composite IQ
ASD	10.9 (0.6)	108.9 (4.8)	105.7 (3.7)	108.6 (4.6)
TD	11.2 (0.6)	111.7 (2.4)	113.1 (3.0)	114.8 (2.6)
t-test	p=0.76	p=0.60	p=0.13	p=0.25

Apparatus

The apparatus used in this experiment was exactly the same as Experiment 1, except that response time was measured by the activation of voice key instead of key presses. If participants in the current experiment were asked to respond through key presses, they frequently looked away from the monitor and looked down at the keyboard to verify if they were pressing the right key. This process added noise to the response time measurement. Therefore, voice key response was used in the current experiment.

Stimuli

The stimuli used in this experiment were the same as the stimuli used in Experiment 2. However, some cartoon figures were used in the beginning and the end of the experiments as well as during the breaks between blocks, in order to make the experiment child-friendly.

Design

The experiment design was the same as Experiment 2, with the following exceptions. First, apart from the Cue Validity, Object Distraction and SOA as within-subject variables, there was a between-subject variable, Diagnosis (ASD vs. TD), in the current experiment. Second, only 4 levels of SOAs (0 ms, 105 ms, 500 ms, 1005 ms) were used in the current experiment in order to reduce the length of the experiment. Third, the experiment consisted of 3 practice blocks followed by 4 blocks of 32 trials for a total of 128 trials.

Procedure

Participants were asked to play a 20-minute Shape Game. The experiment started with 3 practice blocks. The first practice block had 8 trials of object identification, in which only the circle or a square was presented. Participants were asked to say the name of the shape they saw on the screen out loud to the microphone in front of them. During this process, the location and the height of the microphone were adjusted in order to optimize the reception of the voice key trigger. These adjustments were usually made within the first 3-4 trials, and the location and height of the microphone were kept the same throughout the experiment. Before the second practice block, participants were told that in the next block, there might or might not be a triangle distractor on the other side of a circle or square, and they were required to name the circle or square, but ignore the triangle. The second practice block consisted of 16 trials, mixed with same number of target-only trials and distractor-present trials. When this block was finished, participants were introduced to the model used in the *Cued Recognition Task*, and were told that the model held those shapes in one of his/her hands and would look at either of the hand. However, where the model looked at was random, and wasn't helpful at all, so they should focus on their shape-naming task, but ignore where the model was looking at. They practiced for 16 trials with a mixture of the trails in the distractor and non-distractor condition. Afterwards, 4 blocks, with 32 trials in each block were performed by participants. The experiment flow was the same as Experiment 2. However, participants in the current experiment had longer breaks, and were presented rewarding pictures with cartoon figures between two blocks. The experimenter was with the participant throughout the experiment. Response time was measured by the activation of the voice key trigger by participants' verbal report, and the experimenter coded the response by pressing either <c> or <s>, referring to circle or square respectively. If the voice key was activated by non-response noise or utterance, or if the voice key was not activated at all, the experiment marked these trials, and the data of these trials would not be included in the analysis.

Results

Pre-processing

The proportion of trials excluded due to the issues of voice key activation was not significantly different (p=0.97) between ASD participants (M=7.92%, SE=2.6%) and TD participants (M=7.60%, SE=2.1%).

Accuracy

A four-way ANOVA was conducted with Object Distraction (distractor, non-distractor), Cue Validity (valid, invalid) and SOA (0, 105, 500 and 1005 ms) as within-subject variables, and Diagnosis (ASD, TD) as between-subject variable. As expected, the main effect for Cue Validity ($F_{(1,42)}$ =5.02, p<0.05, η_p^2=0.11, $CI_{95\%}$: 0.01, 0.28) and Object Distraction ($F_{(1,42)}$ =10.42, p<0.01, η_p^2=0.20, $CI_{95\%}$: 0.06, 0.39) were both significant. However, the main effects for SOA and Diagnosis were both not significant (all ps>0.2 and all η_p^2s<0.03). Among all the interactions of interest, none of the two-way and three-way interactions involving Diagnosis and Cue Validity were significant (all Fs<1.65, all ps>0.18, all η_p^2s<0.04).

Response time

Response time for practice trials in practice block 2, in which participants performed a target identification task either with or without the presence of the distractor, was analyzed as a baseline measurement. A two-way ANOVA, with Object Distraction as within-subject factor and Diagnosis as between-subject factor was conducted. The main effect of Object Distraction was significant ($F_{(1,42)}$ =15.76, p<0.001, η_p^2=0.27, $CI_{95\%}$: 0.11, 0.46), which was driven by the effect that the response time in the distractor condition was significantly slower than the response time in the non-distractor condition. Importantly, the main effect for Diagnosis was not significant ($F_{(1,42)}$ =0.29, p=0.59, η_p^2=0.01, $CI_{95\%}$: 0.00, 0.11). The interaction between Object Distraction and Diagnosis was not significant ($F_{(1,42)}$ =1.29, p=0.26, η_p^2=0.03, $CI_{95\%}$: 0.00, 0.16) either.

For the response time data collected from the Cued Recognition Task, a four-way ANOVA was conducted with Object Distraction (distractor, non-distractor), Cue

Validity (valid, invalid) and SOA (0, 105, 500 and 1005 ms) as within-subject variables, and Diagnosis (ASD, TD) as between-subject variable (Figure 24). As expected, the main effects of SOA ($F_{(3,126)}$ =13.07, p<0.001, η_p^2=0.24, $CI_{95\%}$: 0.04, 0.20), Object Distraction ($F_{(1,42)}$ =70.23, p<0.001, η_p^2=0.63, $CI_{95\%}$: 0.49, 0.74) and Cued Validity ($F_{(1,42)}$ =15.70, p<0.001, η_p^2=0.27, $CI_{95\%}$: 0.11, 0.46) were all significant. Importantly, the main effect of Diagnosis was also significant ($F_{(1,42)}$ =6.03, p<0.02, η_p^2=0.13, $CI_{95\%}$: 0.02, 0.31), which was driven by the fact that the response time of ASD participants was significantly slower than TD participants. This difference in response time between the ASD and TD participants was significant across all levels of SOAs (all ps<0.06). Among all the interactions of interest, none of the two-way and three-way interactions involving Diagnosis and Cued Validity were significant (all Fs <1.69, all ps>0.18 and all η_p^2s<0.04).

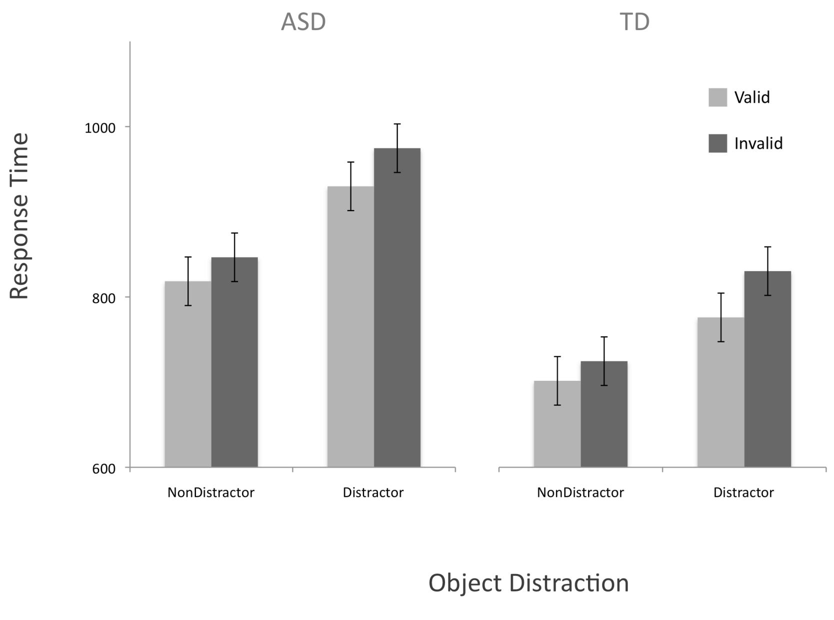


Figure 24. **Response time by Cue Validity, Object Distraction and Diagnosis. Only correct trials (excluding response time outliers) were included. Error bars refer to 95% within-subject confidence intervals.**

Discussion

The current experiment used the Cued Recognition Task to investigate the social cue processing of ASD and TD children. The results suggested that, except for the longer response time across all the conditions, ASD participants did not show a significant difference in the magnitude of social cuing effect than TD participants.

As mentioned in Chapter 1, previous studies using response time (e.g., key press, voice key, saccade, etc.) measurements to investigate the social cue processing of the ASD population did not find converging results. The current experiment did not find any group differences in terms of the size of the social cueing effects, replicating the results from the 8 studies (i.e., Charwarsaka et al., 2003; Greene, Colich, Iacoboni, Zaidel, Bookheimer & Dapretto, 2011; Kuhn, Benson, Fletcher-Watson, Kovshoff, McCormick, Kirkby, & Leekam, 2010; Kylliäinen & Hietanen, 2004; Pruett et al., 2011; Rombough & Iarocci, 2012; Stauder, Bosch & Nuij, 2011; Swettenham et al., 2003), but not the other 5 studies (i.e., Goldberg et al., 2008; Johnson et al., 2005; Ristic et al., 2005; Senju et al., 2004; Vlamings et al., 2005). The current experiment used both the distractor and non-distractor version of the Cued Recognition Task, but found similar results in terms of the group difference between ASD and TD participants in these two conditions, suggesting that the peripheral onset effect didn't interfere with the group differences.

The primary difference between the ASD and TD participants was that ASD participants were slower in response time than TD participants across all the experiment conditions. This was not consistent with the majority of the previous studies. For example, Among the 8 studies that found no difference in the magnitude of social cueing effects between ASD and TD participants, only the studies by Swettenham et al. (2003) and Stauder et al. (2011) found some minor evidence that ASD participants were slower than TD participants in both valid and invalid cueing conditions. However, this effect was not well pronounced in those two studies. To be specific, in the study by Swettenham et al. (2003), this effect only existed at 800 ms of SOA. In the study of Stauder et al., this effect was no longer significant after Bonferroni correction. However, in the current study, this effect was robust and was present at all levels of SOAs.

Why did ASD participants respond slower than TD participants? Some might argue that because of their language impairment, children with ASD were slower in this experiment because they had to articulate the name of the object in order to trigger the voice key response. However, the baseline response time data showed no difference between ASD and TD group in naming the objects, indicating that this difference was not caused by the language impairment of ASD participants, but rather by the delays in social cue processing. Considering that the Cued Recognition Task tap into all the three stages of social cue processing, namely *cue selection*, *cue following* and *object recognition*, the variances in response time could be derived from the differences in one, two or all of the stages of social cue processing. The results suggested that *cue selection* and *cue following* might be differed between ASD and TD participants, but not *object recognition*. The analysis of the baseline response time data showed that, when performing object recognition tasks without the presence of social cues, no difference in response time was found between ASD and TD participants. Therefore, there should be no differences in the *object recognition* stage of the social cue processing. On the other hand, the variances in response time might be derived from *cue selection* and *cue following*. However, these variances in response time did not reflect a qualitative difference between the ASD and TD participants in those stages of social cue process. As showed in Experiment 4, if *cue selection* and *cue following* were impaired, differences should be reflected in the magnitude of the social cueing effect. However, the lack of group difference in the magnitude of the social cueing effect in the current experiment suggested that ASD participants selected and followed the social cues to the same extent as their TD controls. As a result, the difference between ASD and TD participants in social cue processing should only be derived from the efficiency in the selecting and following social cues. First, it was possible that ASD participants took longer time to select the cues than TD participants. This delay in cue selection might contribute to the longer response time of ASD participants compared to their TD controls. Moreover, it was also possible that ASD participants spent longer time in the *cue following* stage than TD participants. Both findings were consistent with the findings from an eye tracking study by Freeth et al. (2010). They found that when viewing naturalistic social scenes, compared with TD participants, ASD participants were slower in orienting their fixations to the face, as well as to the location being cued, suggesting a delay in both *cue selection* and *cue following*. The delay in social cue selection and following might be the result of the inefficiency in orienting attention to social stimulus in individuals with ASD, and the consequence of this issue that it took longer for individuals ASD to interpret the implications of these social cues before they orient their attention accordingly (Chawarska et al. 2003; Dawson et al. 1998; Klin et al. 2003; Osterling & Dawson 1994; Rombough & Iarocci, 2012; Swettenham et al. 1998; Swettenham et al. 2003, but see New et al., 2009). However, an alternative explanation could be that, participants with ASD were slower in attention orientation in general (Casey, Gordon, Mannheim, & Rumsey, 1993; Landry & Bryson, 2004), and therefore, they were slower in orienting attention from the initial fixation location to the face, then form the face to the location cued by the head-turns. However, in order to test these two hypotheses, further investigations were needed, such as measuring attention orienting in a non-social cueing task.

In conclusion, Experiment 5 studied social cue processing of ASD and TD children using the Cued Recognition Task. The results suggested that ASD children identified the target faster in the valid cueing condition than in the invalid cueing condition, and the magnitude of this effect was similar to that of TD children. However, ASD children did have a slower response time in all conditions of the task than TD children, possibly because they spent more time to select the head-turn cues, and/or to orient their attention following the cues provided by the head-turns.

General Discussion

Overview of the Goals

Social cues, such as eye gaze and head-turns, can orient our attention automatically. The temporal dynamics of social cue processing is usually measured by the social cueing task. In the social cueing task, a schematic or real face is presented at the center visual field. The eye gaze of this face is directed to either the left or right side of the visual field. Participants are required to detect or identify a pre-defined target presented either on the left or right side of the gaze cue. The classic finding is that, when the eye gaze has no predictive validity, targets appeared in the validly cued location are detected or identified faster than targets in the invalidly cued location. This cueing effect starts to emerge around 100 ms but diminishes at about 1000 ms after the onset of the gaze cue (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). However, because only one object is presented on one side of the gaze cue, this abrupt single-sided peripheral object onset can also reflexively orient attention (Jonides, 1981; Posner, 1980; Yantis & Jonides, 1996). Therefore, the social cueing effect measured by the social cueing paradigm might be interfered by the peripheral onset effect elicited by single-sided object presentation. It could be hypothesized that the peripheral onset effect might attenuate or even overwhelm the social cueing effect that being measured.

In this dissertation, the Cued Recognition Task was developed to measure the temporal dynamics of social cue processing. The Cued Recognition Task was developed based on the standard social cueing task, with the following modifications. First, head-turn was used as the social cue, rather than eye gaze. Second, except for the face region that usually provides the social cues, other relatively less social body parts, such as shoulders, chest, arms and hands, were also presented. Therefore, the head-turn cue was not pre-selected for the participants. Third, a distractor was presented on the opposite side of the target to eliminate the peripheral onset effect. The Cued Recognition Task used non-predictive head-turn cues and participants were required to perform a target recognition task while ignoring this non-predictive task and the presentation of the distractor. The social cueing effect was measured at 0, 105, 300, 600 and 1005 ms of SOAs.

The first goal of this dissertation was to test if the Cued Recognition Task was able to yield significant social cueing effect. The results from Experiment 1 showed that, consistent with the findings using social cueing task, significant cueing effects were also found in the Cued Recognition Task using non-predictive head-turn cues. However, the social cueing effect was not diminished at 1005 ms of SOA, which was not consistent with previous findings using the social cueing task (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). This difference might be derived from the elimination of the peripheral onset effect in the Cued Recognition Task.

The second goal of this dissertation was to test whether the social cueing effect was interfered by the peripheral onset effect by comparing the social cueing effect measured by the distractor and non-distractor condition of the Cued Recognition Task. In the non-distractor condition, only the target was presented on one side of the head-turn cue, whereas in the distractor condition, a target was presented on one side of the head-turn cue and a distractor was presented on the opposite side. The results from Experiment 2 showed that, the social cueing effect in the non-distractor condition was smaller than that in the distractor condition. Compared to the distractor condition, the social cueing effect was overwhelmed by the peripheral onset effect at 105 and 1005 ms of SOA, and was attenuated by the peripheral onset effect at 300 and 600 ms of SOA in the non-distractor condition.

The third goal of this dissertation was to measure the temporal dynamics of social cue processing without the interference from the peripheral onset effect. The result from the response time measurements in Experiment 1, 2 and 3, as well as the eye movement measurement in the free viewing condition of Experiment 4 showed that, social cueing effect was not significant at 0 ms of SOA, started to emerge at 105 ms of SOA, became relatively stable at 300 and 600 ms of SOA, and sustained at 1005 ms of SOA.

The fourth goal of this dissertation was to investigate the difference between ASD and TD children in terms of social cue processing using the Cued Recognition Task. The results from Experiment 5 suggested that ASD children identified the target faster in the valid cueing condition than in the invalid cueing condition, and the magnitude of this effect was similar to that of TD children. However, ASD children did have a slower response time in all conditions of the task than TD children, possibly because they spent more time to select the head-turn cues, and/or to orient their attention following the cues provided by the head-turns.

In the rest of this chapter, all the findings from the 5 experiments in this dissertation will be summarized and discussed. A conceptual model will be proposed based on those findings, in order to help with the understanding of those findings.

Overview of the Findings

The Temporal Dynamics of Social Cue Processing

The most important finding of this dissertation was the temporal dynamics of social cue processing measured in the condition where the peripheral onset effect was eliminated. According to the findings from studies using the social cueing tasks, when the gaze cue was non-predictive, the social cueing effect emerged at short SOAs (e.g., 105 ms) and disappeared at longer SOAs (e.g., 1005 ms) (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). However, because objects were only presented on one side of the cue in those tasks, the measurement of the social cueing effect was inevitably interfered by the peripheral onset effect, which could reflexively orient attention to the location of the onset (Jonides, 1981; Posner, 1980; Yantis & Jonides, 1996). Different from the single-sided object presentation in the social cueing task, a distractor was presented on the opposite side of the target in the original Cued Recognition Task. Without the contribution from the peripheral onset effect, the results from the Cued Recognition Task reflected the sole influence of the head-turn cue. Results from Experiment 1 and 2 showed that, no cueing effect was found at 0 ms of SOA, but significant cueing effects were found at 105, 300, 600 and 1005 ms of SOA. Experiment 2 utilized delta plots to investigate the relationship between the magnitude of the cueing effect and response speed at each level of SOA. The results showed that the cueing effect began to emerge at 105 ms SOA, increased in magnitude at 300 and 600 ms of SOA, and sustained at 1005 ms of SOA. This was consistent with the eye movement data in the free viewing condition of Experiment 4 that, at 300, 600 and 1005 ms of SOAs, participants' fixations were biased toward the location cued by the head-turn before the objects were presented. After the objects were presented, participants' fixations were more biased toward the distractor in the invalid cueing condition than the valid cueing condition at 105, 300, 600 and 1005 ms of SOAs. In conclusion, results from Experiment 1, 2 and 4 showed that, if the peripheral onset effect was eliminated, the head-turn cueing effect in the Cued Recognition Task started to emerge at 105 ms of SOA, was stable at 300 and 600 ms of SOA and sustained at 1005 ms of SOA. These findings reflected the temporal dynamics of the magnitude of the social cueing effect elicited by head-turn cues in the Cued Recognition Task.

Two Independent Attention Orientation Cues

Findings from Experiment 2 and 4 suggested that, during *cue following*, there seemed to be two independent source of attention orientation effect, namely the social cueing effect elicited by the head-turn and the object onset effect elicited by the single-sided object presentation. These two cues competed with each other, and the result of this competition dominated the orientation of attention.

First, the influence of the object onset cue could be reflected in the comparison between the distractor and non-distractor condition in Experiment 2. In the distractor condition, because a distractor was presented on the opposite side of the target, the object onset cue of the target could be neutralized by the object onset cue of the distractor. Therefore, the aggregated object onset cue did not compete with the social cue. As a result, the attention orientation was purely decided by the social cue. In the non-distractor condition, however, the object onset cue elicited by single-sided object presentation could be neutralized by any other object cues. Therefore, the attention orientation should be decided by the result of the competition between the social cue and object onset cue. At 300 and 600 ms of SOA, the social cue was stronger than the object onset cue in the non-distractor condition, so the attention orientation was biased toward the location cued by the head-turn. But this bias was less pronounced in the non-distractor condition than the distractor condition because of the disturbance from the object onset cue. This could be reflected by the attenuated social cueing effects in the non-distractor than the distractor condition at 300 and 600 ms of SOAs. The analysis of delta plots suggested that, at 105 and 1005 ms of SOA, in trials with fast response time in the non-distractor condition, the attention orientation was still biased toward the location cued by the social cue because the object onset cue has not been fully activated yet. On the other hand, in trials with slower response time, the object onset cue could override the social cue. However, the reason why the object onset cue overrode the social cue was different at 105 and 1005 ms of SOA. At 105 ms of SOA, it was driven by the relatively weak social cue and strong object onset cue whereas at 1005 ms of SOA, it was driven by the relatively strong social cue and even stronger object onset cue.

Second, the function of the social cue could be reflected in the forced fixation condition in Experiment 4. The forced fixation condition eliminated the object onset cue by using the distractor condition of the Cued Recognition Task, and at the same time, eliminated the social cue by forced fixation at the neutral location. The results showed that, when both the object onset cue and the social cue were eliminated, no social cueing effect was presented.

In conclusion, as Table 2 suggested, in the Cued Recognition Task, attention orientation was decided by the results of the competition between the social cue and object onset cue. The interaction between these two cues could be reflected by the attenuated or overwhelmed social cueing effect in the non-distractor condition of Experiment 2. When the object onset cue was eliminated in the distractor condition, attention orientation was decided solely by the social cue, as suggested by the findings from the distractor condition of Experiment 2. Furthermore, when the object onset cue and the social cue were both eliminated in the forced fixation condition of

Experiment 4, no cueing effects were found at all levels of SOA. These findings suggested two independent source of attention orientation in the Cued Recognition Task, namely the social cue and the object onset cue, and the competition between them in order to dominate attention orientation.

Table 2. Two independent sources of attention orientation in the Cued Recognition Task.

Experiment Condition	Attention Orientation Cues		Social Cueing Effect
	Social	Object Onset	
Non-distractor (Exp. 2)	Yes	No	Large
Distractor (Exp. 2)	Yes	Yes	Attenuated
Forced fixation, distractor (Exp. 4)	No	No	None

The Top-down Conflict Resolution Mechanism

Another interesting finding was that the social cueing effect could be voluntarily inhibited at 0 ms of SOA when the task-irrelevant non-predictive social cue did not have enough time to be processed. The evidence for the involvement of inhibitory mechanisms could be found in the delta plot at 0 ms of SOA in Experiment 2, as well as in Experiment 3 that younger children were not able to initiate this inhibition process due to their less developed frontal system of the brain. These findings suggested that a top-down conflict resolution mechanism was moderating attention orientation in the 0 ms of SOA condition of the Cued Recognition Task. The top-down conflict resolution mechanism inhibited the processing of the task irrelevant social cue, but enhanced the processing of the task relevant object onset cue. As a result, in the non-distractor condition, attention orientation was moderated by not only the results of the competition between the social cue and object onset cue, but also the top-down conflict resolution mechanism. In the distractor condition, attention orientation by the social cue could be inhibited by this top-down conflict resolution.

In younger populations, because of the under-development of this top-down conflict resolution mechanism, attention orientation was still dominated by the social cue in the distractor condition.

The Case of ASD

The results from Experiment 5 showed that, ASD participants were slower than age and IQ matched TD participants across all conditions in the experiment, despite the fact that ASD participants could recognize the target as fast as TD participants did. However, no difference in the magnitude of the cueing effect was found between the two groups of participants. These results suggested that, children with ASD selected and followed the head-turn cues, however, the speed of processing in either or both of these two processes were slower than that of TD children. It was suggested that, the difference between ASD and TD participants was not qualitative. Instead, the different might reflect the compromised efficiency of ASD participants in *cue selection* and *cue following*.

Conclusion

Based on the findings summarized above, several important elements in social cue processing measured by the Cued Recognition Task could be identified. First, there were two independent sources of attention orientation cues, namely the social cue and the object onset cue. Attention orientation was decided by the result of the competition between them. Second, the temporal dynamics of the attention orientation effect provided by the social cue started to emerge at 105 ms of SOA, became stable at 300 and 600 ms of SOA and sustained at 1005 ms of SOA, as reflected by the findings in the distractor condition of the Cued Recognition Task. Third, at 0 ms of SOA, social cue processing was inhibited by the moderation from a top-down conflict resolution mechanism, and no social cueing effect was showed. These elements are the crucial components of the Cued Recognition Model, which will be discussed in the next section.

The Cued Recognition Model

In order to explicitly explain how social cues were processed in the Cued Recognition Task, a conceptual model was developed (Figure 25) based on the findings discussed above. This section was devoted to the introduction of this model, and how the model helped explaining the findings from this dissertation

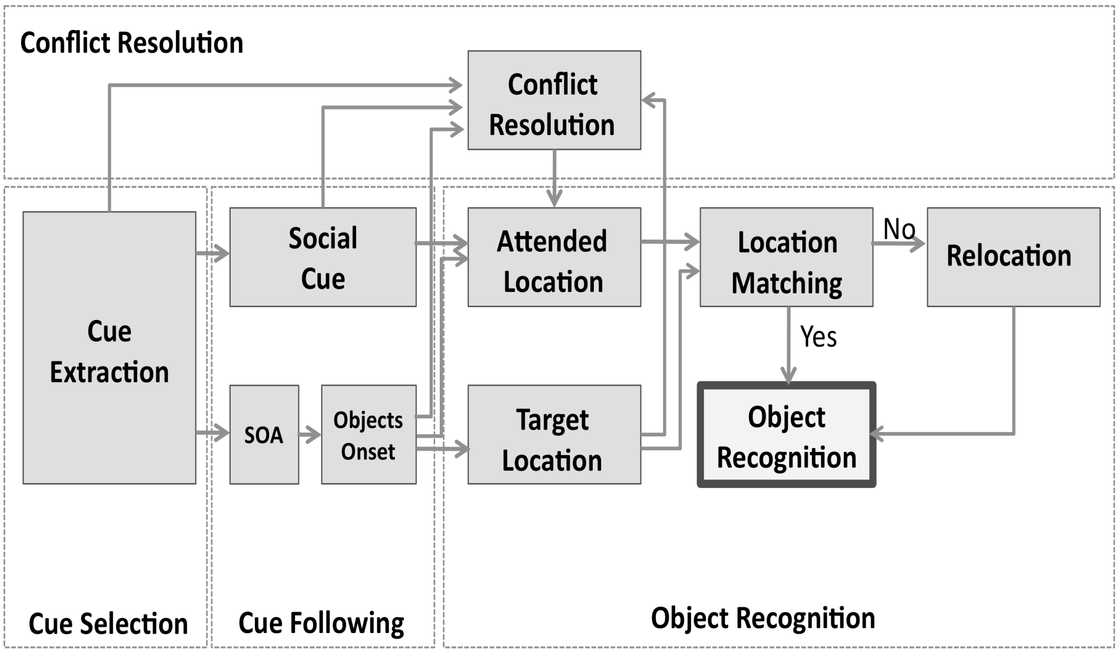


***Figure 25*. The illustration of the Cued Recognition Model**

The structure of the Cued Recognition Model was established based on the three stages of social cue processing, namely *cue selection*, *cue following* and *object recognition*. All the components in this structure, as well as the characteristics of each component, were developed based on the findings from all 5 experiments in this dissertation. In the Cued Recognition Model, all the arrows were unidirectional.

Importantly, the direction of the arrow referred to the direction of time, indicating that all the steps in this model could not be reversed. Moreover, a *conflict resolution* mechanism works parallel to all these three stages. This component interacts with all the three stages of social cue processing by monitoring and modulating any conflicts arise from the processes, and provides top-down inhibition and enhancement to certain aspects of the processing, in order to achieve a more effective performance.

The *cue selection* stage of the model is the most initial step of social cue processing. In the Cued Recognition Task, *cue selection* starts with the onset of the model's picture, and finishes shortly after the onset of the head-turn cues, but before the objects are presented. In all SOA conditions except for 0 ms of SOA, only the onset of the head-turn provides attention orientation cue. It should be noted that it is theoretically possible that the head-turn cue is not selected in the Cued Recognition Task because of the existence of other stimulus, such as the chest, shoulder, arms, and hands of the model. The forced fixation condition in Experiment 4 simulated this situation and found that *cue selection* was a prerequisite for social cue processing. Also, findings from Experiment 5 suggested that, children with ASD might be slower in selecting the social cue in this stage. However, social cues were successfully selected and processed by ASD participants and therefore, they showed comparable magnitude of social cueing effect as TD controls. Afterwards, attention orientation cues selected in this stage will be fed forward to the *cue following* stage of the model.

The *cue following* stage is the second step of the Cued Recognition Model. In the Cued Recognition Task, the *cue following* stage starts right after the completion of *cue selection* and within a short period after the objects are presented, *cue following* can be competed. The *cue following* stage of the model receives all the input of attention cues from the *cue selection* stage, and extracts any new attention orientation cues elicited by the onset of the objects. According to the findings from this dissertation (see Table 2) that attention orientation in the Cued Recognition Task was based on the result of the competition between the social cue and object onset cue, there are two independent components parallel to each other in the *cue following* stage. The attention cue from head-turns is processed in one channel and any attention cues elicited by object onset are processed in another independent channel. If the cue-object SOA is present in the task, the onset of the attention cue elicited by the object presentation will be delayed according to the length of SOA. Importantly, the strength of each cues have different temporal dynamics. The temporal dynamics of the cueing effect elicited by social cues can be informed by the findings from Experiment 1, 2 and 4 that the strength of social cues starts to emerge at 105 ms and does not decay even at 1005 ms after its onset. On the other hand, as indicated by the temporal dynamics of peripheral cueing effect (Jonides, 1981; Posner, 1980; Yantis & Jonides, 1996), object cue has a quick onset but decays quickly, and the magnitude of this onset effect is larger at longer SOAs, as suggested by the foreperiod effect (Bertelson, 1967; Bertelson & Tisseyre, 1968, 1969; Klein & Kerr, 1974; Klemmer, 1956; Posner et al., 1973). The attention orientation effect elicited by social cue and object cue compete with each other, and the result of the competition (i.e., either follow the head-turn cue, or follow the object cue) will lead the orientation of attention. The forced fixation condition in Experiment 4 reflects no activations in both social cue and object cue of the *cue following* stage at all. Therefore, attention orientation is not sensitive to any cueing effect from those two sources. The distractor condition of the Cued Recognition Task reflects the activation of the processing of social cue in the *cue following* stage. In the distractor condition, because a distractor is presented on the opposite side of the target, the object onset cue of the target can be neutralized by the object onset cue of the distractor. Therefore, the aggregated object onset cue does not compete with the social cue in the *cue following* stage. As a result, the attended location is purely decided by the social cue. On the other hand, the performance in the non-distractor condition reflects the competition between the social cue and object cue in the *cue following* stage. Attention orientation is decided by the result of this competition. To be specific, at 300 and 600 ms of SOA, the social cue is stronger than the object onset cue in the non-distractor condition, so the attended location is more biased toward the location cued by the social cue. At 105 ms of SOA, compared to the object onset cue, the strength of social cue is still relatively weaker. As a result, attended location is decided by the object cue. At 1005 ms of SOA, although the social cue is stronger than that at 105 ms of SOA, the object onset cue is also stronger than that at 105 ms of SOA because of the foreperiod effect. As a result, attended location is decided by the object onset cue. In short, the result of the competition between the social cue and object cue is sent to the next stage of the Cued Recognition Model.

The *object recognition* stage is the third step of the Cued Recognition Model. In the Cued Recognition Task, *object recognition* starts right after *cue following*, and will be terminated by the response made by the participants. In the *object recognition* stage, the attended location will be decided by the outcome of the competitions between the social cue and object cue from the *cue following* stage. In this stage, enough time has been provided for objects to be recognized. Therefore, the target location can be decided. If only one object is presented, the target location is the same as the object location. If two objects are presented, the target location can only be decided after one of the objects is recognized. After the attended location and the target location have been specified, these two locations are compared with each other.

If the attended location matches the target location, it suggests that the object being attended to is the target and therefore, *object recognition* can be completed. If the attended location does not match the target location, indicating that the target is not being attended to and as a result, attention will be reoriented to the target location before the identity of the target can be recognized. The relocation step is the main contributor to the different response time between the valid and invalid cueing conditions.

The *conflict resolution* mechanism can only be triggered by the signal from the *cue selection* stage if multiple cues are detected. Once triggered, the input channels from later stages of processing will be opened to receive any updates needed to specify the details of the conflict. Two mutually opposing elements are needed for the conflict representation to be completed, including one task-relevant cue and one task-irrelevant cue. In Cued Recognition Task, the task-relevant cue is object cue, and the task-irrelevant cue is social cue. Once all the necessary details of the conflict have been specified, the *conflict resolution* mechanism will inhibit the processing of the task-irrelevant social cue, and enhance the processing of the task-relevant object cue. During this period of time, the input channel of the *conflict resolution* mechanism will be closed, as suggested by the finding from Experiment 3 that the top-down conflict resolution mechanism works independent of the bottom-up conflict resolution mechanism. The attended location is now subject to the modulation from the *conflict resolution* mechanism. The result of the competition between the social and object onset cue will be further manipulated by the inhibition of the social cue and the enhancement of the object onset cue. As a result, if the social cue is not strong enough, the object onset cue will decide the attended location, and vice versa. The *conflict resolution* mechanism is activated at 0 ms of SOA in Experiment 1, 2 and 3.

In the invalid condition, upon the onsets of the head-turn and the object, more than one cue is detected. The *conflict resolution* mechanism is therefore activated, and is waiting for the information about the social cue and the object cue to be specified. The social cue can be specified shortly after its onset, however, when the object cue can be specified depends on how many objects are presented. In non-distractor condition, only one object is presented. Therefore, the object cue detail can be specified shortly after the object onset. After receiving updates from the detail specification of the social cue and object cue after the *cue following* stage, the *conflict resolution* mechanism modulates the competition between the social cue and object onset cue by inhibiting the social cue and enhancing the object cue. Because this modulation is completed before the object can be recognized, the suppression effect takes place relatively early. Therefore, the inhibition, or even over-inhibition effect can be found in trials with fast response time, but not slow response time, as suggested by the delta plots of Experiment 2. However, in the distractor condition, two objects are presented. Their weights are equal in orienting attention before they can be recognized, and therefore, no information in terms of attention orientation can be provided upon their onsets. As a result, the *conflict resolution* process can only be implemented when the target object is recognized. The target location will serve as the object cue, and will be sent to the *conflict resolution* mechanism. The inhibition of the social cue and the enhancement of the object cue can then be initiated. Therefore, since the *conflict resolution* mechanism is implemented relatively late in the distractor condition, the suppression of the social cueing effects only exists in trials with slow response times, as suggested by the delta plots in Experiment 2.

Implications and Future Directions

The most important implication in this dissertation is that, when measuring social cue processing, the peripheral onset effect should be controlled. Although Friesen et al., (2005) raised concerns for this potential confound and investigated whether the peripheral onset effect really interfered with the cueing effect, they didn't find any evidence for this interference effect. However, as discussed in detail in Experiment 2, this null results was probably due to the go-no-go type of object detection task and the between-subject design used in their study. The Experiment 2 of this dissertation revisited this issue, and found that the peripheral onset effect in the non-distractor condition attenuated the social cueing effect in general. For future researches studying social cue processing, it is suggested that the peripheral onset effect should always be controlled. The method used in the Cued Recognition Task to eliminate the peripheral onset effect can be a reference.

Another important implication is about children with ASD. The results from Experiment 5 replicated the findings from the majority of the studies (8 out of 13 studies) investigating the social cue processing of individuals with ASD that they showed equivalent size of social cueing effect as the TD controls. Moreover, it was also found in Experiment 5 that ASD participants selected and followed the social cues to the same extent as TD controls, but they might have spent longer time in performing these steps. This finding suggested that the potential issues of individuals with ASD in social cue processing is more likely to be processing efficiency, but not some qualitative impairment in *cue selection* and *cue following*. Hopefully, this finding can be informative for the design of intervention programs, especially in the training of joint attention behavioral.

On the other hand, the current dissertation did not provide answers to the following questions. First, although it was evident from Experiment 1, 2 and 4 that the social cueing effect sustained at 1005 ms of SOA, no evidence was provided of when the social cueing effect would diminish. Longer SOAs should be tested in future studies. Second, the current study only investigated the temporal dynamics of the non-predictive social cue processing. Future studies could also use the Cued Recognition Task to test social cue processing under predictive and counter-predictive cueing conditions. Third, the current study did not compare the cueing effects between social cues and non-social cues, such as arrows. It was also unknown whether the peripheral onset effect was an issue in measuring the cueing effects elicited by center arrow cues. Nevertheless, the difference between social and arrow cues should be investigated using a task that is free of the interference from the peripheral onset effect. Last but not least, the Cued Recognition Model was only conceptually developed according to the findings from this dissertation. This model should be computationally developed and tested in future modeling studies. Moreover, the model should also be tested if it is able to successfully explain all the new findings from future studies using the tasks similar to the Cued Recognition Task.

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