Perceptual ability is diminished at peak limb velocity of a goal-directed movement but is unaffected during motor preparation

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Statement of Contribution of Collaborators

I hereby declare that I am the sole author of this Master's thesis. I collected and analyzed the data of the present study under the supervision of Dr. Anthony N. Carlsen who also provided editorial corrections.

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Abstract

Inspection time (IT) is a measure of the amount of time required for a visual stimulus to be presented in order for it to be accurately perceived by a participant. The visual stimulus most commonly used is a “pi” figure with differing leg lengths which is briefly presented (e.g., 20-200 ms) and then rapidly backward masked to prevent further visual processing. Participants are to indicate which side (left or right) of the “pi” figure has the longest leg. IT is typically used to evaluate perceptual processing speed by determining the presentation time required to correctly identify the figure at a preset threshold level (e.g., 75%). Although the IT paradigm has long been used to investigate perceptual processing speed alone, it is unclear how a goal-directed movement may influence perceptual processing. As such, this study examined whether perceptual processing of the IT stimulus would be altered during movement (i.e., peak limb velocity), or shortly before movement (i.e., foreperiod), in comparison to when no movement was required. A fixation cross was visible at the warning tone and disappeared at the go-signal. Following fixation offset in the no-movement condition, a “pi” figure where the left or right leg was longer was presented for between 15 and 120 ms (in 15 ms steps) and was then backward masked. In the movement conditions, however, a rapid movement to a target was required and the “pi” figure was either presented at peak limb velocity, or during the foreperiod interval. Participants verbally responded indicating which leg of the pi figure was longer and rated their response confidence (1= not confident at all; 5= very confident). Results showed that in comparison to the no-movement and foreperiod conditions, perceptual ability and confidence ratings were significantly diminished at peak limb velocity. These findings suggest that perceptual ability may be reduced at peak limb velocity, or when simultaneously performing a secondary task.

Chapter 1: Literature Review

1. Introduction

Visual discrimination can be defined as the process "in which an organism responds differently to the greater and the lesser of two stimuli" (Vickers, 1979) by using the sense of vision. Although often studied in the laboratory using less significant tasks such as telling colors apart or choosing the largest of two objects (Vickers, 1979), this particular ability played a major role in the survival of our primitive ancestors and plays an obviously large role in our daily lives. For example, visual discrimination allowed early hominids to identify a predator's shadow from surrounding visual stimuli, and to recognize fruit trees by their shape, size, and texture, whereas we use this ability to avoid oncoming traffic or to select the largest slice of cake (Vickers, 1979). Innumerable advantages have evidently stemmed from visual discrimination, which is why its function is worth understanding.

In 1992, Goodale and Milner posited a two-visual pathway model suggesting that vision-for-perception (which is important for visual discrimination) is processed in the ventral stream, while vision-for-action (e.g., accurately moving to a visual target) is processed in the dorsal stream. Although much knowledge has been gained regarding how both visual pathways work independently of each other (Goodale and Milner, 1992; Milner and Goodale, 2006), far less is known about whether visual processing may still be optimal, if it is being processed in both pathways simultaneously.

Recent studies have suggested that visual perception (in a general sense) may be altered (Tremblay and Nguyen, 2010) and / or optimized (Hagura et al., 2012) at peak limb velocity and during the short time period prior to movement onset, respectively. Of interest in the current thesis is whether *visual discrimination* is altered prior to or during the performance of a goal-directed movement.

1.1 Information processing stages

In 1795, an astronomer known as Nevil Maskelyne fired his assistant, David Kinnebrook, for consistently miscalculating the position of a star at a given point in time. Maskelyne, who was working on a universal measurement for star alignment, was desperate for accurate readings and could not comprehend why his assistant was always half a second behind his measurements. Maskelyne was neglecting a crucial component regarding reaction time (RT) to a visual stimulus: it is not a fixed measurement and can vary from one person another. Thus, discrepancies between Kinnebrook and Maskelyne's reading were not due to miscalculations in time, but to individual differences in various processing stages (as cited in Jensen, 2006).

Frans C. Donders, a Dutch physiologist from the nineteenth century, was particularly interested in determining the speed of mental processing (as cited in Jensen, 2006). He proposed that humans typically undergo three separate cognitive stages: stimulus identification, response selection, and response programming. The first stage, stimulus identification, is a largely sensory one. In this stage, the presentation of the stimulus is detected and its nature is identified (e.g., it is a light as opposed to a sound). Once identified, an internal representation of the stimulus is transferred to the next stage, response selection, where a decision regarding a response is made. In the third stage, movement programming, a motor program of the type of movement to be executed is formed. After its formation, the program is launched for movement execution (as cited in Schmidt and Lee, 2014).

According to Donders (1969), information processing stage(s) can either be inserted or deleted depending on the type of reaction time (RT) task in which one is engaged. For example, in an A-reaction task, currently known as a simple RT task, a person is typically required to make a single response subsequent to the presentation of a stimulus. Given that the response is always the same, it can be prepared in advanced. However, in a B-reaction task, currently known as a choice RT task, many responses may be required to different stimuli. In this case, the response cannot be prepared in advance given that it cannot be anticipated. Finally, in a C-reaction task, a response to a "positive" and "negative" stimulus is required, respectively. For example, the task can be to tap the right hand when a green light turns on but to inhibit the tapping movement if a red light turns on. To determine the speed of a single processing stage such as visual identification, Donders suggested that the RT of an A-reaction task can be subtracted from the RT of a C-reaction task (as cited in Jensen, 2006 and Schmidt and Lee, 2014). That is, his rationale was that since visual identification had been "inserted" into the C-reaction task, measuring its duration was possible with his subtraction method.

Albeit a clever idea, Donders' subtractive method was strongly questioned. For example, he assumed that inserting a step would only have an additive effect on the overall RT, excluding the possibility of an interaction between the inserted process and all other processing stages. The issue with an RT paradigm is that it inevitably combines both cognitive and motor processes together; therefore, the only possible way to bypass this issue is by measuring cognitive speed in a paradigm that excludes any motor component (as cited in Jensen, 2006).

1.2 Inspection time

Visual inspection time is the minimal amount of time required for a visual stimulus to be shown for it to be accurately perceived (e.g., 80% accuracy). The Inspection Time (IT) paradigm, originally developed by an Australian researcher named Douglas Vickers (1970), typically begins with a brief presentation of a fixation cross that is followed by an asymmetrical "pi" figure consisting of two vertical parallel lines differing in length connected at the top by a horizontal line. The "pi" figure is then covered by a masking stimulus to prevent retinal after-image processing (Vickers, 1979). At the end of each trial participants respond either manually (e.g., keypress) or verbally to indicate the side on which the longest leg of the figure appeared. This task does not measure RT and thus participants are encouraged to respond at their leisure. When the side of the longest leg is uncertain, which typically occurs with shorter display durations of the pi figure, participants are required to "guess" the side. The presentation time of the pi figure typically varies from shorter durations (e.g., 15 ms) to longer durations (e.g., 200 ms). The objective of this paradigm is to determine the duration at which the pi figure must be presented in order for it to be perceived with 80% accuracy (Sadler and Deary, 1996).

1.3 Altered inspection time in clinical populations

Parkinson's disease (PD) patients have been shown to perform poorly on simple RT tasks (Gauntlett-Gilbert & Brown, 1998). Given the nature of this disease, it is intuitive to assume that poorer performance on simple RT tasks is a direct result of motor impairments, in particular in the movement selection and execution stages. However, a study suggested that the impairment may be found in an earlier, more perceptual stage, specifically stimulus identification (Johnson et al., 2004). Johnson and colleagues (2004) argued that if poorer performance on simple RT tasks were due to motor impairments, then PD patients should perform similarly to age-matched individuals on the IT task. Their findings showed that performance on the IT task was significantly poorer in PD patients in comparison to age-matched individuals. That is, for an accurate discrimination, PD patients required the presentation duration of the IT stimulus to be longer than the control group, suggesting an impairment in perceptual speed (i.e., longer time to identify a visual stimulus).

1.4 Altered inspection time in neurologically healthy populations

Although Vickers (1970) was the first to include the IT paradigm in an experiment, this paradigm sparked an interest in many other researchers, specifically because of its presumed ability to measure various perceptual processes. For instance, Kranzler and Jensen (1989) found significant differences in discrimination performances between individuals with differing intelligent quotients (IQs). That is, the likelihood of accurately determining which leg of the pi figure was the longest was greater in individuals with higher IQs, suggesting an association between IQ and speed of perceptual processing on this task. Another study conducted by Nichols and Atkinson (1993) investigated whether differences in the speed of perceptual processing also existed between the left and right hemispheres by examining the right and left visual fields, respectively. Subjects were seated in front of a computer monitor and were required to fixate a cross that was presented at the center of the screen. Once the fixation cross disappeared the inspection paradigm took place either on the left or right side of the monitor, allowing the researchers to investigate the speed of perceptual processing in the right and left visual hemispheres, respectively. Their results suggested that when the visual stimuli were presented to the right visual field, performance on the inspection time paradigm was significantly greater, suggesting that a left hemisphere advantage in speed of perceptual processing may exist. While Nichols and Atkinson (1993) discovered differences in the speed of perceptual processing between the left and right hemispheres, Carlsen and colleagues (2007) have also found differences, but between lower and upper visual fields. More specifically, performance was significantly greater in the IT paradigm when the pi figure was presented to the lower as opposed upper visual field. According to Carlsen et al. (2007), these results may have been due to the greater number of ganglion cells in the superior hemiretina as opposed to inferior hemiretina. A greater number of ganglion cells would hypothetically be more favorable in an IT task, as more information would be available per inspection. The idea is that with more information per inspection the accumulator would reach threshold more quickly and lead to accurate decision regarding the visual stimulus at hand.

1.5 The accumulator model

The IT paradigm is mainly a perceptual task (Jensen, 2006) in that it focuses on measuring the speed of the sensory-perceptual apparatus (i.e., stimulus identification stage), and excludes all motor components comprising a typical RT task. According to Vickers (1970), to correctly discriminate between two visual stimuli the eyes are thought to take visual “samples” every so often, and the minimal amount of time between the IT stimulus and the mask is a direct reflection of the minimal amount time the eyes require to sample evidence for a fairly accurate visual discrimination. In the case of the IT paradigm, Vickers (1970, 1978, 1979) proposed that there are two possible responses (i.e., the right side is longer than the left, or vice versa) that are associated with two separate “accumulators”. It is thought that both accumulators sample evidence at “equally spaced time steps” (Duffy, 2008), while the amount of evidence sampled is stochastic. The first accumulator to sample sufficient evidence up to a preset threshold “wins” the race, and a decision is then based on the “winning” accumulator.

In summary, there have been many attempts to measure the speed of cognitive processing, in particular the visual identification phase. Given the interference of motor processes, however, it has been difficult to obtain an untainted measure of visual identification in

RT tasks. The IT paradigm bypasses this problem by measuring the identification speed of a visual stimulus in a purely perceptual task, excluding any motor component found in an RT task.

Although it may seem that the sole purpose of vision is to allow us to perceive our environment (Milner and Goodale, 2006) (e.g., visual identification), it also plays a major role in controlling our movements, as will be discussed next.

2. The two streams hypothesis: a history

2.1 Visual Cortex vs. Midbrain

In his classic review of the literature Schneider (1969) first proposed the possibility of two separate visual systems: one whose purpose is to identify objects, while the other is to locate them. In his review, particular attention was drawn to one of his experiments which consisted of either surgically removing specific areas of several hamsters' visual cortices or ablating their right superior colliculus. Subsequent to surgery, hamsters underwent a visual pattern discrimination task as well as a stimulus orientation task. During the visual pattern discrimination task hamsters were fairly thirsty; given this, only one of two doors contained water behind it (the door with the plus sign contained water, while the door with the minus sign did not). Thus, hamsters had to correctly discriminate between both patterns (plus and minus) in order to earn their reward. On the other hand, no rewards were given in the stimulus orientation task; hamsters were simply required to orient their head to an auditory or visual stimulus.

Findings of this study showed that hamsters with lesions to their midbrain (super colliculus) performed quite accurately on the visual pattern discrimination task (chose the door with the plus sign most of the time) but performed poorly on the stimulus orientation task (could not correctly orient their head to the stimulus). Conversely, hamsters with lesions to areas of their visual cortices performed very poorly on the visual pattern discrimination task; however, their performance on the stimulus orientation task was left intact.

Given these results, Schneider proposed that the visual cortex allows for identification of objects while the midbrain, specifically the superior colliculus, allows for orientation to visual/auditory stimuli. In other words, the visual cortex identifies *what* the object is, while the midbrain locates *where* it is in space.

2.2 What vs where pathway

In their classic “monkey experiment” Ungerleider and Mishkin (1982) first proposed that vision may have two distinct roles: object and spatial perception. Object perception, the ability to identify what an object is (e.g., this is a coffee mug), was posited to be processed in the ventral or occipitotemporal stream, while spatial perception, the ability to spatially locate an object (e.g., the coffee mug is there), was proposed to be processed in the dorsal or occipitoparietal stream.

Prior to receiving a lesion to either the posterior parietal or inferior temporal cortex, a number of naïve rhesus monkeys were preoperatively trained on landmark and pattern discrimination tasks. In the landmark task were two identical covers from which the monkeys had to choose: one which covered a food-well containing food (correct one) and the other which covered a food-well containing no food (incorrect one). A striped cylinder which served as a ‘landmark’ was always placed closer (5cm) to the cover that contained food and furthest (20cm) from the cover that contained no food. The monkey’s task was to accurately uncover the food-well that contained food by determining which of the two covers was closest to the cylinder.

On the other hand, the pattern discrimination task was slightly different in that monkeys had to uncover one of the two lids that had a particular pattern on its surface. That is, one lid had a pattern of a ‘plus’ sign while the other had a square-shaped pattern. The monkeys’ task was to identify which lid was covering the food by recognizing the learned pattern (plus or square).

Results of this study showed that lesions to the inferior temporal cortex severely impaired the monkeys’ performance in the pattern discrimination task while leaving the landmark discrimination performance intact. Conversely, performance in the landmark discrimination task was significantly compromised when monkeys received a lesion to the posterior parietal cortex.

However, a lesion to the posterior parietal cortex did not significantly hinder the monkeys' performance on the discrimination pattern task.

These findings allowed Ungerleider and Mishkin to propose that the inferior-temporal cortex was the “what” system (e.g., identifies object features such as its shape), while the posterior parietal cortex was the “where” system (e.g., locates an object's spatial position such as in the landmark discrimination task).

2.3 What vs how pathway

Similar to Ungerleider and Mishkin's (1982) “what vs. where” system, Milner and Goodale (1995) proposed a slightly different model, informally known as the “what vs. how” system. Their proposition came about after extensively studying two patients: patient D.F. and patient R.V., which will be described in detail in the following section.

2.3.1 Patient D.F. and visual form agnosia

A defective gas water heater left patient D.F. asphyxiated while taking a shower. The lack of oxygen resulting from carbon monoxide poisoning severely damaged her ventral stream, leading to the development of a perceptual disorder known as visual form agnosia, characterized by an inability to recognize or identify object features. For example, patient D.F. cannot discriminate between common geometric shapes such as squares or triangles, and her ability to draw these simple geometric forms is severely impaired. Occasionally, however, she can identify real objects by their fine texture or color, particularly if they are ‘natural’ objects (e.g., fruits and vegetables).

Within a few weeks of recovery, she could accurately reach towards and grasp objects, and interact with the objects without difficulty (e.g., catching a ball). Although she could not identify the size or orientation of the presented object, she could follow a light with her eyes.

In a study conducted by Milner et al. 1991, patient D.F.'s task was to insert a card into a slot (or move her hand towards the slot) in the correct orientation (0, 45, 90, or 135°). Remarkably, she could accurately complete this task without difficulty; however, a successful completion of this task only occurred when engaging in a goal-directed movement. That is, her ability to verbally report or manually set the orientation of the slot while remaining idle was severely impaired. Similarly, an extended experiment conducted by Goodale et al. (1991) required patient D.F. to make a perceptual report (i.e., identify or recognize) of the rectangular object at which she was looking (e.g., this is a rectangle). Despite the simplicity of this task she was unable to accurately identify the object; however, when she was instructed to grasp it, she would scale her grip to the object's size and turn her hand in the correct orientation when reaching out to it.

In summary, damage to patient D.F.'s ventral stream rendered her incapable of recognizing or perceiving objects. However, given that her dorsal stream was left fairly intact, her ability to properly interact with objects (i.e., her visual-motor control system) was preserved.

2.3.2 Patient R.V. and optic ataxia

After receiving two bilateral lesions to her parietal lobes, patient R.V. developed optic ataxia, a visually-guided movement disorder. For example, patients suffering from optic ataxia due to posterior parietal cortex lesions show great difficulty in scaling their grasp to the object's size, and reaching and orienting their hand in the correct direction. Given this, when required to grasp an object, patient R.V. often failed to correctly position her index finger from her thumb, an essential skill required to avoid dropping handheld objects. Moreover, unlike patient D.F., patient R.V. could not correctly place a card in a slot with differing angles. However, when asked to give a perceptual report of the slot's angle (e.g., the slot is tilted at 45° to the right), she could do so fairly accurately.

In summary, patient R.V.'s perceptual system was intact given that her ventral streams were preserved. However, since she suffered from lesions to her posterior parietal cortices she could no longer utilize vision to correctly guide her movements.

Although both visual streams work together to produce a unified percept of the world (Milner and Goodale, 2006), they may also function independently of one another when either stream is damaged, as evidenced by studies conducted on patient D.F. and patient R.V. However, this does not signify that this is the case for neurologically healthy individuals. That is, although the dorsal and ventral streams are predominantly used in goal-directed movement and perceptual tasks, respectively, it seems unreasonable to assume that a neurologically healthy person would only use one of the streams, in either task, when the other is still intact. That is, the fact that humans can perceive the environment while simultaneously engaging in goal-directed actions (e.g., walking toward a classroom while concurrently playing ''candy crush'' on one's cellular phone) hints at the idea that both streams can function coincidentally. However, what happens when both streams are equally required in a task? For example, say that a person must engage in a perceptual task (e.g., discriminate between two lines of differing leg lengths) while simultaneously having to land accurately on a target. This person's ability to identify which line was longer (perceptual task requiring ventral stream processing) is just as important as accurately homing-in to a target (movement task requiring dorsal stream processing). Therefore, can the way in which visual information is processed during a goal-directed movement be hindered or enhanced by a perceptual task that also requires optimal visual feedback processing?

In order to investigate this possibility, one must first understand the composition of both visual streams (e.g., types of pathways that comprise them) and how that can influence the ways in which both streams communicate.

3. The ventral and dorsal streams: a comparison in function, composition, and speed

According to Goodale and Milner's (1992) two-stream hypothesis, visual information is utilized differently for perception and action. Although much evidence has been provided to support this idea, one weakness of this hypothesis is that it was mainly based on patients with brain lesions. Given this, it is unclear as to whether this hypothesis is applicable to neurologically healthy individuals. A clever way around this, however, is to include visual illusions in a motor task, a method that has been applied in a number of studies.

In the following section, reasons for which the ventral stream, which is predominantly operating during perceptual tasks, is more susceptible to visual illusions than the dorsal stream, which is generally involved in motor tasks, will be explored. Particular attention will be drawn to differences in functionality and processing speed of both visual streams, and why these characteristics are important to take into account in the present proposal.

3.1 Susceptibility of ventral and dorsal streams to visual illusions

In their classic experiment, Aglioti et al. (1995) used an optical illusion known as the Ebbinghaus illusion to study the relationship between action and perception. The Ebbinghaus illusion consists of two annuli (i.e., ring-shaped objects), identical in size, that are placed side by side. A ring of small circles typically surrounds one of the annuli, while a ring of large circles surrounds the other annulus. This particular placement can create a misperception of size; that is, the annulus surrounded by smaller circles may appear to be larger in size than the annulus surrounded by larger circles, thus resulting in the Ebbinghaus illusion.

Half of the trials in Aglioti et al.'s experiment consisted of having both annuli identical in size, whereas on the second half of the trials one annulus was always physically larger than the other. The size of the annulus that was surrounded by the larger circles was increased so that it could appear to be physically identical to the annulus surrounded by the smaller circles. Subjects were instructed to grasp the annulus on the right if both annuli were perceived to be of different size. Conversely, if both annuli were perceived to be of identical size, they were instructed to grasp the annulus on the left. In this manner, the subject's perceptual judgment could be determined by the choice of annulus they grasped. Regardless of the illusory condition in which participants were engaged (i.e., whether or not the annuli appeared to be of identical or different sizes), when they were required to grasp the annulus participants scaled their grasp to the object's actual size, showing no motor susceptibility to the illusory effect. These findings support Goodale and Milner's (1992) two-stream hypothesis which suggested that visual information may be processed and transformed differently in the ventral and dorsal streams. In other words, although participants were perceptually biased by the illusion, their visuomotor system showed no evidence of susceptibly to the seemingly larger or smaller appearance of the annulus.

3.2 The influence of memory on action

Although generally resistant to visual illusions, the dorsal stream may become susceptible to illusory effects if the task at hand requires memory retrieval. For example, when grasping an object in real-time, grip aperture (i.e., the opening between the grasping fingers) typically becomes much greater than the width of the object and, at approximately 70 percent of the trajectory towards the to-be grasped object, maximum aperture is reached. Following maximum grip aperture, the gap between the grasping fingers progressively becomes smaller so that it could be scaled to the object's size (Jakobson and Goodale, 1991). Interestingly, this normal grasping pattern is generally not observed when required to make a grasping gesture (i.e., pantomime) towards a previously shown object. For example, in a study conducted by Goodale et al. (1994), subjects were required to either grasp an object in real-time, or they were shown an object that would then be removed from sight for a total of 2 seconds. In the 2 second delay condition, subjects showed abnormal grip aperture in that the gap between the index and the thumb (i.e., the grasping fingers) remained small throughout the entire movement trajectory. Given these results, Goodale et al. (1994) suggested that when required to retrieve a mental representation of an object from memory, the ventral stream may influence the ways in which information is processed in the dorsal stream.

When grasping movements require memory retrieval of the shape of an object, typical grasping kinematics may be altered. However, grasping movements are not the only actions influenced by memory; that is, a saccade to a remembered location can also be influenced by perception. For example, in one of Wong and Mack's (1981) experiments, a small target surrounded by a frame was presented to subjects and, after disappearing for 500 ms, both visual stimuli later reappeared with subtle changes: the frame had either been displaced to the left or right of the target, while the target itself had remained in its original position. The shift in frame position typically creates the illusion that the target had been displaced in the opposite direction of that of the frame, when in fact it had remained idle throughout the whole trial. Despite this powerful illusion, Wong and Mack noted that saccades were being performed to the target's *actual* and not *perceived* position. However, after subjects had saccaded to the most recent location (i.e., after the frame had slightly shifted positions), they were asked to perform a saccade to the 'original' location of the target (experiment 2). Interestingly, when required to retrieve a mental representation of the "past" location of the target, subjects saccaded to the *perceived* as opposed to *actual* location of the target.

In summary, in comparison to the ventral stream, the dorsal stream is typically resistant to illusions. However, in cases where information must be retrieved from memory (e.g., performing a saccade to the original location of a target, or grasping a remembered object), the dorsal stream may become more susceptible to perceptual or illusory effects.

Not only do illusions, or memories of object features affect the ventral and dorsal streams differently, but both visual pathways also differ in term of the cells of which they are comprised, a concept that will be highlighted in the following section.

3.3 Parvo and magnocellular pathways

The parvo and magnocellular pathways both originate in the ganglion cells of the retina and travel to the lateral geniculate nucleus, into the striate cortex and deep into the posterior parietal and inferior temporal cortices (Milner and Goodale, 2006; Maunsell, 1987; Livingstone and Hubel, 1988). The parvocellular pathway is predominantly comprised of medium-sized body ganglion cells (midget cells) made up of small dendrites, with relatively small receptive fields (Schiller and Logothetis, 1990). Conversely, ganglion cells with larger cell bodies, dendrites, and receptive fields are mainly situated in the magnocellular pathway (Schiller and Logothetis, 1990). Moreover, visual information can be processed at a faster rate in magno as opposed to parvo cells (Bullier and Nowak 1995, Livingstone and Hubel,1988), and the conduction velocity in magno cells is greater than that of the parvo cells (Schiller and Logothetis, 1990).

Livingstone and Hubel (1988) proposed that the parvocellular pathway is involved in object identification, while the magnocellular pathway is involved in object localization, analogous to Ungerleider and Mishkin's (1982) "what" and "where" pathways, respectively. However, this proposition implied that the ventral and dorsal streams only receive input from the parvo and magnocellular pathways, respectively. This proposition was shown to be far from true (Fererra et al. 1992, 1994). That is, although a large amount of input from the magnocellular and parvocellular pathways is predominantly sent to the dorsal and ventral streams, respectively (Merigan and Maunsell, 1993), both streams can still receive a mixture of inputs from both pathways, which can lead to specific interactions between the streams (e.g., enhanced processing of the ventral stream). Whether or not an optimal time window for an interaction between both streams exists remains unknown. However, the possibility of an optimal time window for visual upregulation is suggested to occur during or shortly prior to movement. This proposition will be discussed in more detail in the following section.

4. Altered visual perception during movement

4.1 Altered visual perception at peak limb velocity

Often, when two visual flashes are accompanied by a single auditory beep, subjects mistakenly report seeing a single visual flash, a phenomenon known as the fusion illusion (Shams et al., 2000; Tremblay and Nguyen, 2010; Andersen et al., 2004; Loria et al., 2016). Conversely, when a single visual flash is accompanied by two auditory beeps, subjects will often report seeing two visual flashes (i.e., fission illusion) (Loria et al., 2016, Tremblay and Nguyen, 2010). In 2010, Tremblay and Nguyen investigated whether the effects of the fusion/fission illusion were altered during a goal-directed movement. Subjects performed a 30 cm amplitude horizontal aiming movement with their right index finger from a home position to a target with a goal movement time of between 290 to 350 ms. The fusion/fission illusion occurred at either 0, 50, 100, 150, or 200 ms after movement onset. At the end of each trial participants were required to report whether they perceived one or two visual flashes, which were presented 6 cm below the target. According to Tremblay and Nguyen's findings, subjects were more resistant to the fusion illusion when their limb was moving at higher velocities (i.e., 50 to 100 ms conditions). Conversely, subjects were more susceptible to the fusion illusion (i.e., answers were more likely to be biased by the auditory beep) when their limb was moving at lower velocities (i.e., 0 and 200 ms conditions). Tremblay and Nguyen (2010) suggested that their results may be attributable to optimal integration of multisensory information at peak limb velocity. They also suggested that their findings may be a result of "auditory gating" (i.e., decreased auditory processing) at that particular kinematic marker. However, the possibility of visual upregulation alone occurring at peak limb velocity should not be excluded.

In summary, Tremblay and Nguyen's (2010) experiment strongly suggests that visual processing may be altered at peak limb velocity. However, another experiment has shown a possibility of visual upregulation slightly before movement onset; that is, during the foreperiod.

4.2 Altered visual perception during foreperiod

Prior to striking a fast incoming ball, expert athletes typically report the ball "slowing down" effect; that is, feeling as though the ball is approaching them in slow motion. To investigate whether this phenomenon is due to action-related effects or actual altered visual processing, Hagura and colleagues (2012) designed five separate experiments. In their first experiment, a fixation cross was presented on a computer monitor and was followed by a white filled circle (target) either containing a "+" or an "x" sign, both indicating a cue to press a key. Once the filled circle disappeared participants had to release the key (reach condition) or keep pressing it (control condition) depending on whether they had seen a "+" or "x" sign, respectively. At the end of every trial participants in both conditions verbally judged the duration of the target. Results showed that participants in the reach condition perceived the target duration as longer than the control condition, suggesting that motor preparation may influence time perception. To test whether or not these results were in fact due to motor preparation, and not to merely paying attention to a stimulus, they designed a second experiment. The second experiment was similar to the first but the reaching task was replaced by a letter detection task. That is, following the presentation of a filled white circled target (once again containing either a "+" or "x" sign), the letter "C" or "G" was shown in a hollow circle. If the target contained a "+" participants had to report the letter they had seen (C or G) and had to judge the target duration at the end of every trial. In contrast, if the target contained an "x", participants were only required to judge its duration and ignore the letter detection task. A key was continuously pressed throughout the entire trial in both conditions. Results of the second experiment showed that target duration judgement was similar in both conditions, suggesting that paying more attention to a visual stimulus could not account for the experienced altered perception of time. Given these results, a third experiment was conducted to investigate whether motor preparation had in fact affected time perception. The rationale behind the third experiment was that if motor preparation could affect the perception of time then the amount of motor preparation should be directly proportional to the perceived amount of time dilation. To test for this, participants had to either perform a simple or choice RT task. In a simple RT task the required movement is known in advance (e.g., a finger tap after a light turns on), and thus can be prepared before the go-signal. However, the required movement in a choice RT task cannot be fully prepared prior to the go-signal, given that it is unknown. As predicted, results of the third experiment showed that prepared movements (i.e., simple RT task movements) dilated time perception significantly more than unprepared movements (i.e., choice RT movements), once again suggesting that time perception can be altered by motor preparation.

Although time perception has been shown to be affected by motor preparation, as demonstrated in the three-abovementioned experiments, it was not clear, however, whether these results were merely due to performing an action, or if they were a result of increased perceptual processing speed. To test for this, a flickering light with varying temporal frequencies was presented after a preparation cue to reach ("+") or not to reach ("x") to a target was shown. Results showed that participants in the reach condition perceived the flickering stimulus significantly slower than the no reach condition, suggesting that the flow of visual information may have been increased due to motor preparation. To further test this suggestion, a fifth experiment was designed. In this experiment, 24 letters were presented consecutively after a preparation cue to reach (“+”) or not to reach (“x”) was presented. Subsequent to the preparation cue, 24 letters were presented consecutively, each for 35 ms. Every shown sequence included the letter “C” or “G”. Immediately following the sequence of letters was the presentation of a hollow disc for 12 ms. Shortly after this, a hollow circle containing a “+” or “x” sign cued participants to reach or not reach to a target, respectively. A perceptual task immediately followed which required participants to report which of the two letters (C or G) they had seen in the sequence. Results of this experiment showed that participants who prepared to reach were more likely to correctly detect the letter presented in the sequence, specifically when that letter was shown 300 ms or less prior to the go-signal.

In summary, the abovementioned experiments provide evidence for visuo-perceptual enhancement, particularly at peak limb velocity and foreperiod of a goal-directed movement. If visual perception is indeed enhanced at those particular times, then better performance on the IT paradigm prior to and during a motor task should be observed.

5. Research question

While IT paradigms have been used to assess differences in speed of perceptual processing between visual fields (Carlsen et al., 2007), clinical and healthy populations (Johnson et al., 2004), cerebral hemispheres (Sadler and Deary, 1996), and individuals with differing IQs (Kranzler and Jensen, 1989), it is unclear how a goal-directed movement could influence visual identification speed, specifically in an IT task. For example, if a subject is required to accurately move to a target, a task that is predominantly processed in the dorsal stream, and simultaneously engage in a perceptual task (e.g., inspection time paradigm), which is predominantly processed in the ventral stream, can the speed of perceptual processing be altered (e.g., visual identification duration)?

Understanding how the ventral and dorsal streams operate separately has been made possible by patients who have had severe impairments to one of the two abovementioned streams (e.g., patient D.F. and patient R.V.). However, the ways in which the dorsal and ventral streams work in parallel with one another in a neurologically healthy person is still unclear. For example, the study conducted by Tremblay and Nguyen (2010) showed that subjects were less susceptible to the fusion illusion when their limb reached peak velocity during a goal-directed movement. Although not part of their rationale, Tremblay and Nguyen's (2010) results showed evidence for visual upregulation at peak limb velocity, given the higher resistance to a visual illusion at that particular movement kinematic. Similarly, Hagura and colleagues (2012) showed that visual perception was altered during foreperiod, suggesting that visual upregulation may also occur shortly before movement onset.

The present proposal therefore aims to investigate whether or not visual perception may be altered during a goal-directed movement, specifically at peak limb velocity and during the foreperiod. To test this phenomenon, subjects were required to move to a target while simultaneously engaging in a perceptual task (IT paradigm) once their limb reached peak velocity, or during the foreperiod interval. If visual processing is in fact altered at those time points, results on the IT paradigm are expected to differ from control (non-movement conditions).

Chapter 2: Research Article

Perceptual ability is diminished at peak limb velocity of a goal-directed movement but is unaffected during motor preparation

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Abstract

Due to various shortcomings of the visual system, some visual stimuli can only be identified with 100% accuracy if they are shown for a certain amount of time. This time can be measured using the Inspection Time (IT) paradigm. In an IT task, a “pi” figure with differing leg lengths is typically presented briefly (e.g., 20-200 ms) and is then immediately masked to prevent retinal afterimages. Participants are subsequently required to choose which of the two legs was longer. The objective of this task is to determine the shortest amount of time the pi figure needs to be shown for it to be perceived with 80% accuracy. Given that visual processing has been shown to be altered during and /or prior to a movement, the present experiment sought to test how the requirement to perform a motor task affected IT. Twenty-eight participants took part in the experiment, which was comprised of three conditions: no-movement (NM), peak velocity (PV), and foreperiod (FP). In the NM condition, participants grasped a manipulandum and engaged in the IT paradigm. At the end of every trial, participants verbally stated which leg they believed was longest. In the PV condition participants made a rapid movement to a target, and the IT stimulus was presented when their limb reached peak velocity. Finally in the FP condition the IT stimulus was presented during foreperiod (FP). In all three conditions the IT stimulus was randomly presented from between 15-105 ms (in 15 ms increments) and masked for 400 ms. Results showed no significant differences on the IT task between the NM and FP conditions, suggesting no visual upregulation during foreperiod. However, IT performance was significantly poorer in the PV condition in comparison to both the NM and FP condition, suggesting a visual downregulation at that particular movement kinematic.

Keywords: Perceptual processing speed, ventral stream, dorsal stream, visual upregulation, visual downregulation, inspection time paradigm, peak limb velocity, foreperiod

Introduction

It has been previously proposed that vision may be utilized for two separate purposes: vision-for-perception and vision-for-action (Goodale and Milner, 1992). The vision-for-perception pathway, also known as the “what” pathway, predominantly processes visual information in the ventral stream so as to allow for object recognition and identification (e.g., this object is a coffee mug). However, the vision-for-action pathway, also known as the where/how pathway, aids in identifying the location of an object (e.g., the coffee mug is here) and how to interact with that object (e.g., scaling one’s grasp to the coffee mug’s size) by processing visual information mainly in the dorsal stream.

Much research has focused on understanding how these pathways operate independently, particularly through the use of patient populations (Sanders et al. 1974; Weiskrantz et al. 1974, 1986; Goodale and Milner, 1992; Milner and Goodale, 1993; Milner et al. 1991; Jakobson et al., 1991, and Goodale et al., 1993); however, little is known in regards to how these pathways work in parallel with each other. For example, when performing a visuo-motor task (e.g., pointing to a coffee mug) visual information is thought to be predominantly processed by the dorsal stream. In contrast, when required to engage in a perceptual task (e.g., identifying the width of a coffee mug) visual information is said to be processed mainly by the ventral stream. Of particular interest, however, is what happens when required to simultaneously engage in both a motor and perceptual task. In other words, does the processing of visual information become favored by one stream over the other, or do both streams work harmoniously? There is evidence suggesting that visual perception may be upregulated before (Hagura et al. 2012) and during (Tremblay and

Nguyen, 2010) a single goal-directed movement, a phenomenon investigated in the present study.

In 2012, Hagura and colleagues investigated a perceptual effect reported by professional baseball and tennis players of the ball “slowing-down”. That is, elite athletes often report feeling as though the speed of the ball is in slow motion before it is struck. Given that this phenomenon typically occurs just prior to movement onset, Hagura and colleagues suggested that motor preparation (i.e., planning for a goal-directed movement) may alter temporal and visual perception. Five separate experiments were conducted to investigate both phenomena. The first 3 experiments were fairly similar in that each tested for the so-called “slowing-down” effect by requiring participants to judge the duration of a visual stimulus, which was presented during a reaction time foreperiod (i.e., time interval between the warning and go-signal). Results showed that when the visual stimulus was presented during foreperiod in reaching trials, its display duration was judged as significantly longer than its duration in control trials (no movement), and these results were not due to merely paying more attention to the visual stimulus. Further experiments showed that not only could time perception be influenced by motor preparation, but also the flow rate of visual information as rapidly presented sequences of letters were more accurately perceived when presented just prior to a reaching movement (Hagura et al., 2012).

Although motor preparation has been suggested to alter visual perception, another study has shown that the presentation of visual stimuli at peak limb velocity during a goal-directed movement may have a similar effect. This was exemplified using the “fusion illusion” where two visual stimuli (e.g., two flashes) are perceived as a single visual stimulus when they are accompanied by a single acoustic stimulus (Shams et al., 2000). Tremblay and Nguyen (2010) reported an increased resistance to the fusion illusion when it was presented during a pointing task. Specifically, susceptibility to this illusion was significantly decreased at peak limb velocity, suggesting visual perception may be altered when visual information is most pertinent. Although it is also possible that their results could be attributed to optimal integration of multiple stimuli at that particular movement kinematic, or a decrease in auditory processing (i.e., auditory gating) (Tremblay et al. 2012), the possibility that visual processing alone may have been upregulated at peak limb velocity should not be excluded.

In order to isolate whether visual processing is indeed altered during the foreperiod of a reaction time (RT) task or during movement at peak limb velocity, it is critical to use a measure of visual processing. Inspection time (IT) is a psychophysical paradigm that measures the amount of time that a visual stimulus must be presented in order for it to be accurately perceived by a participant (Vickers, 1970). The visual stimulus most commonly used is a “pi” figure with differing leg lengths which is briefly presented (e.g., 20-200 ms) and then rapidly backward masked to prevent further visual processing. Participants are typically required to indicate which side (left or right) of the pi figure has the longest leg. When the pi figure is presented for a brief amount of time (e.g., 20 ms) the reported side with the longer leg typically does not differ from chance (accuracy of ~50%). However, as the pi figure is presented for longer periods of time participants are more likely to correctly determine which leg of the pi figure was longest, with nearly 100% accuracy achieved at longer presentation times (e.g., 200 ms). Of particular interest, however, is the amount of time the pi figure must be presented for subjects to determine, with an accuracy of at least 80%, which leg of the pi figure is longest as this will determine their IT (Sadler and Deary, 1996). Vickers (1970, 1979) previously suggested that in a two-choice discrimination task such as the IT paradigm, two separate “accumulators” sample evidence for both choices (e.g., right or left leg is longer). A decision is thought to biased towards the accumulator that gathers sufficient information first (i.e., information reaches threshold).

By integrating the IT paradigm into a motor task, an alteration in visual processing ability may be detected. That is, if the flow rate of visual information is altered during foreperiod or at peak limb velocity of a movement, then IT should differ between movement and non-movement conditions. Based on the abovementioned literature, it is hypothesized that visual IT will be shorter (i.e., participants will require less time to accurately perceive the longest leg of the figure at a rate of 80%) when the pi-stimulus is presented during foreperiod and at peak limb velocity in comparison to no-movement trials.

Methods

Participants

Twenty-eight healthy individuals (15 females; 13 males), with a mean age of 25.8 years, participated in this study. Sample size was determined by performing a power calculation using an effect size (d=0.5) that was estimated based on a previous study that investigated the effects of an irrelevant acoustic stimulus on inspection time performance (Hajj and Carlsen, 2015). All participants signed an informed consent prior to testing. Testing took place in the Neuromotor Laboratory located in the Montpetit building at the University of Ottawa. This study was conducted in accordance with the ethical guidelines set by the Behavioural Research Ethics Board at the University of Ottawa and was conformed to the latest revision of the Declaration of Helsinki.

Experimental set-up

Volunteers were seated in a height adjustable chair at a table whose height and distance was adjusted so that reaching to targets and viewing visual stimuli was performed comfortably.

The participant's right arm was placed in a custom-made manipulandum with a vertical handle on the end that allowed arm flexion/extension movement about the elbow in the horizontal plane. The home position of the arm was with the shoulder flexed approximately 45 deg, abducted 15 deg, and internally rotated 15 deg, with the elbow flexed at 90 deg, such that the medial aspect of the forearm was downward and parallel to the floor and the hand gripped the handle comfortably. Visual stimuli were projected from an ASUS VG248QE LCD monitor (refresh rate of 144 Hz and a response time of 1 ms) onto a reflective mirror situated 27 cm beneath the monitor. The manipulandum was located 27 cm below the reflective mirror such that the stimuli appeared in the same plane as the manipulandum; thus, the participant's hand was hidden from view (see Figure 1 for visual depiction of participant position and visual display). A potentiometer attached to the pivot point of the manipulandum was used to measure elbow angular displacement (deg) which was then used to calculate angular velocity (deg/s) in real time (~5 ms lag) using a custom LabVIEW program (National Instruments Inc.).

Stimuli

Visual stimuli were presented on the monitor and viewed on the mirrored surface. The home position was located approximately 20 cm in front of the participant in their midline and consisted of a 1 cm diameter white dot presented against a black background. Visual feedback was provided by a 0.5 cm diameter red dot that indicated the position of the handle of the manipulandum superimposed over the home position at the start and end (terminal feedback) of every trial. The target region consisted of two white vertical lines (3 cm apart and extending the vertical length of the screen) presented against a black background approximately 15 cm to the right of midline. The home position and target region were always visible. A fixation cross (10mm x 10mm) appeared centrally inside the target region and always in the same location (approximately 40 cm in front of the participant and its center was 75 mm from the top of the screen). A white “pi” figure and masking stimulus were presented inside the target in the location of the fixation cross, with the legs of the pi figure differing in length. One leg of the pi figure was 57 mm long while the other was 70 mm long and both legs were 3 mm from the edges of the target and joined at the top by a 24 mm horizontal line, 50 mm from the top of the screen. In a random order, the longest leg equally appeared on the right and left side of the figure. In order to limit further processing of the stimulus, the pi figure was backward masked by two 81 mm long legs which were composed of triangular shaped protrusions centered at 57 mm from the top of the figure (e.g., lightning mask; for a graphical depiction of similar stimuli see Carlsen et al., 2007).

Procedure

All participants performed a total of 252 trials of the IT task (see below for paradigm description). The entire experiment was made up of 3 conditions, with each made up of 3 blocks of 28 trials. In one condition the IT figure was presented at peak limb velocity; in a second condition the IT figure was presented during the RT foreperiod; and in a final condition the IT paradigm was presented alone with no movement. Order of presentation of the experimental conditions was counterbalanced across participants. A chronological schematic representation of stimulus display events for each condition is presented in Figure 2.

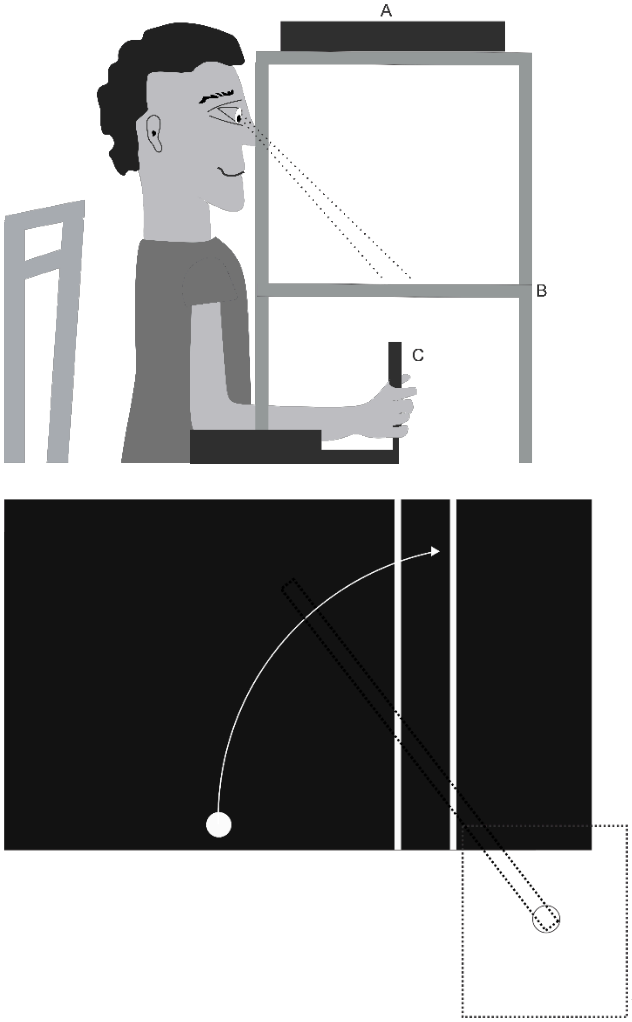
No movement condition (NM). Subjects began by placing their right arm at the home position. A warning tone (200 Hz, 80 dB, 100 ms) was presented which was followed by a “go” signal (1000 Hz, 80 dB, 40 ms). The time interval between the warning and go signal (foreperiod) varied between 3000 to 3500 ms. A visual fixation cross projected on the monitor in the location noted above appeared at the beginning of every trial up until the presentation of the go signal. Subsequent to the go signal, a blank target area was shown for 300 ms. The pi figure was then presented for either 15, 30, 45, 60, 75, 90, or 105 ms, and was backward masked for 400 ms. At the end of the trial, participants were required to verbally state whether the right or left leg of the pi figure was longest, and how confident they were of their response on a scale from 1 to 5 (1 = not confident at all; 5 = very confident). Once the participant provided their responses, the researcher took note of the answers by entering them into the data collection program and waited approximately 5 seconds before beginning the next trial. Before beginning the 3 NM blocks, a total of 10 practice trials, identical to the above mentioned NM procedure, were performed to ensure familiarity with the task.

Movement with IT paradigm occurring at peak limb velocity (PV). Participants began by moving their limb such that an online visual feedback dot would be located at the home position. A visual fixation cross projected on the monitor in the location noted above appeared at the beginning of every trial up until the presentation of the go signal. A warning tone (200 Hz, 80 dB, 100 ms) was presented and online visual feedback of the limb position was removed. After a variable foreperiod of 3000 to 3500 ms an acoustic go signal (1000 Hz, 80, 40 ms) was presented. The fixation cross then disappeared at the presentation of the go signal. Participants were then required to make a 30 deg movement to the location of the fixation cross as rapidly as possible. Although the fixation cross was located 30 degrees from the target, a movement was considered accurate if it ended between the two vertical lines resulting in a target width of approximately 10 deg. Data from the potentiometer, which was sampled at 4 kHz (National Instruments, PCIe-6321), was used to calculate the point at which the limb reached peak velocity. This was accomplished by performing a point-by-point differentiation of a mean of the previous 10 ms of displacement data. A peak picking algorithm was then used to determine when a peak occurred that was in excess of 200 deg/s within a region of interest (width) of 10 ms. Testing of this procedure found that true peak velocity was typically within 5 ms of the point identified by the online algorithm. Once peak velocity was reached, the pi figure was immediately presented inside of the target region at the location of the fixation cross for between 15 and 105 ms (in 15 ms steps) and was then backward masked for 400 ms. At the end of each trial (following mask offset), terminal feedback was provided (i.e., the red dot reappeared) and subjects verbally stated which leg of the pi figure was longest as well as their confidence in the choice, while the researcher took note of their answers by entering them into the data collection program. Participants then moved back to the home position for the start of the next trial. Before beginning the 3 PV blocks, a total of 10 practice trials, identical to the abovementioned PV procedure, were performed to ensure familiarity with the task.

Movement with IT paradigm occurring during foreperiod (FP). Participants began by moving the online visual feedback dot to the home position. A warning tone (200 Hz, 80 dB, 100 ms) was presented and online visual feedback of the limb position was removed. The visual fixation cross was visible for between 1000-2200 ms after the warning signal. Subsequent to the disappearance of the fixation cross, the target area remained blank for 300 ms, which was followed by the pi figure being presented for between 15 and 105 ms (in 15 ms steps), that was then backward masked for 400 ms. The target area was again blanked for a further 495 – 1285 ms to complete the remainder of the 3000 – 3500 ms variable foreperiod. An acoustic go signal (1000 Hz, 80, 40 ms) was then presented and participants were then required to move to the location of the fixation cross as rapidly as possible. Terminal feedback was provided at the end of every trial. Participants verbally stated which leg they thought was longest along with their confidence score and returned to the home position to begin the next trial. Before beginning the 3

FP blocks, a total of 10 practice trials, identical to the above mentioned FP procedure, were performed to ensure familiarity with the task.

Inter-trial intervals were a minimum of 5 seconds so that a reduction in reminiscence effects from the previous trial would be reduced (Cheng et al., 2008).



1A

1B

Figure 1. To the left (1A) is a visual depiction of the experimental apparatus. “A” is the computer screen projecting onto the mirror, “B”; “C” is the manipulandum, situated under the mirror. To the right (1B) is a visual depiction of the 30^o elbow extension to the target required in both movement conditions. The white circle is the home position, and the dashed object represents the manipulandum arm, situated under the mirror and thus hidden from view.

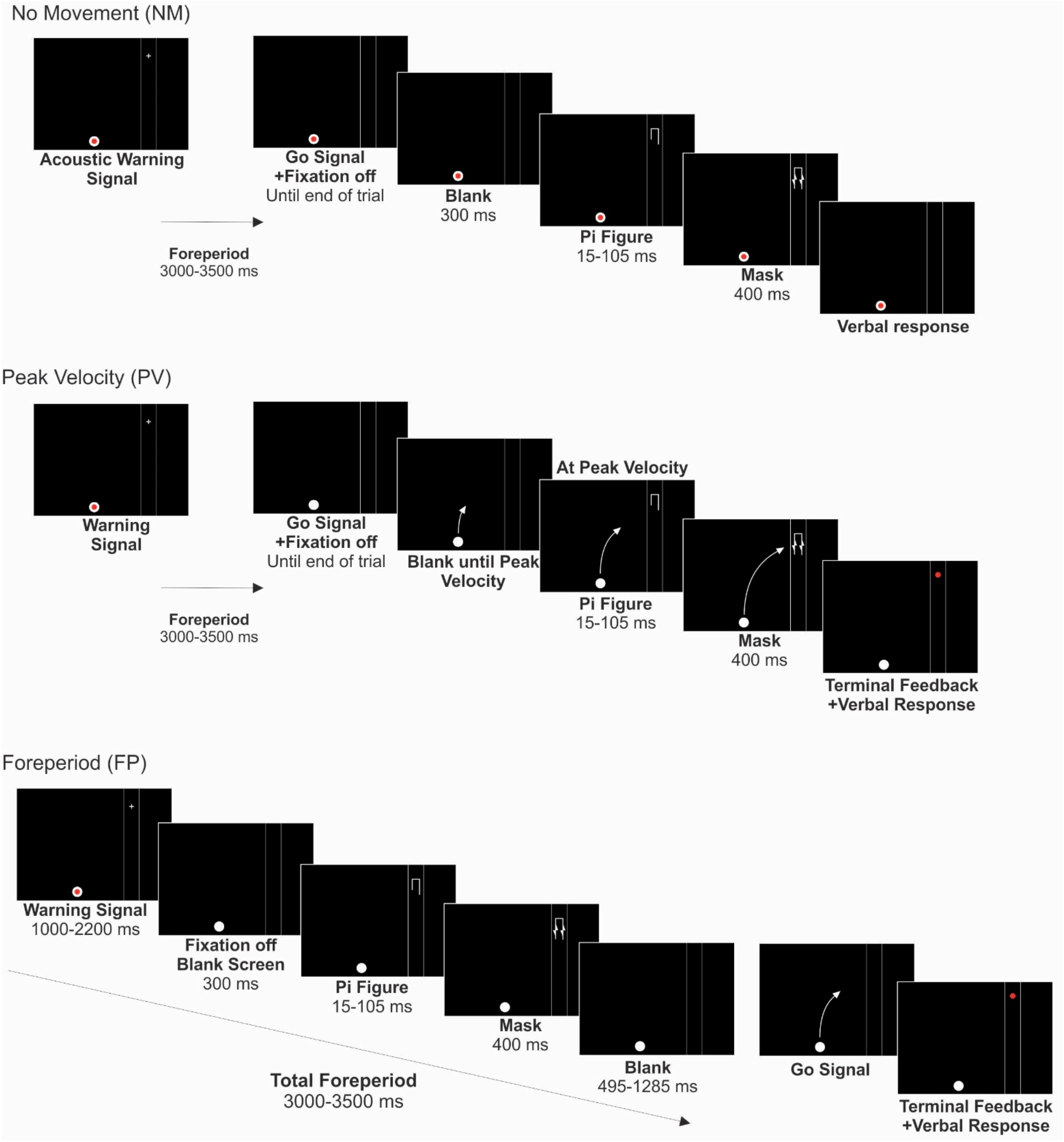

No Movement (NM)
Acoustic Warning Signal
Go Signal +Fixation off
Until end of trial
Blank
300 ms
Pi Figure
15-105 ms
Mask
400 ms
Verbal response
Foreperiod
3000-3500 ms
Peak Velocity (PV)
Warning Signal
Go Signal +Fixation off
Until end of trial
Blank until Peak Velocity
At Peak Velocity
Pi Figure
15-105 ms
Mask
400 ms
Terminal Feedback +Verbal Response
Foreperiod
3000-3500 ms
Foreperiod (FP)
Warning Signal
1000-2200 ms
Fixation off Blank Screen
300 ms
Pi Figure
15-105 ms
Mask
400 ms
Blank
495-1285 ms
Go Signal
Terminal Feedback +Verbal Response
Total Foreperiod
3000-3500 ms

Figure 2. A chronological depiction of the visual stimuli projected onto the mirror in the NM, PV, and FP conditions.

Data reduction and analysis

Response congruence with the visual stimulus were determined based on whether responses were classified as correct or incorrect. For example, if the longest side of the pi figure was on the right and participants responded by choosing the right side, this response was considered correct. Proportion of correct responses was determined for all participants for the three conditions at all stimulus durations. Movement onset was determined as the first point where displacement changed more than 0.2 deg. Peak velocity and peak displacement were defined as the displacement at the point at which angular acceleration crossed zero the first and second times, respectively, after movement onset. Movement final position was defined as the first point at which angular velocity fell below, and remained below 8 deg/s for at least 150 ms.

A 3 (condition) x 7 (display duration) repeated measures ANOVA was used to analyze differences between proportion of correct responses in both conditions. Prior to the repeated measures ANOVA analysis, data were transformed by performing an Aligned Rank Transform (ART), a statistical method used for non-parametric factorial repeated measures ANOVAs (Wobbrock et al., 2011). The locus of any significant main effects was determined by using preplanned pairwise comparisons with a Bonferroni correction. Additionally, a Chi-square analysis at each visual stimulus duration was performed for all three conditions to determine the time at which the proportion of correct responses was significantly greater than chance.

For the self-reported confidence data, the ART method was once again used to transform the data. Subsequent to the data transformation, a 3 (condition) x 7 (display duration) repeated measures ANOVA was performed. Multiple Wilcoxon signed rank tests were performed to determine the locus of interaction effects.

Finally, kinematic features of the movement including movement onset time, time to peak velocity, time to peak displacement, peak displacement, final displacement, and movement time were compared between the FP and PV conditions using 2 (condition) x 7 (time) RM AVOVAs.

All analyses were performed using the statistical software package SPSS 21 for Windows (IBM Inc., Armonk, NY, USA), and alpha was set a priori to $p < .05$ for all tests.

Results

Proportion of correct responses observed in each condition and at each time are shown in Figure 3. Significant main effects for movement condition [$F(2,27)=8.315$, $p = .001$, $n^2_p=.235$] and time [$F(6,27)=111.947$, $p < .001$, $n^2_p=.806$] were found for the proportion of correct responses. Pairwise analyses showed that the percentage of correct responses was significantly lower in the PV condition compared to both the NM ($p = .005$) and FP ($p = .0148$) conditions. However, the NM and FP conditions were not significantly different from each other ($p = 1.0$) For the main effect of time, the percentage of correct responses at each successively longer display duration was significantly different from the previous display duration, except the last, whereby percent correct at durations of 90 and 105 ms were not significantly different. Chi-square analysis showed that when the pi figure was displayed for 30 ms the proportion of correct responses was significantly greater than chance in the NM ($X^2 = 10.33$, $p < .05$) and FP ($X^2= 9.51$, $p < .05$) conditions. However, the proportion of correct responses in the PV condition only became significantly greater than chance at the 45 ms duration ($X^2=15.23$, $p < .05$). This suggests that discrimination performance in the NM and FP conditions required less time than the PV condition to become significantly greater than chance (Figure 3). Finally, the time at which an 80% criterion was reached in all three conditions was assessed graphically. Inspection time is typically determined once performance exceeds 80% accuracy (Sadler and Deary, 1996). Inspection time exceeded 80% accuracy at 60 ms for both the NM and FP conditions, whereas it did not exceed 80% until 75 ms in the PV condition (Figure 3).

Confidence ratings for responses made in each condition and at each stimulus duration are shown in Figure 4. Analysis of confidence ratings showed main effects for both condition [F(2,27)=10.900, $p < .001$, n^2_p=.288] and time [F(6,27)=172.863, $p < .001$, n^2_p=.865]. However, these were superseded by a significant interaction effect between condition and time [F(12,27)=2.671, $p < .001$, n^2_p=.90]. Wilcoxon signed rank post-hoc tests showed that within each condition, confidence increased with each increase in duration (all p-values < .001). In addition, Wilcoxon signed rank post-hoc tests performed at each display duration showed that confidence ratings were significantly higher in the FP and NM as compared to the PV condition at all display durations ≥ 45 ms (all p-values < .027), although they were not different at display durations of 15 or 30 ms (p-values > .05). Confidence ratings in the FP and NM conditions were not significantly different from each other at any of the display durations ($p < .05$).

Finally, significant differences were found for the movement kinematic variables between the FP vs PV conditions. Specifically movement onset analysis showed a main effect for condition [F(1,27)=37.919, $p < .001$, n^2_p=.584] but no main effect for time [F(6,162)=1.77, $p = .106$, n^2_p=.062]. However, a significant interaction effect between condition and time was found [F(6,162) =3.440, p = .003, n^2_p= .113] (Figure 5). Moreover, analysis of time to peak velocity showed main effects for both condition [F(1,27)= 11.450, $p = .002$, n^2_p= .298] and time [F(3.4, 92.0)= 4.980, $p = .002$, n^2_p= .156]. These were also superseded by a significant interaction effect [F(3.4, 92.3) = 3.038, $p = .027$, n^2_p= .101] (Figure 6). For time to peak displacement, significant main effects were found for both condition [F(1,27)= 13.466, $p = .001$,

n^2_p= .333] and time [F(6,162)= 3.519, p = 0.003, n^2_p= 0.115], but these were also superseded with a significant interaction effect between the factors [F(4.0, 108.6) = 3.259, p = .014, n^2_p= .108] (Figure 7). Analysis of peak displacement showed a main effect for condition [F(1,27)=7.635, p = .010, n^2_p= .220] but no main effect for time [F(6,162) = .611, p = .721, n^2_p=.022], or interaction effect [F(4.1, 110.5)=.989, p = .418, n^2_p= .035]. Similarly, a main effect for condition [F(1,27)= 5.214, p = 0.030, n^2_p= .162] but no main effect for time [F(6,162)= .963, p = 0.452, n^2_p=.034], and no interaction [F(3.9,105.9)=1.225, p = .305, n^2_p= .043] was also found for final displacement. Finally, for movement time a significant main effect was found for condition [F(1,27)= 17.351, $p <$ .001, n^2_p=.391] but no main effect was found for time [F(3.2, 86.1)= 0.207, p = 0.974, n^2_p=.008], and there was no interaction between the factors [F(4.2,114.2)=.994, p = .431, n^2_p= .036] (Table 1).

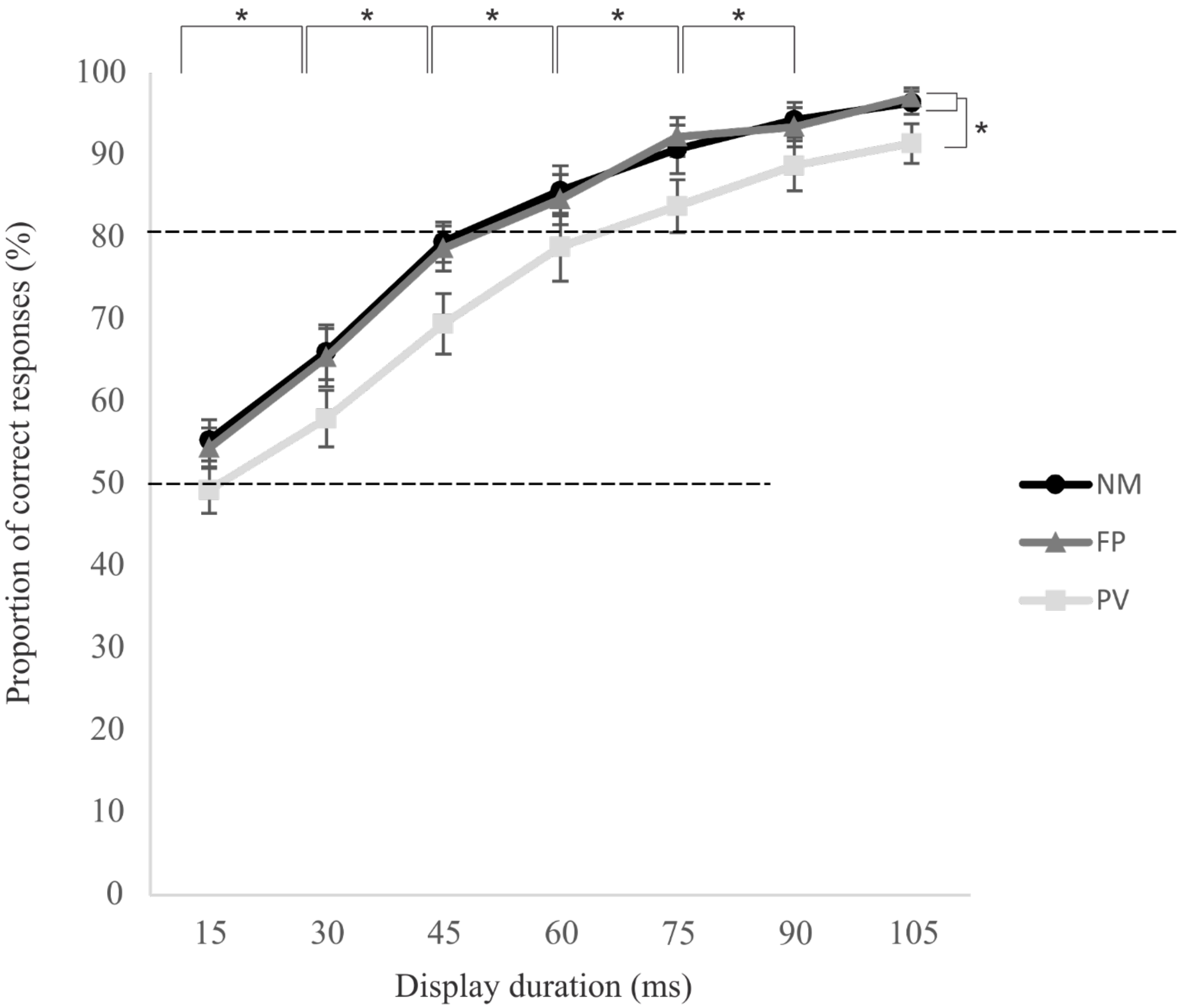


Figure 3. Mean (SE) probability of correct responses (%) as a function of stimulus presentation time (ms) in three different conditions. In the first condition (NM), the visual stimulus ("pi" figure) was presented for different display durations (ms) while participants remained idle. In the second condition (FP), a visual stimulus ("pi" figure) was presented for different display durations between the warning and go-signal. In the third condition (PV), a visual stimulus ("pi" figure) was presented for different display durations when participants' movement reached peak velocity. The dashed lines indicate the 50% chance and 80% accuracy level. * Signifies significant differences (p < .05).

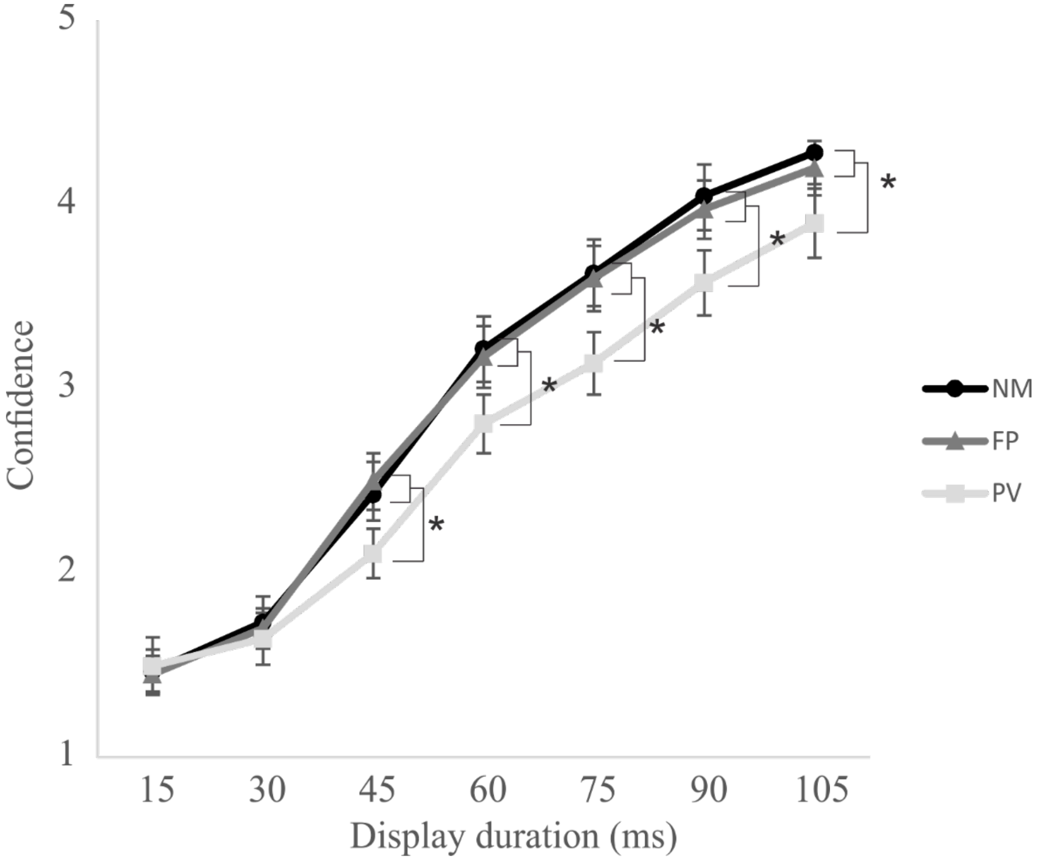


*Figure 4***.** Mean (SE) confidence ratings (1= not confident at all; 5= very confident) as a function of stimulus presentation time (ms) in three different conditions (NM, FP, and PV). * Signifies significant differences (p < .001).

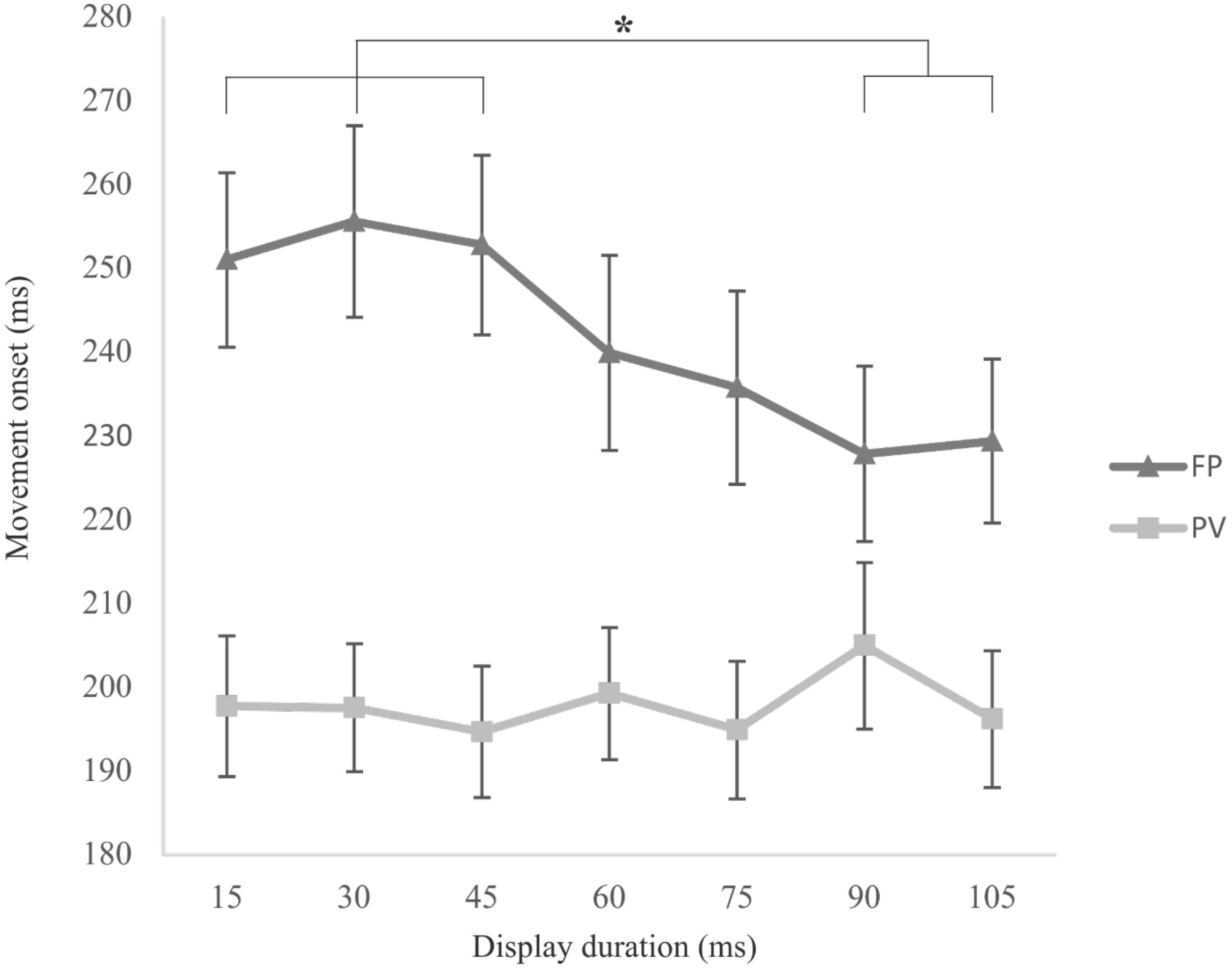


Figure 5. Mean (SE) movement onset (ms) as a function of stimulus presentation time (ms) in two different conditions (FP and PV). * Signifies significant differences (p < .02).

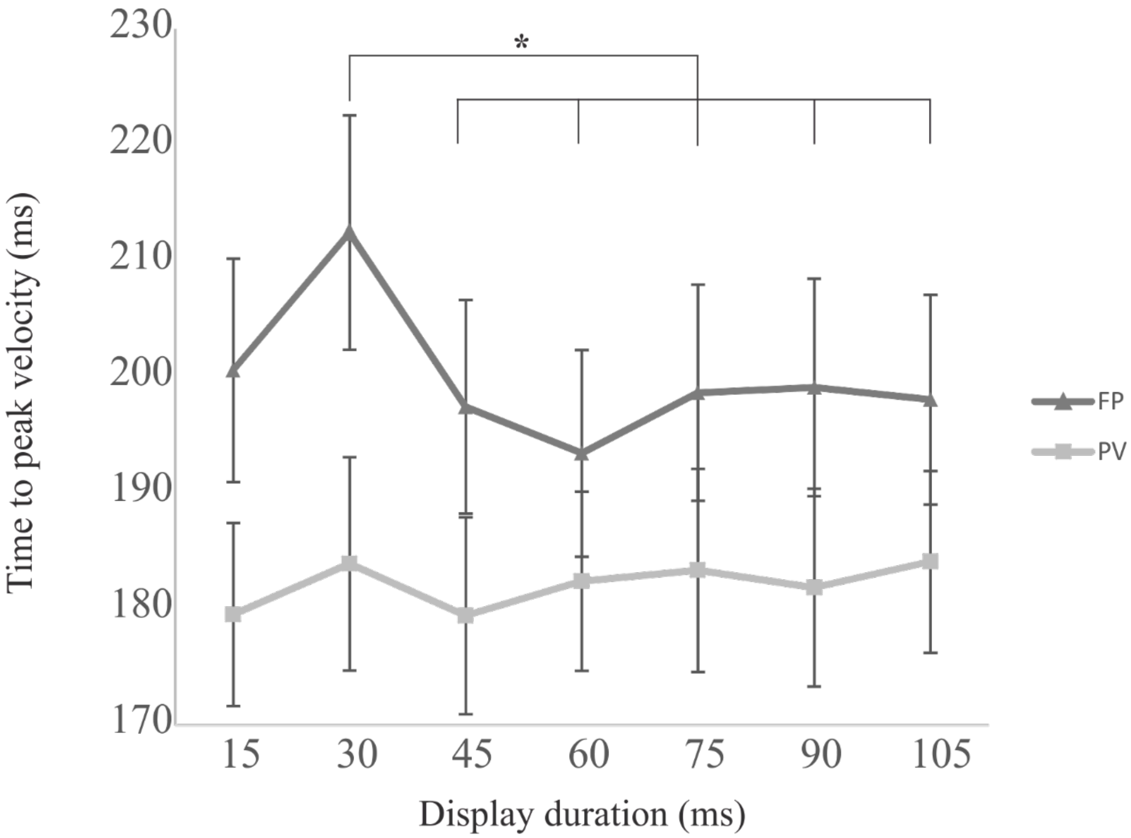


Figure 6. Mean (SE) time to peak velocity (ms) as a function of stimulus presentation time (ms) in two different conditions (FP and PV). * Signifies significant differences (p < .01).

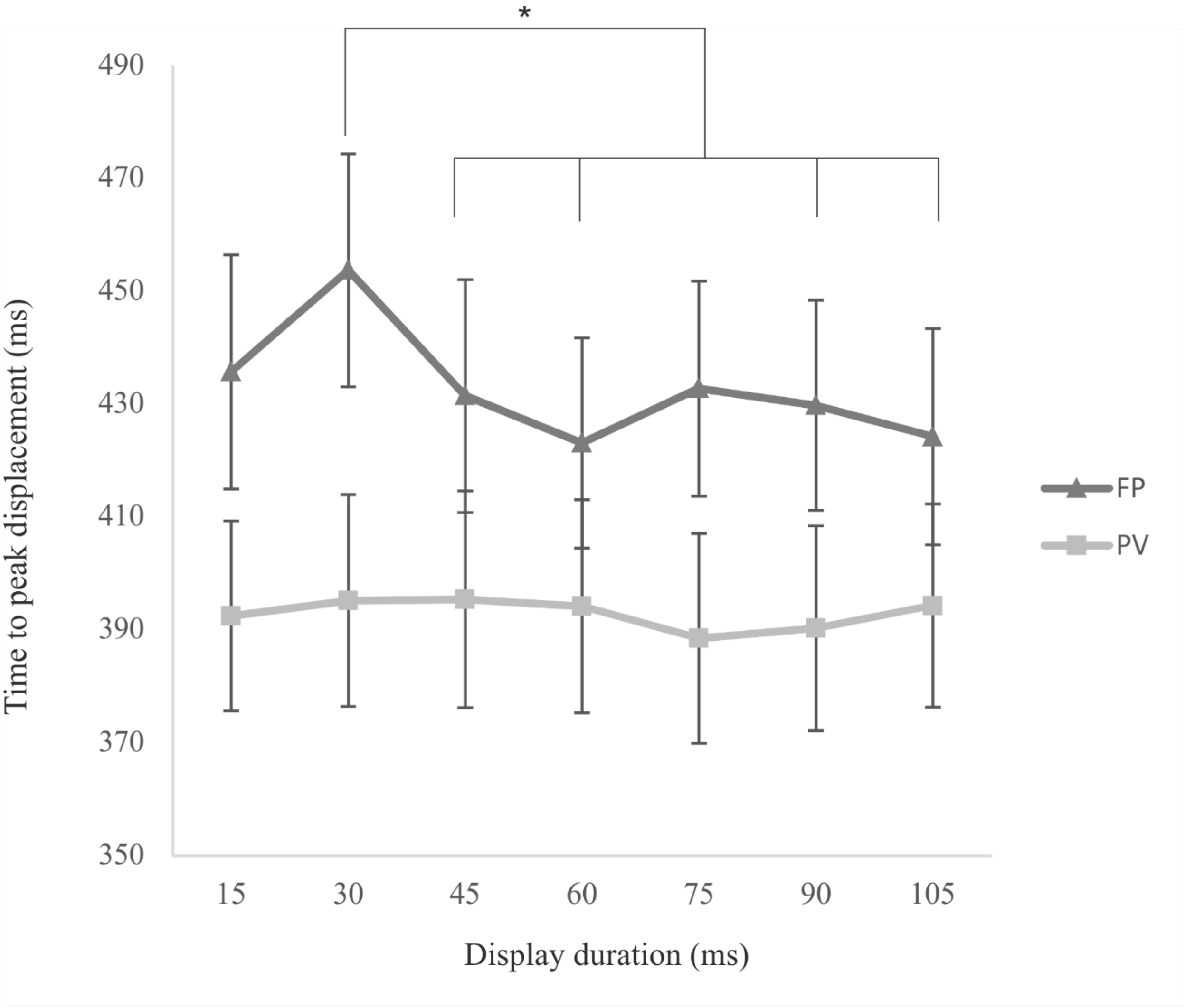


Figure 7. Mean (SE) time to peak displacement (ms) as a function of stimulus presentation time (ms) in two different conditions (FP and PV). * Signifies significant differences (p < .02).

Table 1

Mean (SE) peak displacement (PDx) and final displacement (FDx) of a movement to a target whose width measured 10 degrees in both the FP and PV condition at every display duration (ms) of the pi-figure

Duration	FP-PDx	FP-FDx	PV-PDx	PV-FDx
15	36.1 (1.5)	33.5 (1.4)	32.4 (0.9)	31.2 (0.9)
30	35.9 (1.3)	33.3(1.2)	32.7 (1.0)	31.1 (0.9)
45	36.2 (1.4)	33.6 (1.3)	32.5 (0.9)	30.9 (0.8)
60	35.8 (1.4)	33.6 (1.4)	32.3 (0.9)	30.5 (0.7)
75	36.5 (1.5)	34.0 (1.4)	32.5 (0.9)	30.8 (0.9)
90	35.8 (1.2)	33.6 (1.2)	32.8 (1.0)	31.1 (0.8)
105	36.0 (1.3)	33.9 (1.3)	32.8 (0.9)	31.2 (0.9)

Note. Given the 10-degree target width, a movement was considered accurate if it landed between 25 to 35 degrees from the home position.

Table 2

Mean (SE) movement time (ms) in both the FP and PV condition at every display duration (ms) of the pi-figure

Duration	FP	PV
15	525.0 (24.0)	455.6 (20.8)
30	510.8 (25.9)	475.7 (22.7)
45	534.5 (26.0)	468.6 (21.1)
60	520.9 (20.7)	468.6 (18.4)
75	530.6 (22.7)	460.3 (22.6)
90	513.9 (21.7)	473.1 (23.1)
105	515.8 (25.1)	473.6 (22.5)

Discussion

The present study aimed to investigate whether preparing for a movement or moving the limb at peak velocity altered the temporal acuity of visual perception. This was tested by integrating a perceptual IT task with a limb-targeting paradigm. The rationale was that if the time required for accurate visual perception was indeed affected by motor preparation then performance on the IT paradigm would differ significantly from when the IT stimulus is presented during the foreperiod in comparison to when it is presented randomly while sitting idly (NM condition). Likewise, if visual perceptual ability was altered at peak limb velocity then presentation of the IT stimulus at that particular movement kinematic would result in different performance in comparison to that observed in the NM condition.

The initial hypothesis was that performance on the IT paradigm would be better in the FP and PV conditions in comparison to the NM condition. This hypothesis was based on previous literature that suggested an alteration in visual perception when visual stimuli were presented during foreperiod (Hagura et al., 2012) and at peak limb velocity (Tremblay and Nguyen, 2010). However, performance on the IT task in the FP condition was not significantly different from performance in the NM condition, showing no evidence for visuo-perceptual enhancement due to motor preparation, as found in Hagura et al.'s (2012) study. The first possible explanation for these results could be related to the time at which the IT stimulus was presented. That is, Hagura et al. (2012) observed a significant change in letter detection 300 ms before the "go" signal, while letters presented before that time interval (< -300 ms) were not better detected. That is, detection rate in reaching condition was similar to that of the non-reaching condition at that point. In the present study, the IT stimulus in the FP condition was always presented from between 895 to 1685 ms before the "go" and never within the -300 to 0 ms interval, as in Hagura et al.'s study. It is possible that participants in Hagura et al.'s study were more highly prepared (i.e., motor preparation was completed or closer to completion), given the chronological proximity between the presentation of the stimulus and the go signal. In comparison to our study, the level of motor preparation in Hagura et al.'s experiment may have been greater, perhaps resulting in a visuo-perceptual enhancement.

In the PV condition, performance on the IT task was significantly poorer in comparison to the NM condition, contradicting the initial hypothesis. Interestingly, performance on the IT task was significantly poorer in the PV condition in comparison to both the FP and NM conditions, which were not significantly different from each other. In contrast to Tremblay and Nguyen's (2010) findings, the presentation of visual stimuli at peak limb velocity appears to have been detrimental to performance in the IT task (Fig. 3). This suggests that visual up-regulation may not occur at peak limb velocity, as initially hypothesized. One possible explanation for the significantly poorer identification of the IT stimulus in the PV condition may be attributed to the multiple tasks that were required to be performed simultaneously. Given that movements were fairly accurate in the PV condition (Table 1), it is possible that participants placed more focus on the motor task instead of the perceptual task when the IT stimulus was presented at peak velocity, leading to a decreased performance on the IT task in the PV condition.

Movement kinematics were analyzed and compared between the FP and PV conditions and it was found that movements were generally slower in the FP condition in comparison to the PV condition at all display durations of the pi-figure (Figures 5, 6, 7, and Table 2). For example, the reaction time (RT) results showed that RT was significantly longer in the FP condition compared to the PV condition (Figure 5). Moreover, this RT difference was greater at shorter IT durations compared to longer ones. That is, a more difficult perceptual task, such as when the pi figure was displayed very briefly (i.e., 15, 30, and 45 ms), resulted in a longer RT, while an easier version of the perceptual task (i.e., pi figure displayed for 90 or 105 ms) resulted in a faster RT. These results suggest that engagement in a perceptually challenging task may interfere with the motor preparation prior to an imperative “go” stimulus. Furthermore, perceptual tasks that are more difficult appear to result in even greater interference. Similar results were previously found in a study conducted by Maslovat et al. (2015) where participants were required to engage in a primary cognitive task with two levels of difficulty while preparing to react to a go-stimulus by making a targeted wrist extension movement. The easier version of the cognitive task required participants to count backward by two, starting from an even number, while the more challenging version required participants to count backward by seven from either an odd or even number. As noted, participants were required to perform a RT task when either a control tone (80 dB) or a startling acoustic stimulus (SAS; 120 dB) was presented during the cognitive task, regardless of the level of difficulty. Previous studies have shown that a SAS can trigger an early release of a preplanned movement in a simple RT task (Valls-Solé et al. 2008; Carlsen et al. 2012), as evidenced by SAS-induced RTs as early as 70 ms, by presumably bypassing cortical initiation processes through subcortical pathways (Carlsen et al. 2012). Given this, Maslovat et al. (2015) used a SAS in their paradigm to assess whether or not the levels of motor preparation were affected by a primary cognitive task. Their findings showed that when the cognitive task was more difficult, RT increased significantly in comparison to when the motor task was performed alone (single task), irrespective of the tone that was used (control tone or SAS). Because the SAS-induced RTs were also longer during the performance of a cognitive task, it was concluded that preparatory activation level for the secondary motor task was affected by the cognitive requirements. Together with these previous findings, the current RT results (Figure 5) along with longer time to peak velocity (Figure 6) and longer time to peak displacement (Figure 7) suggest that performance of a perceptually demanding task may have interfered with preparation to perform the targeted movement.

Alternatively, given that the ventral and dorsal stream are thought to control movement planning and movement execution, respectively (Milner and Goodale, 2004), the present results may suggest that ventral stream processing is limited in its capacity to share resources (Liu et al., 2008). For example, although movements were slower in the FP in comparison to the PV condition, they did not seem to differ in accuracy (Table 1). That is, even though peak displacement and movement final position were significantly different between the FP and PV conditions, movements in both conditions nevertheless ended within the target zone. Given that identification of a visual stimulus and movement planning are both thought to be processed in the ventral stream (Milner and Goodale, 2004), cases such as in the FP condition where identification of a visual stimulus begins first may interrupt movement planning. Looking at peak displacement in the FP condition (Table 1), it is evident that participants were more likely to overshoot the target, which may be associated with poor movement preparation. However, this poorer preparation did not greatly affect final displacement in the FP condition as the movement still ended in the target zone (Table 1). This is an expected result, and in line with previous findings (Liu et al., 2008), given that motor execution is generally considered to be controlled primarily by the dorsal stream.

A final possibility is that the present results reflect limited attentional resources. That is, as Schneider (1995) proposed: “a visual attention model argues for a unitary, object-centered view of attention and predicts that if attention is focused on one target for perception, it cannot simultaneously focus on a second target to complete an action" (cited from Liu et al., 2008). Specifically, dorsal and ventral stream processing seem to play a larger role in the PV and FP conditions, respectively, which may be reflected in the confidence ratings. That is, in comparison to the NM and FP condition, confidence ratings were consistently lower at every display duration in the PV condition (Figure 3). Given that conscious awareness of visual stimuli is thought to be processed in the ventral stream (Goodale and Milner, 1992), and that confidence rating has been proposed to be directly proportional to discriminability and accuracy (Vickers, 1979), the lower confidence ratings suggests diminished awareness of the presented visual stimulus, which in turn may imply decreased processing in the ventral stream. Of interest is the confidence rating found at the 105 ms display duration in the PV condition. That is, confidence has been shown to be a direct function of display duration of a given stimulus (Vickers et al., 1985), and indeed, discriminability was close to 100% at that particular display duration in the NM and FP conditions. Still, a decrease in awareness in the PV condition was nevertheless observed, suggesting decreased processing in the ventral stream. According to Vickers' proposed accumulator model (Vickers, 1970), a large mean difference between both accumulators arises when one accumulator reaches threshold before the other, leading to a more confident final decision. In contrast, when the mean difference between both accumulators is small, discriminability is suggested to become more difficult, and in turn decreases confidence rating (Vickers, 1979). The lowered confidence ratings in the PV condition suggests that less perceptual information was accumulated in this condition, and the higher confidence ratings in the FP condition suggest the opposite.

Whereas in the current study we showed decreased perceptual ability when the limb was at peak velocity, Tremblay and Nguyen's (2010) showed quite the opposite. It is possible that any purported visual processing advantage observed at peak limb velocity in Tremblay and Nguyen's (2010) study may have been due to differences between peripheral and focal vision. That is, in the current experiment the IT stimulus was presented in the location of the fixated target (in focal vision) while visual stimuli in Tremblay and Nguyen's experiment were presented 6 cm *below* the target (in peripheral vision). It is therefore possible that peripheral vision may be enhanced at peak limb velocity while focal vision remains unaffected, or indeed degraded. Evidence has shown that the dorsal stream is largely responsible for processing peripheral visual information (Rossetti et al., 2005). For example, the vision-for-action pathway (e.g., scaling one's grasp to an object's size) is largely impaired in patients with optic ataxia, while their vision-for-perception pathway (e.g., identifying an object) is seemingly intact (Milner and Goodale, 2006). However, this seems to be the case only when optic ataxia patients are presented with visual stimuli in the central as opposed to peripheral visual field. For example optic ataxia patients can accurately point to a target presented in central vision (Buxbaum and Coslett, 1998; Gréa et al., 2002; Pisella et al., 2000; Rossetti et al., 2003, and Rossetti et al., 2005), however, the more eccentric the visual target, the less accuracy patients have in pointing to it (Rossetti et al., 2005, Vighetto and Perenin, 1981). Given this close relationship between peripheral vision and dorsal stream processing, it is certainly plausible that different effects on visual processing may be observed if the IT stimulus had been presented in peripheral, as opposed to central vision.

In summary, no evidence for visual upregulation was shown at peak velocity of a goal-directed movement, a finding not in line with Tremblay and Nguyen's (2010) results. However, an important distinction between the present and Tremblay and Nguyen's study is the locus of visual stimulus presentation. That is, the IT stimulus in our study was presented in central vision, as opposed to Tremblay and Nguyen who presented visual stimuli in peripheral vision. Given the neural differences in central and peripheral visual processing (i.e., dorsal and ventral stream predominantly process peripheral and central visual information, respectively), it is possible that visual upregulation may occur, but only in peripheral vision. Similarly, no evidence for visual upregulation was found during foreperiod of a goal-directed movement. These findings contradict those of Hagura and colleagues' (2012); however, these findings may largely be attributable to the presentation time of visual stimuli. That is, visual stimuli in Hagura et al.'s study were presented closer to the go-signal (-300 ms) while visual stimuli in our study were oftentimes presented long before the go-signal (-1685 ms), perhaps prior to completion of motor preparation.

Chapter 3: General discussion

The main findings of the present study did not correspond to what was initially expected. For instance, performance on the IT task was greatly diminished in the PV condition in comparison to the NM and FP conditions, suggesting that visual perception was downregulated as opposed to upregulated, in contrast to other findings (Tremblay and Nguyen, 2010). These divergent results may be attributed to several factors. Firstly, when the ventral stream must concurrently process two tasks (e.g., movement planning and visual stimulus identification) then the first task may take priority over the other. Secondly, while visual upregulation might occur at peak limb velocity under certain circumstances, these findings may only apply to central vision; therefore, the possibility of peripheral visual upregulation should not be excluded. Third, the perceptual task used here was purely a visual task where Tremblay and Nguyen (2010) used an audiovisual integration task. It may be that while visual perception per se is not improved at peak limb velocity, the integration of different modalities is upregulated. Finally, ocular motion was not tracked throughout the experiment and therefore renders it difficult to ensure that participants consistently fixated the cross. Thus, it is possible that poor performance on the IT task may have simply been due to “missing” the visual stimulus by not looking at the target.

Another unexpected finding was the lack of significant differences on the IT task between the FP and NM condition. As previously highlighted, the visual upregulation during foreperiod found in Hagura and colleagues’ (2012) was only evident when visual stimuli were shown 300 ms before the go-signal. In the present study, however, visual stimuli were presented between 895 and 1685 ms before the go signal. It would have been ideal to analyze task performance in trials where the IT stimulus was displayed later in the foreperiod (i.e., closer to 300 ms before the go-signal, as used by Hagura et al (2012)) as compared to earlier in the foreperiod, but unfortunately foreperiod duration on a trial-by-trial basis was not recorded, and thus time at which the visual stimulus was displayed with respect to the go-signal is unknown.

In future experiments, eye trackers may be utilized to ensure that participants fixate the target consistently, and exclude the possibility of unwanted saccades. Also, future studies may determine whether differences in presentation time of the IT stimulus with respect to the go-signal affect perceptual ability. That is, some IT stimuli should be presented closer to 300 ms before the go-signal in FP conditions, possibility by decreasing the display duration of the masking stimulus. Finally, it may be interesting to investigate whether perceptual performance on the IT task would be different in peripheral vs central vision.

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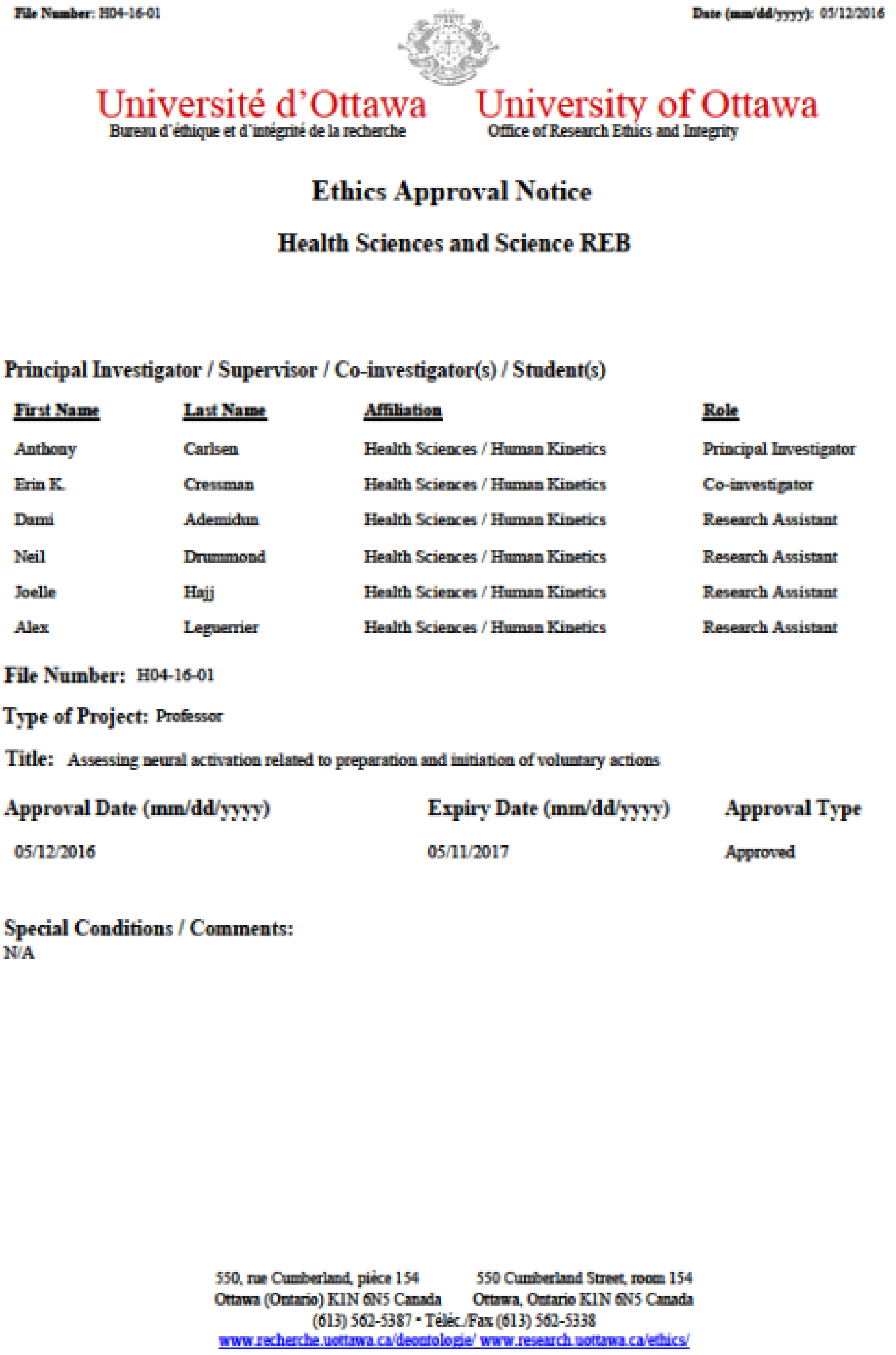
Appendix A



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Ethics Approval Notice

Health Sciences and Science REB

Principal Investigator / Supervisor / Co-investigator(s) / Student(s)

First Name	Last Name	Affiliation	Role
Anthony	Carlsen	Health Sciences / Human Kinetics	Principal Investigator
Erin K.	Cressman	Health Sciences / Human Kinetics	Co-investigator
Dami	Ademidun	Health Sciences / Human Kinetics	Research Assistant
Neil	Drummond	Health Sciences / Human Kinetics	Research Assistant
Joelle	Hajj	Health Sciences / Human Kinetics	Research Assistant
Alex	Leguerrier	Health Sciences / Human Kinetics	Research Assistant

File Number: H04-16-01

Type of Project: Professor

Title: Assessing neural activation related to preparation and initiation of voluntary actions

Approval Date (mm/dd/yyyy)	Expiry Date (mm/dd/yyyy)	Approval Type
05/12/2016	05/11/2017	Approved

Special Conditions / Comments:
N/A

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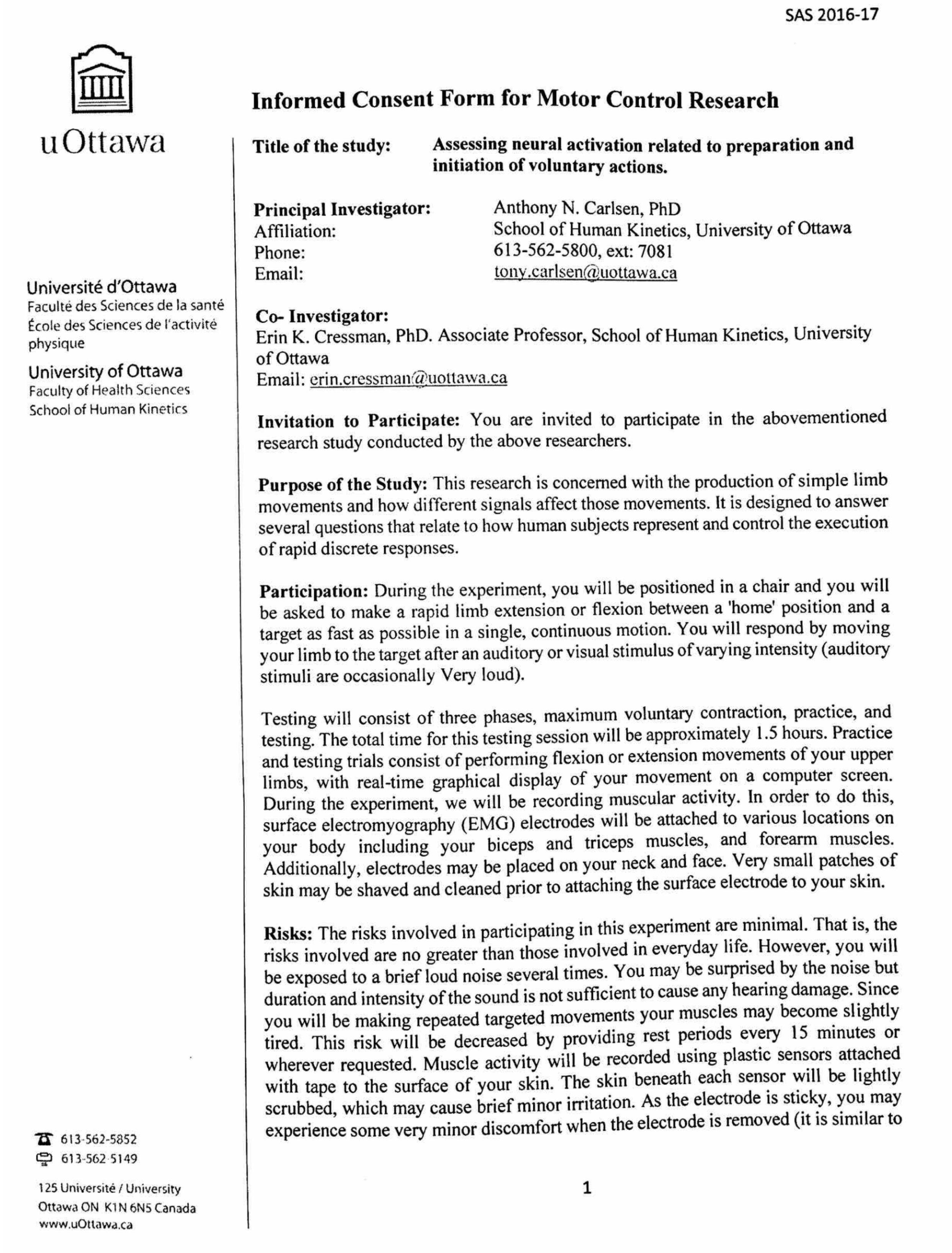
www.recherche.uottawa.ca/deontologie/ www.research.uottawa.ca/ethics/

Appendix B



SAS 2016-17

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Faculté des Sciences de la santé
École des Sciences de l'activité physique

University of Ottawa
Faculty of Health Sciences
School of Human Kinetics

Informed Consent Form for Motor Control Research

Title of the study: **Assessing neural activation related to preparation and initiation of voluntary actions.**

Principal Investigator: Anthony N. Carlsen, PhD
Affiliation: School of Human Kinetics, University of Ottawa
Phone: 613-562-5800, ext: 7081
Email: tony.carlsen@uottawa.ca

Co- Investigator:
Erin K. Cressman, PhD. Associate Professor, School of Human Kinetics, University of Ottawa
Email: erin.cressman@uottawa.ca

Invitation to Participate: You are invited to participate in the abovementioned research study conducted by the above researchers.

Purpose of the Study: This research is concerned with the production of simple limb movements and how different signals affect those movements. It is designed to answer several questions that relate to how human subjects represent and control the execution of rapid discrete responses.

Participation: During the experiment, you will be positioned in a chair and you will be asked to make a rapid limb extension or flexion between a 'home' position and a target as fast as possible in a single, continuous motion. You will respond by moving your limb to the target after an auditory or visual stimulus of varying intensity (auditory stimuli are occasionally Very loud).

Testing will consist of three phases, maximum voluntary contraction, practice, and testing. The total time for this testing session will be approximately 1.5 hours. Practice and testing trials consist of performing flexion or extension movements of your upper limbs, with real-time graphical display of your movement on a computer screen. During the experiment, we will be recording muscular activity. In order to do this, surface electromyography (EMG) electrodes will be attached to various locations on your body including your biceps and triceps muscles, and forearm muscles. Additionally, electrodes may be placed on your neck and face. Very small patches of skin may be shaved and cleaned prior to attaching the surface electrode to your skin.

Risks: The risks involved in participating in this experiment are minimal. That is, the risks involved are no greater than those involved in everyday life. However, you will be exposed to a brief loud noise several times. You may be surprised by the noise but duration and intensity of the sound is not sufficient to cause any hearing damage. Since you will be making repeated targeted movements your muscles may become slightly tired. This risk will be decreased by providing rest periods every 15 minutes or wherever requested. Muscle activity will be recorded using plastic sensors attached with tape to the surface of your skin. The skin beneath each sensor will be lightly scrubbed, which may cause brief minor irritation. As the electrode is sticky, you may experience some very minor discomfort when the electrode is removed (it is similar to

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🖷 613-562-5149

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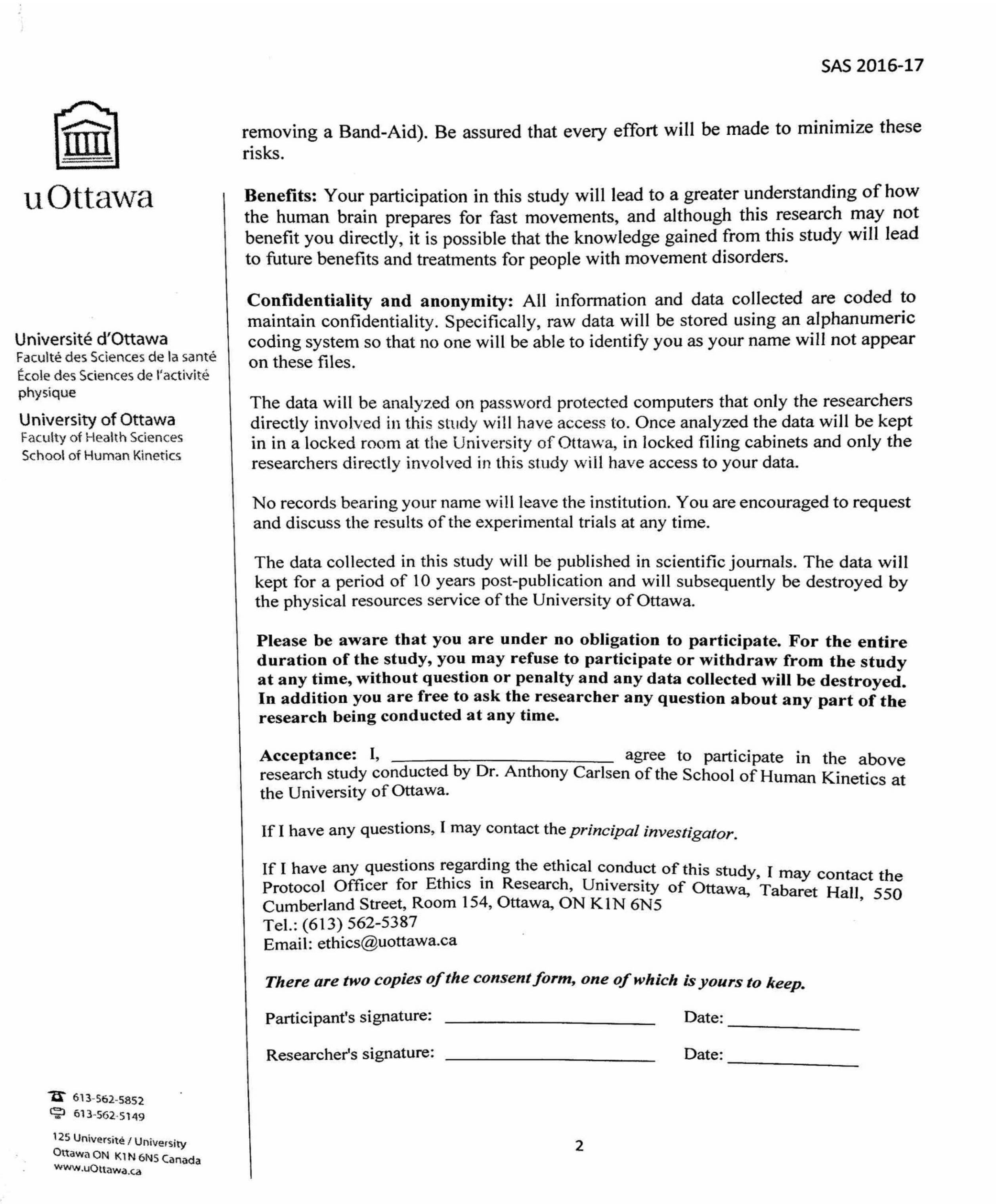

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University of Ottawa
Faculty of Health Sciences
School of Human Kinetics

removing a Band-Aid). Be assured that every effort will be made to minimize these risks.

Benefits: Your participation in this study will lead to a greater understanding of how the human brain prepares for fast movements, and although this research may not benefit you directly, it is possible that the knowledge gained from this study will lead to future benefits and treatments for people with movement disorders.

Confidentiality and anonymity: All information and data collected are coded to maintain confidentiality. Specifically, raw data will be stored using an alphanumeric coding system so that no one will be able to identify you as your name will not appear on these files.

The data will be analyzed on password protected computers that only the researchers directly involved in this study will have access to. Once analyzed the data will be kept in in a locked room at the University of Ottawa, in locked filing cabinets and only the researchers directly involved in this study will have access to your data.

No records bearing your name will leave the institution. You are encouraged to request and discuss the results of the experimental trials at any time.

The data collected in this study will be published in scientific journals. The data will kept for a period of 10 years post-publication and will subsequently be destroyed by the physical resources service of the University of Ottawa.

Please be aware that you are under no obligation to participate. For the entire duration of the study, you may refuse to participate or withdraw from the study at any time, without question or penalty and any data collected will be destroyed. In addition you are free to ask the researcher any question about any part of the research being conducted at any time.

Acceptance: I, ______________________ agree to participate in the above research study conducted by Dr. Anthony Carlsen of the School of Human Kinetics at the University of Ottawa.

If I have any questions, I may contact the *principal investigator*.

If I have any questions regarding the ethical conduct of this study, I may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, Ottawa, ON K1N 6N5
Tel.: (613) 562-5387
Email: ethics@uottawa.ca

There are two copies of the consent form, one of which is yours to keep.

Participant's signature: ______________________ Date: ______________

Researcher's signature: ______________________ Date: ______________

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