NON-DIRECTIONAL, SYMBOLIC CUES IN A GO BEFORE YOU KNOW TASK

by

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Abstract

Inhibition of Return (IOR) has been observed in reaching movements to a known target location following predictive symbolic cues. Facilitatory like effects, as they appear in traditional cue-target paradigms, have not yet been observed in response to these cues. The aim of the current study is to determine if facilitatory like effects occur in response to centrally presented, predictive symbolic cues. At cue presentation participants initiated a reach to a potential target location and the true target location was revealed at movement onset. Participant's choice of side was influenced by the predictive symbolic cues wherein they reached right more often following a right target predictive cue compared to a left target predictive cue or a neutral, non-predictive cue. These findings provide evidence that under end-goal uncertainty symbolic cues elicit facilitatory effects; participants used the learned association between cue type and target location advantageously to facilitate target acquisition.

List of Abbreviations Used

ANOVA	Analysis of variance
CTOA	Cue-target onset-asynchrony
DIP	Distal interphalangeal joint
FANOVA	Functional analysis of variance
GBYK	Go-before-you-know
IRED	Infra-red emitting diode
IOR	Inhibition of Return
MT	Movement time
NT	Neutral cue
PIP	Proximal interphalangeal joint
PL	Predictive left cue
PR	Predictive right cue
RT	Reaction/response time
S1	Stimulus 1
S2	Stimulus 2
SOA	Stimulus onset asynchrony

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CHAPTER 1: INTRODUCTION

Our environment is full of a variety of stimuli that can influence our behaviour. Certain cues have the advantage of automatically orienting the actor to a peripheral location, such as a loud sound or a flashing light. However, how do we gain information or respond to other, less salient, more symbolic cue types in the environment? Imagine driving through a neighbourhood and seeing toys and play equipment on a lawn. Or imagine interpreting the body language of an approaching person to determine whether they are going to hug or hit you. These are not onset cues, yet they should change your behaviour. Their meaning and associated action needs to derived from experiences with these cues.

Previous research has shown that participants can implicitly learn the predictiveness of a central, non-directional, symbolic cue and that the subsequent use of this information produces an inhibition like response in an upper limb reaching task (Swansburg & Neyedli, 2019). Non-directional, symbolic cues were presented to the participant, and following a long (1000 – 2200ms) cue-target onset asynchrony (CTOA) a target appeared at one of two potential target locations on either side of the cue. Participants were instructed to reach out and touch the target. Participants' reaching movements to the predicted side, following the predictive cue, deviated toward the non-predicted side indicating that the response to the predicted side may have been inhibited. The results of this study are similar to inhibition of return (IOR) type effects for which participants' responses are inhibited to a cued location following long CTOAs.

Traditional, peripheral-onset, cue-target paradigms have repeatedly shown evidence of IOR through saccadic or upper limb reaction times for both visual search and action centred tasks. One widely accepted explanation for the presence of IOR is that it is a mechanism that evolved to help with visual search. This still remains a valid explanation in certain circumstances (e.g., within the oculomotor system), however it seems less useful for upper limb reaching movements. Cowper-Smith and Westwood (2013) suggested that the motoric form of IOR exists across several motor systems as a general mechanism to help avoid repetitive behaviour that would inherently impede goal-directed action.

In traditional peripheral cue-target tasks, the interval between presentation of the cue and the appearance of the target is predetermined – creating a window in which planning a movement can occur and subsequently be inhibited. For peripheral onset cues, facilitatory effects in reaction times (Posner & Cohen, 1984) and trajectories (cf. Neyedli & Welsh, 2011) have been revealed at shorter CTOAs; however, such facilitatory effects have not been observed in trajectory deviations for centrally presented symbolic cues using a traditional cue-target paradigm with a short CTOA (unpublished data set). This lack of observation is surprising, because based on Swansburg and Neyedli's (2019) previous finding of inhibitory effects, it is implied that there was a planned response to be inhibit. Therefore it would be expected that the link between a predictive symbolic cue and the target of an upcoming movement could lead to an advantageous pre-planning of the predicted movement at a short CTOA.

One possible method to elicit facilitatory or strategic action planning would be to force participants to respond as soon as they are cued. Thus participants must start their movement before they know where the target is (known as a go-before-you-know task; see Chapman et al., 2010a) which may result in deviations towards the cued location because participants may use the symbolic information to help predict the unknown future target location. When there are two potential target locations in a go-before-you-know task, participants aim between the two locations before updating their movement towards the target upon target appearance. Chapman et al. (2010a) suggested that participants perform a centralized movement between the two target locations because participants were averaging the movement associated with the two locations. When participants were presented with three potential target locations – two on one side of the screen and one on the other, participants' movements were biased to the side of the screen that held two potential targets. Chapman et al. (2010a) suggest that this effect was again due to movement averaging, with the trajectory biased to the side that contained more potential movements.

Wong and Haith (2017) offered an alternative explanation to the intermediate movements observed in the go-before-you-know paradigm. In the same experimental set-up participants were to initiate reaching movements to two potential target locations, prior to knowing the end goal, while executing either 'slow' (peak velocity 0.3-0.7m•s^{-1}) or fast (peak velocity, 0.8-1.5m•s^{-1}) movements. They argue that the intermediate movements are a strategic plan executed to optimize motor performance rather than a summation, or spatial average, of competing motor plans. The rationale for this manipulation was that if the movement was required to be completed quickly, the intermediate movement was no longer 'strategic' because participants would not have time to correct their action to aim to the target when it appeared. Instead, it would be more advantageous to guess which target may appear and aim in that direction. It was found that under the fast condition more direct and fewer intermediate movements were made when compared to the slow condition. The authors suggest that this finding indicates that even in the slower condition the intermediate movements may have been strategic because it gave the participant the best opportunity to adjust their movement to successfully touch the target.

The term “strategy” is used above several times in what seems to be an interchangeable manner. Neither Chapman et al. (2010a) or Wong and Haith (2017) clarify what type of strategy it is that results in intermediate movements. Broadly when one discusses strategy in this context, one could refer to mechanisms inherent in the motor system that influence movement task success. However, one could also be referring to ‘meta-strategies’, wherein the participant is more explicitly selecting a movement to plan that would lead to task success. Each of these ‘flavours’ of strategies can be seen in the conclusions of previous research. Wong and Haith (2017) argue that intermediate movements are a result of a more explicit meta-strategy used to optimize performance under end-goal uncertainty. Chapman et al. (2010a) speculate that the strategy is implicit in nature wherein activating multiple potential actions is a strategy that the movement preparation system uses to deal with target location uncertainty.

This discussion of strategy type is relevant for the current work with symbolic cues. In previous research using symbolic cues, participants implicitly learned to associate the cues with an upcoming target location, however as it was briefly mentioned only inhibitory like effects have been observed following these cues. It is unclear under what conditions, if any, participants can strategically use symbolic cues to produce more facilitatory type effects either implicitly or explicitly. Therefore the goal of this study was to begin to unfold the conditions in which participants may use the information provided by these cues to facilitate task success. To this end we created a situation in which participants were forced to explicitly select a target location to aim to following a symbolic cue, but prior to target appearance. Specifically, participants had to finish their movement within a short movement time constraint (similar to Wong & Haith 2017), thus they would have to select which target to aim to at movement onset. Given that participants were operating under maximum uncertainty they may strategically use the predictive characteristic of the cues to select which target location to aim to.

1.2 Purpose

The purpose of the current study is to determine whether strategic facilitatory effects occur in response to a centrally presented, predictive symbolic cue when participants must select to aim to a target location, before they are presented with target information.

1.3 Hypothesis

It is hypothesized that participants will implicitly learn to associate predictive symbolic cues with an upcoming target location, and under a short movement time constraint will more often select/execute a reaching movement to the predicted side. Further, it is hypothesized that under the same movement time constraints participants' movement selection following a neutral, non-predictive cue, will reflect decisions based on chance.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Inhibition of Return (IOR)

The phenomenon known as inhibition of return (IOR) is an effect that has been, and continues to be, investigated in depth. Initially identified by Posner and Cohen (1984) IOR occurs when, after a period of time, a previously attended to location or object is marked with an inhibitory tag slowing the response to the location or object. Traditionally a stimulus (cue) is presented peripherally (either to the left or right of centre) after a brief fixation period. Following the presentation of this cue, a second stimulus (target) is presented at either the left, right or central locations and participants respond via keypress when the target is detected. Because the target and the cue location can overlap, a target appearing at the same location as the cue is referred to as 'cued' whereas a target appearing in a different location is 'uncued.' Posner and Cohen identified that an inhibitory effect followed a longer cue-target onset asynchrony (CTOA) to the cued target location. Participants responded slower to a target in the cued location compared to the uncued location following a CTOA greater than_300ms. A facilitatory effect was also observed in which participants responded significantly faster to the cued targets following a CTOA of less than 150ms. Further research has demonstrated the same effects at greater than 300ms, and less than 200ms (see Klein, 2000 for review).

Generally speaking, in the vast literature on IOR, studies have traditionally looked at keypress or saccadic eye movement RTs in simple visual search or detection, but there is a growing body of research that suggests there may be motoric forms of IOR that operate beyond stimulus detection.

Through a set of experiments Abrams and Dobkins (1994) produced an inhibitory effect in an exogenous condition that was twice as large as the inhibitory effect in the endogenous condition. Their explanation was that peripheral target search enhanced IOR effects while the smaller response in the endogenous condition indicated a motor (or output) form of IOR as well as an attentional (input) component to IOR. Results found by Abrams and Dobkins later could not be replicated, specifically in the exogenous cuing condition, however researchers have since provided more evidence to support the idea that there are two forms or "flavours" of IOR processes rather than additive components. By investigating the distinct experimental differences between Abrams and Dobkins (1994) and Taylor and Klein (2000), Hilchey, Klein and Ivanoff (2012) determined that it was the separation of target types per block, not a fixation removal confound or a perceptual confusion, which led to Abrams and Dobkins (1994) declaration of two additive components of IOR.

Taylor and Klein (2000) demonstrated these two different "flavours" of the inhibitory effect through a series of experiments and conditions in which participants were required to respond (or not respond) in various manners to two stimuli (S1 & S2) that could be peripheral (exogenous) or central arrows (endogenous). Participants had to either not respond, respond with a saccade or respond with a button press indicating left/right (manual) to S1 then subsequently respond via saccadic eye movement or keypress to S2 (e.g. of the 6 possible combinations of response modes for S1 and S2, respectively, these could be: no response-manual or manual-manual). Response time to peripheral S2 were inhibited only when no eye movement was involved (i.e., no-response-manual and manual-manual), regardless of S1 type (i.e., IOR was generated by both peripheral and central cues when no eye movement involved) while no IOR was observed following central S2s. This "flavour" of IOR was said to occur at the input end of processing. Response time to both central and peripheral S2 was inhibited only when there was an eye movement involved (see Figure 1, taken from Hilchey, Klein & Ivanoff (2012)). The motor inhibition in the saccadic-manual condition was interesting because a manual response to a central S2 would not typically require a need to attend to the periphery. However given that Taylor and Klein (2000) intermixed S2 conditions, unlike Abrams and Dobkins (1994) attention to the periphery was indeed required. Therefore it was suggested that the saccadic response to S1 in the periphery inhibited the subsequent motor response to the same prior location.

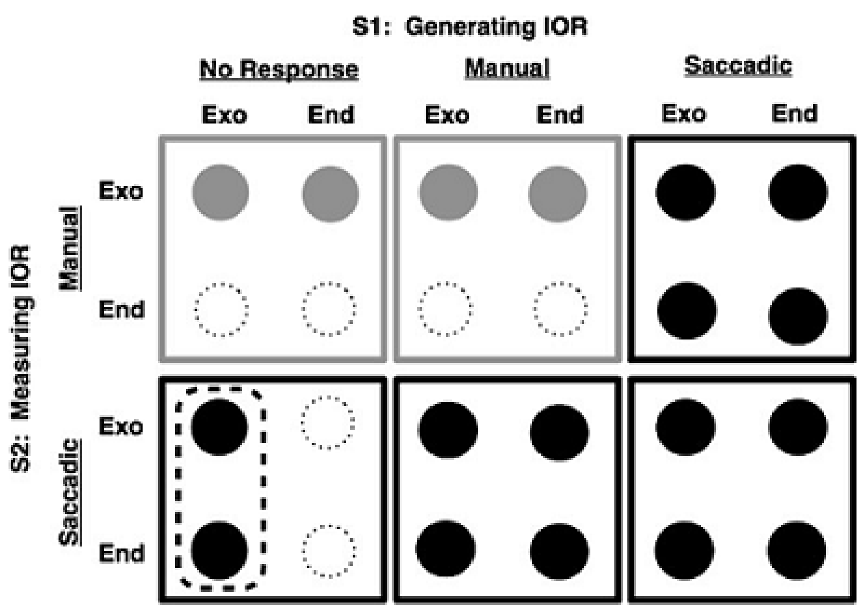

Figure 1. **Taylor and Klein (2000) Results.** Visual explanation by Hilchey, Klein & Ivanoff (2012) of the findings by Taylor and Klein (2000). "Exo" cues/targets are those in which a peripheral (exogenous) stimulus was used, while "End" cues/targets refer to the centrally presented directional arrow (endogenous). Grey circles denote input flavours of IOR, empty dotted circles represent no IOR findings, and solid black circles denote output or motoric flavours of IOR. The two conditions isolated by a dotted oval indicate the condition in which Taylor and Klein (2000) could not replicate findings of Abrams and Dobkins (1994). (Graphic taken from Hilchey, Klein & Ivanoff (2012))

Although the aforementioned studies were able to demonstrate that IOR operates at two points of processing(input vs output), it remained unclear if the motor IOR that had been observed was in fact movement related, restricted to the oculomotor system or a general form of IOR. Cowper-Smith and Westwood (2013) were able to show that motoric IOR is in fact evident outside of the oculomotor system, in the reaching control system. In two experiments they had participants execute two reaching movements to targets following peripheral or central cues. There was a RT advantage for reaches to targets separated by 90˚ or 180˚ compared to 0˚ (same location) for the peripheral condition, results that further support previous IOR findings. Similar to the peripheral condition, responses to the second target were slower for targets located at 0˚ compared to 90 ˚ and 180 ˚ in the central-cue condition. These findings in the central condition show that motor IOR effects are seen outside of the oculomotor system when responses to both stimuli are manual reaching tasks, in contrast to Taylor and Klein's (2000) findings that motor IOR effects were only seen in the central cuing condition when one of the responses was saccadic.

The study of inhibitory effects on response time and action execution, studies have begun to include different cue types (central vs peripheral) as well as different response actions (key press vs reach trajectory). Neyedli and Welsh (2012) analyzed reach trajectories and response times following peripheral cues in the form of thickening the outline of a potential target location that were present for 50ms. Various CTOAs were used (100, 350, 850 and 1100ms) to further understand the time course of IOR in various settings. Following the 850ms CTOA there was an inhibitory effect on the reach trajectory for which a movement following a peripheral cue on the left, participants' movements were more rightward. Interestingly, in the 100ms condition, movements following a rightward cue were more rightward, demonstrating a facilitatory effect.

When analysing the response times following these peripheral cues, they found no significant facilitatory effect at the 100ms CTOA, and an inhibitory effect at CTOAs greater than or equal to 350ms. Maruff et al. (1999) and Neyedli & Welsh (2011) both found that when the cue disappears before the target presentation, facilitation does not occur. Taken together the results of Neyedli and Welsh (2011) demonstrate that IOR has both motoric and attentional components that operate on different temporal landscapes.

2.2 Symbolic Cues

Symbolic cues are used in the real world in a number of settings. Take for instance the red light on the stove when the burner is on; the red light cues an individual that the burner is hot, and therefore should not be touched. Not all symbolic cues are explicitly taught however, rather they are learned implicitly and can be considered a form of contextual cueing wherein the visual context can guide and direct preferential processing for stimuli in the environment (Chun, 2000). Imagine an athlete assessing the field of play – opposing players' body language and positions create a complex visual scene full of cues to facilitate the decisions the athlete makes. Chun and Jiang (1998) have demonstrated that familiar global context can aid target detection in a visual search task. Over repeated blocks of trials, participants located a target faster among a complex scene of visual distractors when the target-distractor scene was repeated compared to novel scenes. Thus, the context directed the participant to search a specific location of the screen. The learned context was implicit, participants could not identify the repeated display in a forced choice recognition task. Further work showed that repeated contexts could also enhance search for an object of a particular appearance, independent of spatial location, and that familiar motion contexts also improved visual search (Chun & Jiang, 1999).

In a traditional cue-target paradigm, Lambert, Naikar, McLachlan, and Aitken (1999) presented participants with two potential target locations. On each trial, the letter ‘S’ appeared beside one placeholder and the letter ‘W’ beside the other placeholder. The letter was predictive, in that the target would appear in the placeholder next to one of the letters 80% of the time (e.g., in the placeholder beside the ‘W’). When the cue-target-onset asynchrony was short (100ms) responses were faster at the predicted location compared to the non-predicted location; when the cue-target-onset asynchrony was long (600ms) this pattern reversed with quicker responses to the non-predicted side. This finding demonstrates that symbolic peripheral cues can also elicit both facilitatory and inhibitory effects. Of note, however, the symbolic peripheral cues were still appearing in closer proximity to the potential target location, thus, the symbol and the location of the target were tightly correlated (i.e., the target would always appear close to the ‘w’). Thus it is unclear whether centrally presented cues, whose location does not correspond to the upcoming target location, will have similar effects. Similar learned associations have also been shown to improve visual search performance when the target appears within a predictable location, or a consistently colored region within a cue object (Kristjansson, Mackeban, & Nakayama, 2001; Kristjánsson & Nakayama, 2003).

Gozli, Moskowitz, and Pratt (2014) trained participants to associate a shape with a particular color outcome. They presented participants with an irrelevant colour cue following a predictive shape cue. When the colour was incongruently associated with the shape, there was no RT benefit for valid over invalid shape cues. This finding suggests that participants’ performance was affected by a learned an association between an irrelevant colour cue and a predictive shape.

Archer fish have been shown to associate predictive (colour) cues with an upcoming target location (Saban, Sekely, Klein & Gabay, 2017). Using centrally presented, predictive (valid 80% of the time) colour cues (red or green), the fish were able to associate the colour with the cued target location. The fish were presented with the colour cue at both a short and long CTOA, and it was shown that the fish respond faster to the cued target location following the short CTOA while following the long CTOA, they respond slower to the cued location (IOR). These findings indicate that the fish, without a neocortex, are able to associate a target location with the predictive colour cue.

Fewer studies have explored the effects of learned, non-directional symbolic cues on action planning. Swansburg & Neyedli (2019) used non-directional symbolic cues to examine the effects on action planning and execution. At trial start, two target placeholders appear equidistant to the left and right of a centrally presented fixation cross. After a brief period (500ms) a non-directional, symbolic cue is presented in place of the fixation cross for 1000, 1400, 1800 or 2200ms. Following this variable period, either the left or right target location was filled in solid black. There were four symbolic cues, randomly assigned to be high-predictive or low-predictive, to the left or the right (4 predictive-side combinations total). Participants implicitly learned to associate the predictive non-directional cues with an upcoming action to a left or right target location. RT data as well as reach trajectories were analyzed. Critically, reach responses to the predicted location, following the high-predictive cue type, deviated away from the predicted location; no such difference in reach trajectories was seen following the low predictive cue. Of note however, no strong inhibitory or facilitatory effects were observed in reaction time.

Following the 2019 study, Swansburg and Neyedli conducted a study (unpublished) using non-directional, predictive symbolic cues presented at short (100ms) and long (1000ms) CTOAs in an attempt to elicit facilitatory effects at the short CTOA; however, no facilitation effects in either reaction times or trajectories were observed. These effects may not have emerged due to the complex experimental design with four independent variables (CTOA, predictability of the cue, target side and block). The experimental design necessitated 900 trials, and block was included to explore if the effect of the predictive cues emerged over time as participants learned the association between the symbol and upcoming target location. Another possibility is simply that facilitation effects are nonexistent or not as robust to symbolic cues as inhibitory effects.

Facilitatory effects have not always been observed or their time course modified in more traditional cue-target paradigms. When the task was more complex than detection (i.e., colour discrimination) both inhibitory and facilitatory effects were observed at a later time (Lupianez et al. 1997) than in a simple target-detection task. In one experiment participants were to press the 'B' key when the target, regardless of colour, appeared in a peripheral target location. In the second experiment, participants were to press the 'X' for red targets and 'M' for yellow targets (regardless of location). It should be noted that half the participants had to push 'X' for red targets and 'M' for yellow to eliminate left and right biases. It was found that facilitatory effects were observed in both tasks at the short (100ms) stimulus onset asynchrony (SOA). At the longer (400ms) SOA facilitatory effects were seen only in the discrimination task, while inhibitory effects were present only in the simpler, key-press detection task. At longer SOAs (700, 1000 & 1300) IOR like effects were present in both detection and discrimination tasks. Interestingly, IOR not only appears later, but decays faster in the discrimination task. Lupianez et al. (1997)

findings lend support to the notion that object-based (discrimination) and location-based (detection) IOR operate on different time courses (Tipper et al. 1991; Abrams & Dobkins, 1994).

Through a series of experiments Maruff et al. (1999) showed that the temporal presentation and overlap of the cue and the target can influence facilitation and inhibition. If the duration of the cue presentation creates a temporal overlap of the cue-target presentation, at a short stimulus onset asynchrony (SOA), a facilitatory effect is observed. If the duration of cue presentation remains the same, but a long SOA is used, inhibition occurs. The use of a go-before-you-know paradigm and reach trajectories may provide a better opportunity to observe strategic or facilitatory effects for centrally presented symbolic cues.

2.3 Reach Trajectories

Action-centred theories of attention explain that actions associated with attended stimuli are automatically planned. It has been shown that more than one action can be activated simultaneously in regions such as the premotor cortex (Cisek 2007; Cisek & Kalaska, 2005) meaning actions planned to multiple stimuli in the environment can be planned in parallel. One very useful and informative way to understand the competition and execution of these parallel movement plans is through the use of reach trajectories. Reach trajectories provide a host of information regarding the action selection process, attentional orientation and cognitive process (Song & Nakayama, 2008).

The utility of trajectory deviations are due to the functional structure of the motor cortex. Georgopoulos (1990) explicitly demonstrated that movements are often are preplanned before they are even initiated. Directionally tuned neurons that have a preferred direction within 45˚ of the upcoming movement are also activated, while those in the opposite direction are inhibited

(Georgopoulos et al., 1982). A summation vector of directionally tuned neurons within the motor pathways of the brain indicate the directionality of the subsequent movement. Trajectory deviations occur when these movements are planned prior to the target onset, as the movement is initiated based on the summation vector of the population of neurons (Georgopoulos, 1990).

With the assumption that multiple motor plans can be activated in parallel (Cisek & Kalaska, 2005), trajectories can ultimately provide information about complex neural processes by creating a picture of the progression of internal spatio-temporal events (Song & Nakayama, 2009); for instance, how the locus of attention change in the presence of distractors during choice reach tasks. Reach trajectories have deviated toward distractors when they are to be considered potential target locations or when the distractor is congruent with a pre-cue or stimulus; in contrast, trajectories deviate away from distractors when they are irrelevant, inhibited or to be ignored (see Song & Nakayama, 2009 for review).

Earlier studies using reach trajectories to gain insight into the processes behind action selection and execution used a variety of discrimination tasks. Song & Nakayama (2008) asked participants to reach and touch an odd coloured target (red or green) that was presented with two identically shaped distractors (if target was red, distractors were green and vice versa). Single target trials were also implemented in which only one stimulus was presented in one of the three potential target/distractor areas. Trajectories to the single targets displayed little to no curvature, or corrective movements, while reach trajectories in the discrimination task often displayed corrective properties, wherein the movement was initially directed toward a distractor before being corrected to the pathway to the target. This finding suggests that target selection was not complete upon movement initiation. Previous work by Song & Nakayama (2006) shows that these corrective movements are not simply due to the presence of the distractors. Trajectories were less curved when targets and distractors are kept consistent across trials, thereby weakening the target selection competition. The corrections made to the reach trajectory in-flight demonstrates that actions can be carried out in parallel with selection and other cognitive processes (Song & Nakayama, 2008).

Similar to a previous study linking colour cues and associated words, Finkbeiner, Song, Nakayama and Caramazza (2008) presented participants with a masked, initial cue of either the word ‘red’ or the word ‘green.’ Neutral primes of ‘boy’ or ‘mouth’ were also used. Five green referents and five red referents were used as target words while a red and a green target were consistently displayed on the left and right side (respectively) of the screen. Participants were asked to identify the target word by reaching out and touching the coloured square that that word represented. For example, if the target word was cucumber, the participant would reach out and touch the green square; while if the target word was tomato the participant would touch the red square. They found that when the initial stimulus word was incongruent with the final target word, participants’ initial reach trajectories were directed to the opposite colour square (e.g., if the masked stimulus word was ‘red’ and the target word was cucumber, initial reach trajectories were directed toward the red square on the left of the screen). Finkbeiner et al. (2008) findings suggest that the initial prime is based on an initial motor plan that then needs to be corrected in-flight. Taken with other works, this provides evidence of competing motor plans that are initiated once a stimulus is identified.

2.4 Go-Before-You-Know

The capture and analysis of reach trajectories have been vital in understanding the underlying cognitive processes in decision making tasks in which people already know the endpoint goal. Chapman et al. (2010a) developed a paradigm in which participants must initiate a rapid reaching movement *prior* to knowing the endpoint or target location, a technique that can more directly measure the decision making process which unfolds during the reaching movement. This ‘go-before-you-know’ paradigm creates an environment in which all potential target locations are equally likely to be the end goal based on location and visual characteristics (i.e., colour), unlike the target-distractor studies wherein participants are aware that some stimuli information will need to be ignored/inhibited prior to movement initiation. In creating this paradigm, Chapman et al. (2010a) have combined the “final stages of planning an action, with the on-line control of a rapid reaching movement,” allowing for a specific measure of when the decision to act has occurred.

In a series of three experiments, Chapman et al. (2010a) showed that the ‘global effect’ or spatial averaging behaviors previously seen in trajectory analyses can be manipulated by spatial and probabilistic distributions of potential target locations. In their first experiment participants were shown a screen with one or two potential target locations (Figure 2). At movement onset, one of the targets was identified for participant selection. In single target displays, participants initiated a direct movement while in the two-target displays participants initiated a reach that was aimed toward the midpoint of the two potential options.

In the second experiment participants were presented a two-target display, this time one condition presented an already identified target with a distractor while the other was identical to the two-target condition from Experiment 1. Similar results to Experiment 1 were observed wherein participants aimed directly for the pre-identified target in the target-distractor condition and to the midpoint in the two-target display. Suggesting that spatially averaged movements are observed when the target locations are viewed with equal potential and not as distractors.

In Experiment 3, Chapman et al. (2010a) manipulated the spatial and probabilistic distribution of potential target locations. First, the spatial distribution was manipulated by laterally shifting the potential target locations, thereby altering the midpoint between the two. They showed that the initial reach trajectory followed the midpoint shift. In manipulating the probabilistic distribution, participants were presented with a 3-target display. As in the previous 2-target displays, two targets were to the left and right of fixation, on the same horizontal plane. A third potential target location was added on either the left or right, on the same vertical plane as one of the already existing potential target locations. Leaving two targets on one side, and one side on the other. The initial reach trajectory in these 3-target displays still produced a spatially averaged movement, now slightly biased toward the side with two potential target locations. By having participants initiate a movement before the target is selected for action, researchers get a real-time map of how and when the decision and subsequent movement occur

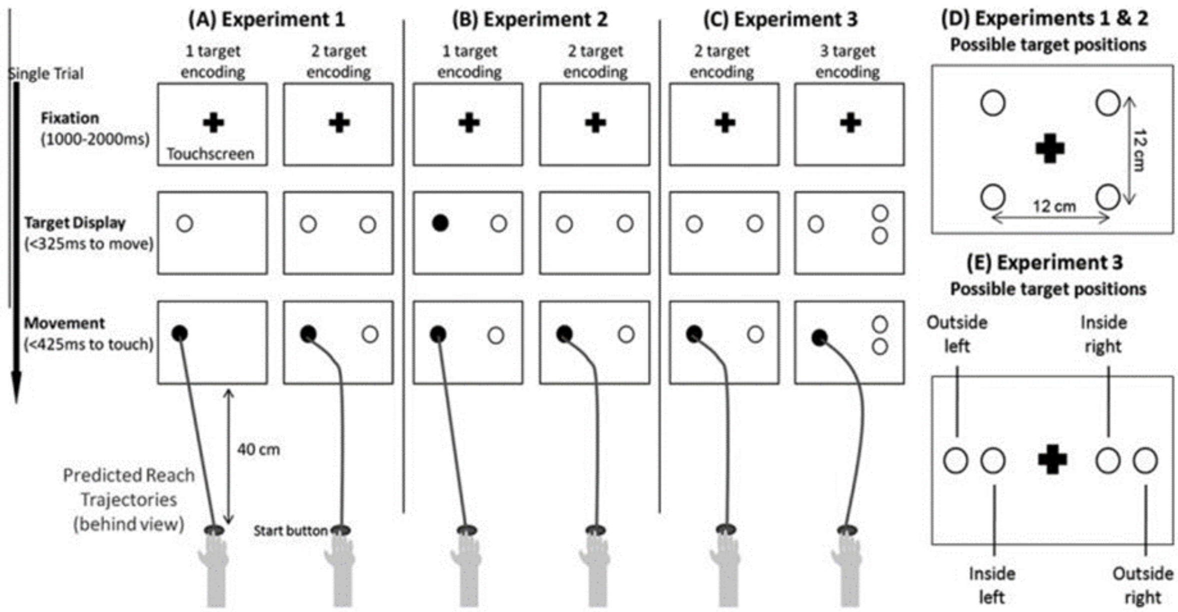

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Figure 2. **Chapman et al. (2010a) Methodology.** Methodology of Chapman et al., 2010a experiments. The timings displayed on the left, top to bottom. In all experiments participants began with a fixation cross and were presented with 1, 2 or 3 potential target locations. In all instances (except E2, 1 target encoding for which one target was cued prior to movement onset to mimic 1 target encoding in E1) participants were required to initiate a movement before a target was cued for selection. (Graphic taken from Chapman et al., 2010a).

The 'go-before-you-know' paradigm can also demonstrate that previous target locations can influence the planning of the current movement (see also, Maljkovic & Nakayama, 1996; Rosenbaum et al., 2007). Chapman et al., (2010b) again presented participants with a 2-target display with one of the targets being cued following movement onset however the same target location was repeated 2-5 times before a switch/random trial in which the target location would change. Their findings showed that following repetitive trials in which the same target was cued, participants made spatially averaged movements biased to the location of the target of the previous trials. These results demonstrated that trial history could also be added to the list of factors affecting simultaneous encoding of motor plans. Wood et al., 2011 predicted that presented in short duration, target salience would overpower the effect of spatial averaging. Conversely, if the targets were presented for a longer duration there would be no effect of salience and the spatial averaging effect previously observed would resurface. Participants in the "short" condition were instructed to initiate the reach as soon as the potential target location was presented, while the participants in the "long" group were shown the potential target locations, and thus the corresponding salience, for 500ms before being cued to move. In Experiment 1, Wood et al., (2011) showed that when the potential target locations differed in salience/luminance the initial reach trajectory was biased toward the higher salience target location regardless of which target location was cued after movement onset (immediately at potential target presentation). Experiment 2 had participants in two groups, short and long. Consistent with their prediction, following the long (500ms) display period the resulting bias of salience on initial reach was replaced by the spatially averaged reach. Taken together, these two experiments provide evidence that spatially averaged trajectories are temporally modulated by target salience.

More recent work using the 'go-before-you-know' paradigm is providing contradicting evidence to the movement averaging theory (Wong & Haith, 2017). Rather than saying that spatially averaged movements are a result of simultaneously encoded and competing motor plans, there is evidence supporting the notion that the spatially averaged (or intermediate) movement is a result of a singular motor plan developed to optimize performance under goal uncertainty, or the normative planning theory. It is not refuted that there are competing motor *goals* (rather than competing motor plans), but that the intermediate movement is one singular movement plan to optimize success for as many of the motor goals as possible.

To this end, Wong and Haith, (2017), implemented a 'go-before-you-know' paradigm but altered the movement time constraints. In this study some movements were to be carried out "slowly" (peak velocity 0.3-0.7 $m \cdot s^{-1}$, movement time 0.61s +/- 0.1s) or "fast" (peak velocity 0.8-1.5 $m \cdot s^{-1}$, movement time 0.33s +/- 0.02s). Using posits of the normative theory they suspected that intermediate movements would only be evident during slower reaches given that there is more time to take corrective action once the correct target location is cued. During a faster movement there would be less time for corrective movements and intermediate movements would not be beneficial under conditions of goal uncertainty, therefore they would not be present. Instead, they hypothesized that participants would guess the upcoming target location and initiate a movement directly to one of the two target locations. They present evidence that supports the normative theory's idea that intermediate movements are developed to optimize success while movements are slower. In slower movement time, intermediate movements were more prevalent (57% were intermediate) and had higher success rates compared to direct movements (55% and 27% correct, respectively). The opposite was found with faster movements wherein direct movements were more prevalent (only 31% were intermediate) and more successful (40% and 27% correct, respectively).

Taken together, all of these findings show that intermediate movements occur when people initiate a rapid reach task under goal uncertainty and can be modulated by a variety of factors. Both the movement averaging theory and the normative theory provide rationale for the presence of these movements, suggesting that further research needs to be conducted regarding when or why these intermediate movements occur. One possibility is that in some instances (i.e., chance of reward) the normative theory is a strong plausible explanation, while in other instances (i.e., reaching toward the salt and pepper at the dinner table when you hear "can you pass the…")

the movement averaging theory may offer a more realistic explanation of the intermediate movement.

The current experiment exploits the normative theory by using short movement time constraints to encourage participants to ‘guess’ an initial movement direction. The expectation is that as participants associate a symbol with an upcoming target location, they will bias their guess in the direction of the predicted target side. While previous research has not shown a facilitatory effect associated with symbolic cues for *action planning*, if participants show a bias with which target they select to aim to in the current study this would show strategic (advantageous) use of the symbolic cue in *action selection*.

CHAPTER 3: METHODOLOGY

3.1 Participant Population

Participants were recruited using the Dalhousie Psychology & Neuroscience Experimental Participation System, SONA. Using this system, compensation was provided in the form of credit points to be used toward an eligible Psychology or Neuroscience course of the participant's choosing. In total, 27 participants (8 male) were recruited, all participants were in the first four years of their individual undergraduate programs. Participants were either right handed, or comfortable reaching and pointing with their right hand (four left handed participants in total) and had normal (or corrected to normal) vision.

3.2 Study Design

This study used a within subjects design. Participants completed one session lasting approximately 1 hour. Three symbolic cues were used (Figure 3), two highly predictive with the subsequent target appearing on either the left of right side of the screen 80% of the time (one predictive cue for each side) while the other cue was neutral with the target appearing equally on the left or right (50/50); each of the three cues was presented an equal number of times within each block. Participants were instructed to make rapid reaching movements to one of two potential target locations at cue onset, prior to target appearance (GBYK). In the single session each participant was exposed to each of the six conditions (Cue Type (Right predictive; Left predictive; Neutral, non-predictive) by Target Side (Left and Right)) over a total of 360 trials, broken into 4 blocks (Table 1). Probabilities of each cue type were preserved within each block, meaning for example, the target went to the right side for 80% of the Right Predictive Cue trials. Prior to the start of the experimental trials participants went through a short practice block (36 trials) to allow familiarization with the sensitivity of the screen and the procedure for each trial. In the practice block participants responded to a solid black rectangle rather than one of the three symbolic cues that was used in the following experimental trials. The symbols used in this study come from Swansburg and Neyedli (2019) in which 4 symbolic cues were used; three symbols that were the most similar in size to one another and completely symmetrical were selected.

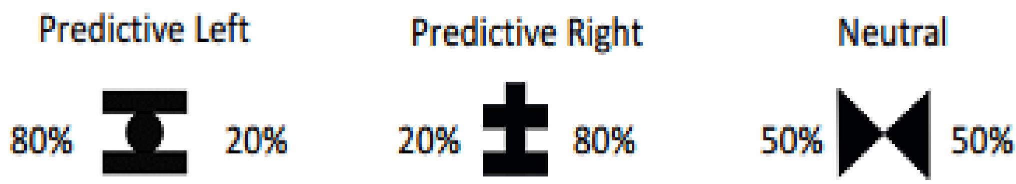

Figure 3. **Exemplar cue assignment.** A visual representation of each condition type as an exemplar of each cue assignment. Note that actual symbol assignment to cue type was randomized for each participant.

Table 1 **Target breakdown by block.** The table below provides a breakdown of the number of times the target will appear per side, within a single block of trials, x4 blocks.

Cue Type	**Target on Left (per block)**	**Target on Right (per block)**
Predictive - Left	24	6
Predictive - Right	6	24
Neutral	15	15

3.3 Materials & Measures

Participants stood in front of a table, 75cm tall, and used a touch-screen computer screen (58cm, 1,920 x 1,080 resolution) placed horizontally 7cm from the front edge of the table. MATLAB (Mathworks Inc.) custom programming was used to display the figures on the touchscreen, see *3.4 Procedures* for further detail of items appearing on screen. Reaction time

(RT), movement time (MT) and movement end points (side touched) measurements were collected from the screen which can detect where and when the screen is touched using the same custom program. RT was defined as the time between cue appearance and finger liftoff, MT was defined as the time between finger liftoff and the subsequent touch. The end point of the reaching movement was collected to determine which side of the screen was touched on each trial.

Two infra-red emitting diodes (IREDs) were placed on the lateral aspect of the participant's right index finger, one at each of the distal interphalangeal joint (DIP) and the proximal interphalangeal (PIP) joint using standard medical tape. The Optotrak 3020 (200Hz), was placed to the left of the participant and used to collect positional data of the participant's hand during the reaching movement. The positional data was then used to map the trajectory for each reach.

3.4 Procedure

Upon arrival to the lab, participants were given the informed consent pages to read on their own, immediately afterward a member of the research team reviewed the forms with the participant. Procedure for the experiment was verbally explained to the participant. Upon informed signed consent, the IREDs were placed on the participant's index finger.

The entire experiment was self-paced and therefore the participants initiated each trial. To initiate a trial, participants placed their finger on a 'home button' in the middle of the horizontal aspect, near the bottom of the screen. Participants were instructed to hold their finger on this home location until movement execution. Immediately following trial initiation, a fixation cross appeared (21cm) above the home button with two potential target locations (7cm to the closest edge) to the left and right of fixation. The potential target locations were marked with two empty 6x6cm boxes. After a variable fore-period (450 – 1000ms) a symbolic cue appeared at the place of fixation, signalling the participant to execute their reaching movement. During practice trials the 'go' cue was a solid black rectangle, however during the experimental trials the cue used was one of three symbols that had been randomly assigned to a specific cue type (Predictive Left (PL), Predictive Right (PR) or Neutral (NT)). Once the participant initiated their reach (i.e., removed their finger from the home button) the target appeared (one of the potential locations turned solid black).

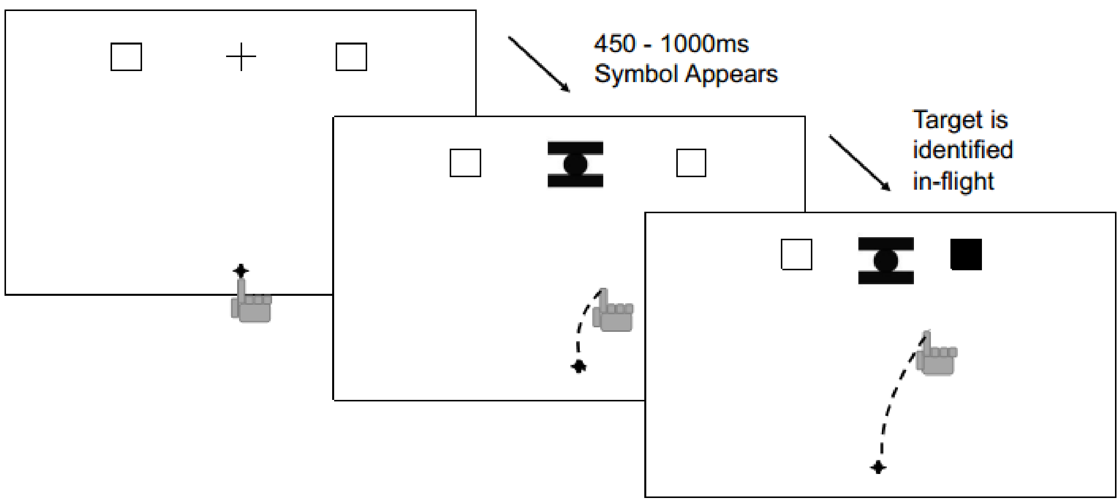

Figure 4. **Current procedure.** Progression of a single trial with a sample symbolic cue. Note that this is an example of one of four scenarios (moving right, target right). The participant can move left or right and the target can appear on the left or right, target will always appear on movement initiation.

Closely following the go-before-you-know set up from Wong and Haith (2017) participants had 1,000ms to initiate their movement following the presentation of the cue/go signal, and a subsequent 350ms to complete the movement (touch the target). Due to the movement time constraints and the physical distance between the two target locations, participants did not have time to execute a 'change of mind.' The time constraint thus forced the participants to choose a movement direction in hopes that the target would appear in that location. To ensure participants were meeting the temporal demands of the task, if participants failed to release the start button within the 1,000ms timeframe a "Time Out" message appeared on screen. If participants anticipated the movement and released the home button before the cue appeared, a "Too Early" message appeared. If participants took longer than the allotted time, they were presented with a "Move Faster!" message.

As mentioned, the total number of trials was spread over 4 blocks, each block took participants an average of 10 minutes. Participants were asked in between each block if they wanted to take a break. When the fourth block was finished, participants were instructed to remove the tape and IREDs from the finger.

To determine if participants became explicitly aware of the nature of the cues the experimenter asked a series of detailed questions (e.g., Did you notice anything about the shapes? Did you notice if any of the shapes were predictive? – the full list of debrief questions is in Appendix B). Once the participants had answered these questions the experimenter then explained which of the cues were predictive left/right and which was neutral and the purpose for the experiment.

3.5 Data Processing

Using another custom program (MATLAB, Mathworks Inc.) the kinematic data from the Optotrak was used to select movement start and end during each trial. Using the positional data, and the velocity profile (found by differentiating the positional information) movement start was identified as the first of ten consecutive samples in which the velocity exceeded 30mm/s. The movement end point was identified as the first of ten consecutive samples in which the velocity fell below 30mm/s. Each movement selection was visually inspected to ensure accuracy of the velocity cut off points and in some cases the movement start and/or end points occasionally had to be adjusted manually if the velocity criterion captured a 'finger wiggle' on the start button as the main movement. Following the movement selection process the data was passed through a second-order, dual-pass Butterworth filter with a low-pass cut-off frequency of 12Hz. Once filtered, the selected kinematic data for each trial was normalized with respect to movement amplitude. The normalized data was then added to a pre-existing matrix that was generated by the custom program used to run and collect the RT, MT and end point data during the experiment, to ensure that all information from each trial, moving forward, could be processed simultaneously. For the Choice Proportion, RT and MT analysis, trials were excluded if they violated the MT or RT criteria. Individual trials could be excluded because the RT was either too short (anticipatory response, RT < 100ms) or too long (late response, RT > 1000ms) or if the participant did not meet the MT constraints (350ms) previously outlined. The included trials were further processed and sorted first by cue type, then by target location, then side touched. When trajectories for each participant were plotted and analyzed, trials with poor IRED data (i.e., IRED missing for 5 more consecutive samples) were also excluded from analysis.

3.6 Statistical Analysis

3.6.1 Choice Proportion

To determine whether the participants selected the predicted side more often for the predictive cues, the proportion of trials that the participant decided to aim right (measured by Side Touched) was calculated for each Cue Type in each Block. More specifically, the number of times that participants decided to go right was divided by the total number of (usable) trials for that cue, in each block of trials. These data were analyzed using a 4 Block x 3 Cue type (predictive right, predictive left and neutral) repeated measures ANOVA. Trials were initially sorted by Target Side location and a 4 Block x 3 Cue Type x 2 Target Side repeated measures ANOVA was done to determine if participants were using the Target Side information to adjust their movements. There was no significant effect of target side, so trials were collapsed together across target side to run a 4 Block x 3 Cue Type repeated measures ANOVA. Planned orthogonal contrasts comparing the Right Cue to the Neutral and Left Cue were performed as a post-hoc analysis to determine if the choices following each cue type were different from each other. Trend analysis was used to explore any significant main effects over blocks of trials. To determine if the appearance of the target at movement onset influenced the final reach location, choice proportion by target side was analyzed using a 4 Block x 3 Cue Type x 2 Target Side (predictive vs non-predictive) x 2 Side Touched (predicted vs non-predicted) repeated measures ANOVA. Trials were grouped by target location and further separated by side touched. The number of trials in which the participant reached to the right target location and had the target appear on the predicted side was divided by the number of trials in which the target appeared in the probable location (per block). All alpha values were set at $p = 0.05$.

3.6.2 Trajectories

The average trajectory, along the x-axis, for each participant was calculated for each combination of block, cue type, target side and the side touched by the participant. Plotting and running a Functional ANOVA (FANOVA) on this kinematic data revealed there were no differences in the reach trajectories based on the cue type therefore, the trajectories will only be used for observation and insight into how participants performed the task.

3.6.3 Reaction & Movement Times

Average RTs were calculated for each combination of Block, Cue Type, and Side Touched (by participant) for each participant. Target side was not included in analysis because when participants initiated a movement, the target side was unknown and therefore could not influence RT. Moreover, the initial analysis of choice proportion that included Target Side revealed that there were no effects, providing evidence that the participants' choice of 'Side Touched' was determined at RT. For this reason Side Touched was used in the RT analysis because it indicates whether participants were faster to initiate a movement based on their decision of which side to reach to. Average MTs were calculated for each combination of Block, Cue Type, Side Touched and Target Side. Target side was included for MT analysis as it was revealed during the reaching movement, providing visual feedback thereby having the potential to influence MT through the speeding or slowing of their movement. Because participants could choose where to reach, in some blocks, there were no included trials in which participants selected to reach to one of the sides for one of the cue type by target side conditions. Therefore, Blocks 1 and 2 were averaged together for the first half of the experiment, and Blocks 3 and 4 were averaged together for the second half of the experiment to maximize the number of participants that could be included for analysis. RT was analyzed in a 2 Block x 3 Cue Type (predictive right, predictive left and neutral) x Side Touched (right, left) repeated measures ANOVA, while MT was analyzed in a 2 Block x 3 Cue Type (predictive right, predictive left and neutral) x Target Side (right, left) x 2 Side Touched (right, left) repeated measures ANOVA.

Chapter 4: Results

4.1 Choice Proportions

After the choice proportion for each condition for each participant was calculated, two participants were removed from the final analysis. These participants were removed because their numbers showed that these participants employed a strategy of choosing to reach to the right target location 95-100% of the time regardless of Cue Type or Block (the average choice proportion values by Cue Type for the remaining participants can be seen in Figure 5). In total, the data from 25 participants was used in the choice proportion analysis which is summarized in Table 2.

The main effect of Block was significant, F (3, 72) = 4.05, p = 0.010, η_p^2 = 0.14. The post-hoc analysis revealed that there was a significant linear trend, F(1,24) = 4.83, p = 0.038, r = 0.41 wherein participants more frequently reached to the right as they progressed through the experimental blocks with this trend lessening in the final block of trials (see Figure 5).

More importantly for the main hypotheses of the study, the main effect of Cue type was also significant and the Greenhouse-Geisser estimate of departure from sphericity was ε = 0.73, F (1.47, 35.25) = 4.89, p = 0.021, η_p^2 = 0.17. Based on Figure 5 participants appeared to have reached to the right target location more often when preceded by the Right cue, than when preceded by either the Neutral or Left cue. Simple contrasts revealed that participants reached to the right significantly more following the Right cue than the Left cue, F (1, 24) = 6.11, p = 0.021, r = 0.45. The interaction of Block x Cue type was not significant, F (3.27, 78.58) = 1.05, p > 0.1, η_p^2 = 0.042.

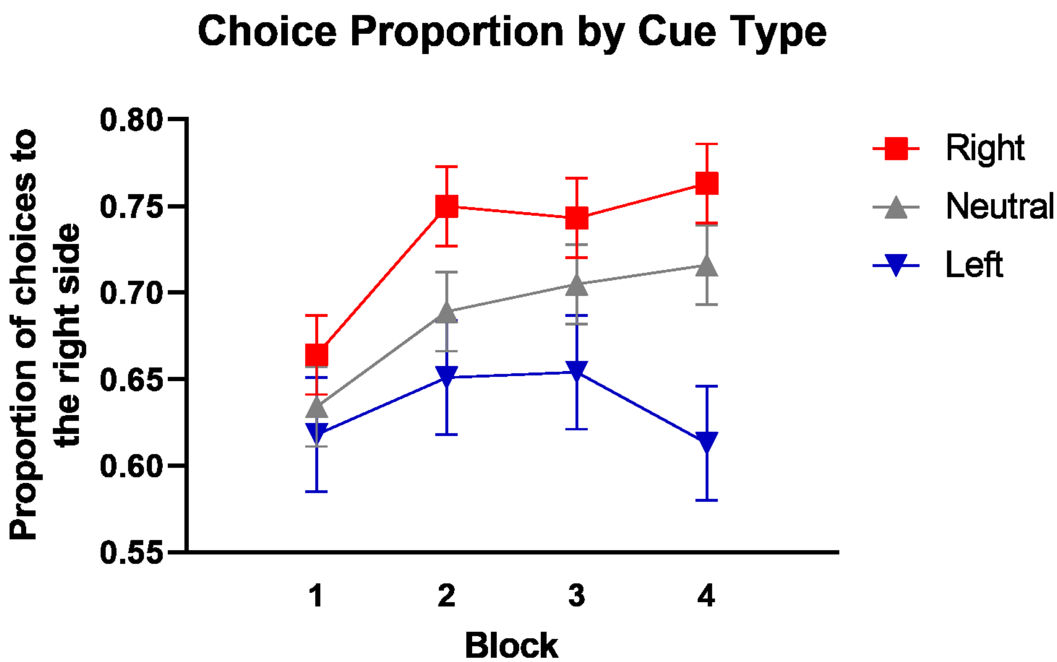

Figure 5. **Choice Proportion by Block.** The proportion of trials in which participants reached to the right target location following each of the Right, Neutral and Left cues. Despite an overall bias of reaches to the right, participants reached to the right target location following the Right cue significantly more than either the Neutral or Left cue. Error bars represent the standard error of the mean.

Table 2 **Choice Proportion ANOVA Table** Significant findings are marked with by a *

Variable	df	df(error)	F	p	ηp^2
Block *	3	72	4.05	0.010	0.14
Cue Type *	1.47	35.25	4.89	0.021	0.17
Block x Cue Type	3.27	78.58	1.05	>0.1	0.042

As mentioned in Section 3.6, kinematic data (i.e., reach trajectories) were plotted for observation and to provide insight into the participants' behaviours during the reaching tasks. When plotted together there are no deviations to any particular side in the beginning stages of the reaching movements, rather much like the task design intended, participants directly chose which target location to reach to (Figure 6) rather than selecting an intermediate movement between the two targets.

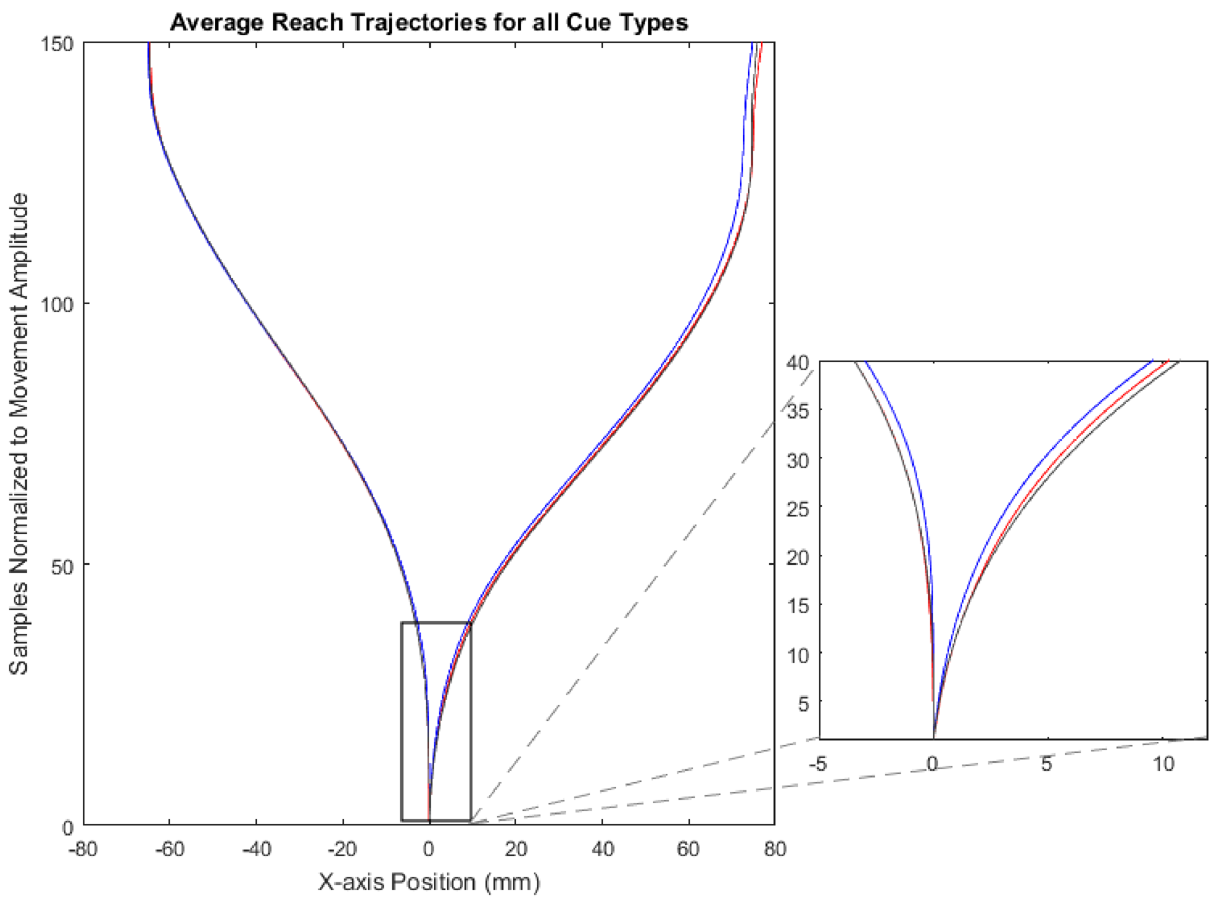

Figure 6. **Kinematic Data.** Average trajectories for each combination of Cue Type and Side Touched, Right (red), Left (blue) and Neutral (grey). The first ~27% of the movements are enlarged to better show how similar the trajectories to each of the sides following all three cues are.

As discussed, participants were asked a series of questions following the reaching task to gain an understanding of the conscious processes (strategies or methods) involved regarding decision making during the task. The qualitative data was also used to determine if any explicit knowledge regarding the nature of the cues had developed throughout, only two participants were able to explicitly identify the predictive nature of the cues based on the open ended question 1 (Figure 7 below provides further detail regarding participant answers). Despite the explicit knowledge these participants expressed, close inspection of their data shows that their choice proportion data was similar to other participants and removing their data from the analysis did not change the overall pattern of the results. For the remaining participants, they did not notice that the cues were predictive and/or across participants, were not able to identify the predictive nature of the cues at a rate greater than chance when asked to indicate or guess which cues were predictive and for which target they predicted.

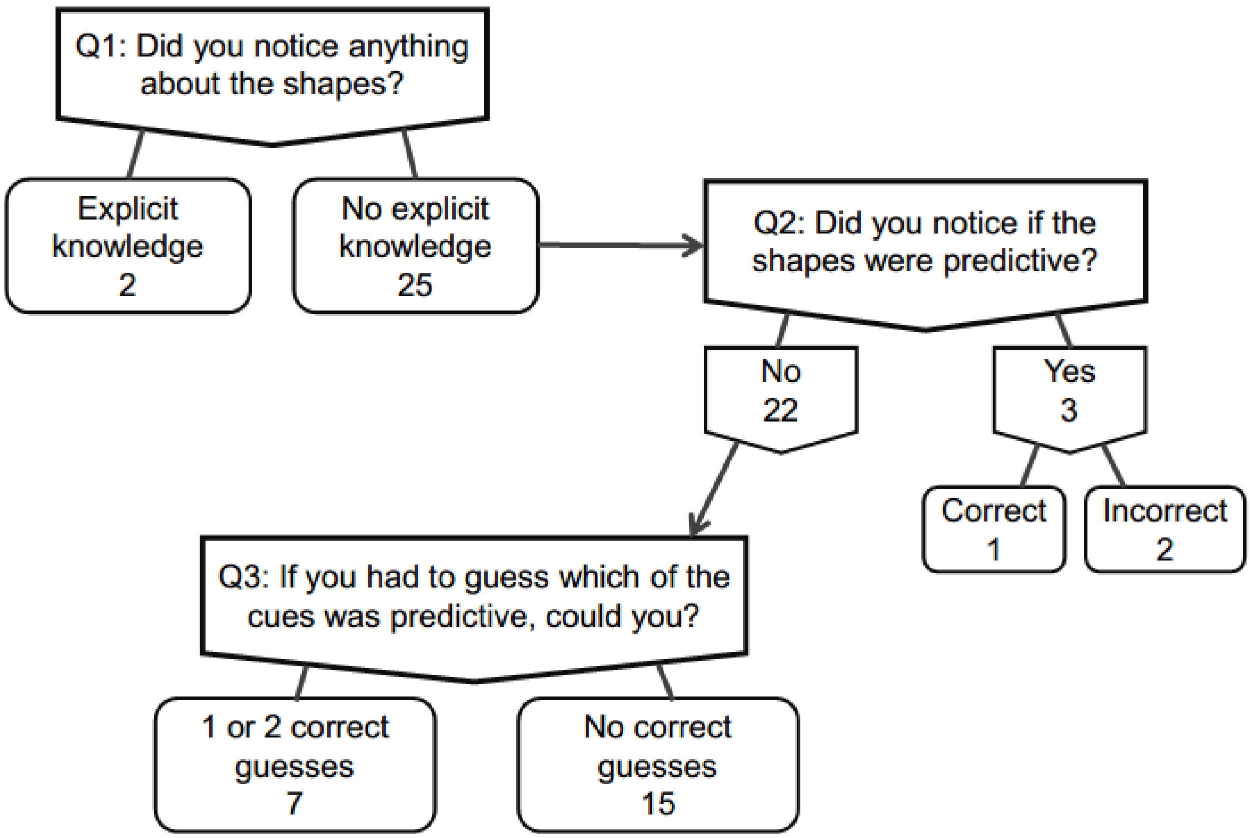

Figure 7. **Qualitative Data.** This flow chart outlines the questions asked to each participant upon completion of all trials and the number of participants belonging to each category based on their answers.

4.2 Reaction & Movement Time

After all usable trials were included, there were 19 participants in total for both RT and MT analysis. In terms of RT there were no statistically significant main effects or interactions (see Table 3 for detailed statistics), however the main effect of Cue type did approach conventional levels of significance, $F(2,36) = 3.22$, $p = 0.052$, $\eta_p^2 = 0.152$. The RT following the Right cue, M=417ms, SEM = 14ms was numerically shorter than the Neutral cue M = 434ms, SEM = 18ms and the Left cue, M = 422ms, SEM = 15ms. On average participants were faster to react on trials that started with the Right cue and slowest to react to trials in which the Neutral cue was used. Due to the fact that there were no significant effects or interactions, no post-hoc analyses were done.

Table 3 **RT ANOVA Table.** Note that there were no significant findings.

Variable	df	df(error)	F	p	η_p^2
Block	1	18	0.417	0.527	0.023
Cue Type	2	36	3.220	0.052	0.152
Side Touched	1	18	2.431	0.136	0.119
Block x Cue Type	2	36	0.459	0.636	0.025
Block x Side Touched	1	18	0.487	0.494	0.026
Cue Type x Side Touched	2	36	1.616	0.213	0.082
Block x Cue Type x Side Touched	2	36	0.043	0.958	0.002

With regard to MT only the main effect of Side Touched was significant, F (1, 18) = 135.0, $p < 0.001$, r = 0.939. Participants moved significantly faster, M = 253ms, SEM = 10ms when reaching to the right side than when reaching to the left, M = 278ms, SEM = 9ms (Figure 8) regardless of Cue Type. All statistical values for MT analysis can be found in Table 4.

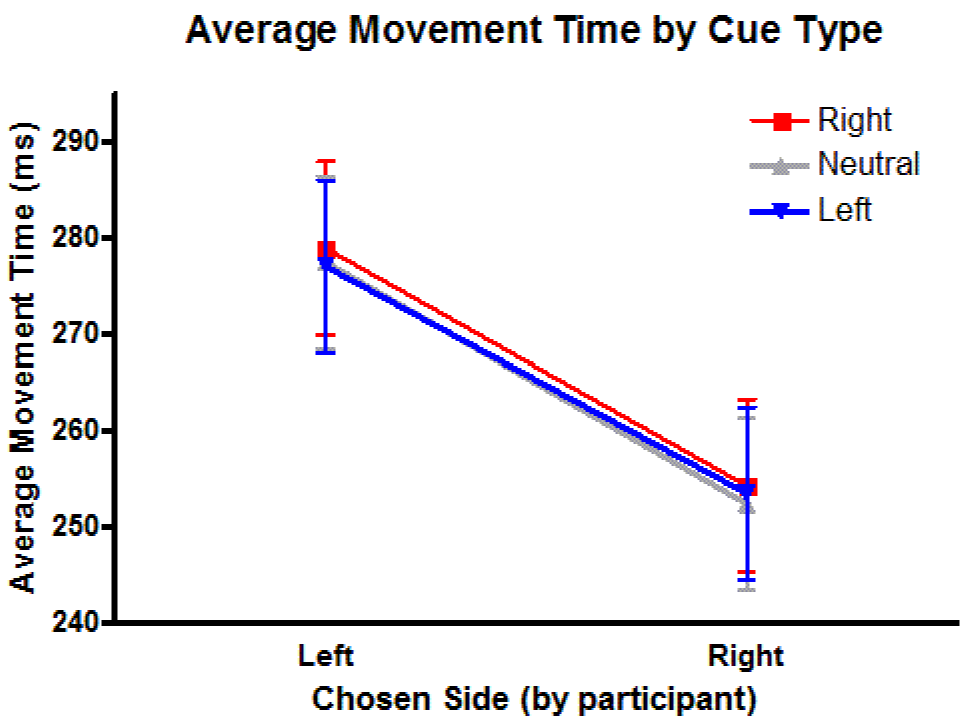

Figure 8. **Average MT by Side.** The above graph shows the significant difference between MT to the right target location, M = 253ms, SEM = 10ms and to the left target location, M = 278ms, SEM = 9ms.Participants moved faster to the right side regardless of Cue Type.

Table 4 **MT ANOVA Table.** Note that any significant findings are marked with an asterisk (*).

Variable	df	df(error)	F	p	$\eta_p{}^2$
Block	1	18	0.072	0.791	0.004
Cue Type	2	36	1.144	0.33	0.060
Target Side	1	18	2.377	0.141	0.117
Side Touched *	1	18	135.02	0.00	0.882
Block x Cue Type	2	36	0.986	0.383	0.052
Block x Target Side	1	18	1.547	0.230	0.079
Cue Type x Target Side	1	36	0.161	0.852	0.009
Block x Cue Type x Target Side	2	36	0.597	0.556	0.032
Block x Side Touched	1	18	0.341	0.567	0.019

Variable	df	df(error)	F	p	η_p^2
Cue Type x Side Touched	2	36	0.208	0.813	0.011
Block x Cue Type x Side Touched	2	36	2.133	0.133	0.106
Target Side x Side Touch	1	18	2.219	0.154	0.11
Block x Target Side x Side Touched	1	18	0.383	0.544	0.021
Cue Type x Target Side x Side Touch	2	36	0.184	0.833	0.010
Block x Cue Type x Target Side x Side Touched	2	36	0.374	0.61	0.020

Chapter 5: Discussion

The primary aim of this project was to determine if a learned association between a cue and a target location, could and would influence a participant's choice of which target location to reach to prior to knowing where the target was going to appear. Participants were presented with two potential target locations to the left and right of a fixation cross, and upon presentation of a centrally-presented symbolic cue were to initiate a reaching movement to one of these target locations. Both reaction and movement time constraints were put in place to force participants to choose a side rather than to perform an intermediate movement between the two locations. The side the target actually appeared on did not affect which side the participant selected, therefore, the choice proportion data was not influenced by the actual target location. With regards to the choice proportion data, as hypothesized, participants aimed to the right more often following the right predictive cue compared to the left predictive cue and the neutral non-predictive cue although overall there was a bias to aim to the right location. Overall, the preference for the right side was mirrored in the MT data in which participants' movements to the right target location were significantly faster than to the left target location. Although no significant effects were found in the RT analysis, participants' reaction times were, on average, slightly slower following the Neutral cue than either the Right or Left cue.

Few participants expressed any explicit knowledge regarding the nature of the cues during the question period (at the end of the experimental trials). Together, various choice proportion values and qualitative data provide evidence that facilitation-like effects can be elicited by non-directional, predictive symbolic cues. In this study, participants appear to have used implicitly learned information advantageously to inform an explicit choice that increases the likelihood of successful target acquisition (i.e., reaching to the predicted target location following a predictive cue).

5.1 Tying it all together

Previously it has been demonstrated that centrally presented non-directional symbolic cues can lead to IOR-like effects on trajectories, wherein, following a long CTOA (1000ms – 2200ms) participants' movements to the predicted target location deviated toward the non-predicted side following the high predictive cue (Swansburg & Neyedli, 2019). This finding was novel because IOR effects are typically observed following peripherally onset cues or centrally presented directional cues (see Klein, 2000 for review). Neyedli and Welsh (2011) and Welsh & Elliott (2004) also observed facilitation and inhibition in reaching movement following peripheral cues wherein participants deviated towards the cued location at short CTOAs and away from the cued location at long CTOAs. However, to date, no facilitation like effects in aiming movements have been observed following centrally presented, predictive symbolic cues when shorter CTOAs were used (unpublished data set).

Facilitation like effects to peripherally presented symbolic cues have been observed in response time. Lambert et al. (1999) used symbols (the letters 'S' and 'W') in the periphery, for which the target appeared next to one of the letters 80% of the time, to facilitate response times. At short CTOAs participants responded more quickly to the cued target location while at longer CTOAs response to the cued location was slower. Presenting the symbolic cues at the target location added relational spatial information to the symbol, which could have had an effect on attentional cuing (Pratt, Hillis & Gold, 2001). In contrast to Lambert et al., (1999) the present study used a centrally presented symbolic cue that had no explicit spatial relationship to the upcoming target location, yet still showed effects of the cue.

In order to increase the potential to observe facilitatory-like effects, a temporally constrained GBYK paradigm was used. This paradigm creates the best opportunity to observe these effects because it is placing the participant in a forced choice scenario. By forcing participants to make an immediate choice under strict RT and MT constraints, the implicit association must be incorporated into movement selection immediately – if such association did not exist then participants would presumably make decisions that reflect chance levels.

In the GBYK task, participants correctly selected the target location on the right side more often following a right predictive cue than a neutral or left predictive cue. The effect of Cue type was evident in the first block of experimental trials therefore participants were able to implicitly and quickly learn the association between the symbolic cue and the upcoming target location. IOR like effects with symbolic cues were also evident within the first block of trials where participants' movements deviated toward the non-predicted target location when reaching to the predicted side (Swansburg & Neyedli, 2019). Taken together, these findings indicate that participants learn the association between the cue and the target location rapidly.

Less surprising however is the lack of statistical difference between the reach trajectories (kinematic data) in response the predictive cues in the present study because the time constraints of the task were designed so the participants were forced to select one target or the other. In the previous study a reach was executed as a response to the appearance of a target. Evidence suggests that there was a pre-planned motor response that was subsequently inhibited before movement execution. In this study a reach was executed in response to the appearance of the symbolic cue rather than the target. Because there was no CTOA, there was no time to produce or inhibit a pre-planned response. Instead, due to the strict time constraints it appeared participants moved directly to one of the two potential target location as observed in Wong and Haith (2017). The movement time constraint was so strict that even the in-flight target appearance did not elicit any deviations or changes of mind during the movement execution. The absence of a significant effect on the choice proportion when analyzed based on Target Side supports the initial finding that the cue itself influenced the participants' choice of side and not the in-flight appearance of the target. The task used was designed in such a way that participants were forced to make a choice between sides immediately, creating a shift in strategy.

Previous research suggests that decisions made in a GBYK task are a product of a strategy employed by the visuomotor system; specifically that resulting intermediate movements are an average of simultaneously encoded movement plans (Chapman et al. 2010a). Wong and Haith (2017) using different movement time constraints, suggested that participants planned a single intermediate movement as a strategy for optimal performance. It is unclear however whether they consider this to be an implicit motor planning strategy, or an explicit strategy used by the participant based on knowledge of the time limits, particularly considering that the slow condition was roughly 200ms longer than that of Chapman *almost* forcing an intermediate movement. Providing feedback about movement speed during the reach task likely set up the participants to execute an explicit strategy in particular because the trials were blocked (fast or slow) providing more explicit knowledge for the participant to use.

In the present study, and Chapman et al., participants were implicitly provided with information regarding the upcoming target location. Wong and Haith dispute Chapman and colleague's interpretation of the findings, however it appears, especially when taken with the current findings, that both interpretations of the use of a "strategy" is correct. The type of and actual strategy that are employed however remain dependent on the specific parameters of the situation.

When provided with probabilistic information in a task for which the outcome or end goal is uncertain, people can implicitly learn choice-outcome contingencies through repetition, which then influence explicit decision making (Forman-Alberti & Hinnant, 2016). The predictive cue used here is similar in nature to the 2 vs 1 target set up used by Chapman et al. (2010a), because it provides information regarding the probability of the location of the upcoming target. The difference here being that this probabilistic information was learned implicitly via predictive or non-predictive cues wherein visible target placeholders provide explicit probabilistic information. Implicit learning occurs so that without conscious effort, advantageous decisions, in this case the decisions to reach to the predicted target side, can occur (Frensch & Ruger, 2003). Because Target Side had no effect on participants' choices, the probability of reaching to the predicted side and the probability of accurately acquiring the target became independent of one another. Using the predictive information from the cue to more often choose to reach to the predicted side itself increases the participant's chance of accurately acquiring the target.

Verbal feedback from participants included things like trying to use previous target location or keeping track of the number of times the target appeared consecutively on one side. All of the participants however also indicated that once they were wrong a few times, they stopped trying to figure it out or thinking about it and by the end all but few had any explicit knowledge. Following the first, very broad, question regarding the nature of the cues, only two participants expressed any knowledge about the predictiveness. As the next two questions became more specific fewer participants were able to correctly identify any of the cue as being predictive. In total one more participant identified each of the cues correctly; in the end seven of the remaining participants correctly guessed a maximum of two cue identities.

Evidence of implicit learning is also congruent with the findings of Saban et al., (2017) that had three archer fish implicitly learn to associate a colour cue with a target location. As discussed the fish do not have a neocortex, therefore explicit learning could not have occurred. Suggesting that the cortical processes involved with the control of facilitatory and inhibitory effects seen in cuing paradigms is yet to be completely explored and is an interesting avenue for future research.

Information obtained from the debrief questionnaire shows that participants were not explicitly aware of the nature of the predictive cues, despite choosing the target location predicted by the symbolic cue on a given trial more often than the non-predicted target location. Together, these results show that the explicit choices made by participants were influenced by implicitly learned information.

5.2 Timing

Interestingly, but not surprisingly, is that regardless of the cue type participants' MTs were significantly faster to the right side than to the left. A couple of participants indicated that they saw the "Move Faster!" prompt on screen more often when reaching to the left side than when reaching to the right. Faster movements to the right side are congruent with a natural, general bias for the right side of the body found in eating habits and general movements in most vertebrates (i.e., human and non-human primates, whales and other animals) (see MacNeilage

2014 for review). A predominant bias to the right was also present because all participants used their right hand for reaching. It is therefore unsurprising that participants aimed to the right more often, regardless of cue-type given that they were more likely to achieve the MT constraint if they reached to the right.

There were no statistically significant effects of RT in the current study; however, there were some emerging trends. Participants on average, respond slower to the Neutral, non-predictive cue than either the Right or Left predictive cues. Such a pattern could suggest that the behaviours observed in response to the cue are a facilitatory type effect. It may be that when presented with either of the predictive cues a motor plan was pre-planned, at least in part, such that it required less processing than the Neutral non-predictive cue. Because there was no association learned from the Neutral cue, participants may have needed more time to consciously select a side for reach. Again while the finding was not significant, the trends indicate that participants hesitated following the non-predictive cue, while no such pattern was seen following the predictive cues. Further research, specifically designed and powered can be used test this hypothesis.

5.3 Limitations and Future Directions

The current study forced participants to make a choice eliminating the opportunity for intermediate movements, and given the main effect of Cue type found it creates a possibility for several future studies to follow up. The next natural step would be the same study design in a GBYK task but with an increase in the movement time constraint. An increase in that time constraint would allow for intermediate movements, facilitatory effects in reach trajectories (deviations), or both to manifest. A study similar in design to that of Swansburg and Neyedli

(2019) using varying, shorter CTOAs may give way for a more traditional facilitatory effect as IOR like effects were observed with the use of long CTOAs.

It is unclear in Chapman et al. (2010a) whether participants were averaging two vs. one movement on each side to produce the observed deviation or whether participants planned a single movement that was biased by the probabilistic nature of the stimuli. Given the predictive symbolic cues also indicate the probable location of the target it would be interesting to observe whether deviations or direct movements occurred using predictive symbolic cues in a modified 2 vs 1 target layout (e.g. 2 targets on a horizontal axis rather than vertical). If deviations occurred following the symbolic cues, such results could not be explained by movement averaging, reinforcing the notion that predictive symbolic cues can elicit facilitatory like effects. While we purposely forced participants to make a choice by immediately reaching to a target location, if participants were able to view the predictive symbolic cue and execute a reach at an auditory go-signal it would allow the use of varying CTOAs in a GBYK task, delving further into the specifics of IOR and facilitatory type effects.

5.4 Final Thoughts

The purpose of the current study was to determine if centrally presented, non-directional, predictive symbolic cues could be used by the participant to facilitate accurate target selection as previously observed with peripheral or centrally presented directional cues. Participants more often chose to reach to the target side that corresponds with the predictive nature of the cue (i.e., left side following Left cue). Verbal feedback from participants following participation also confirmed the absence of explicit knowledge regarding the nature of the cues and that observed effects are a result of implicit learning of the cue-target association. While participants were forced to make an explicit choice of where to reach, an implicitly learned association facilitated those decisions providing an advantage for optimal performance.

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Appendix A

Consent Form

Project title: Measurement of Reach Trajectories to Two Targets

Lead researcher:
Dr. Heather Neyedli

Assistant Professor
School of Health and Human Performance
Phone: (902) 494-6786
Email: hneyedli@dal.ca
Funding provided by: National Science and Engineering Research Counsel of Canada (NSERC)

Introduction

We invite you to take part in a research study being conducted by Dr. Heather Neyedli & Jennifer Swansburg at Dalhousie University

The Health Sciences Research Ethics Board of Dalhousie University has reviewed the project and found it to conform to current ethical guidelines. These guidelines require:

1) That you be informed of the purpose of the research project and any attendant inconvenience, risk or benefits.
2) That the character of the task required be explained to you
3) That you be made aware that participation is entirely your choice and that you may decline to continue at any point during the course of the research project, without loss of expected compensation. Further, if you are a student at Dalhousie University, there will not be any academic impact based on your decision of whether or not to participate and/or a decision to withdraw from the study at any point.
4) That you be assured that all information assembled is entirely confidential.

Please ask as many questions as you like. If you have questions later, please contact the lead researcher.

Purpose and Outline of the Research Study

Our study serves to characterize the movement pattern of the hand when reaching to two different targets. You will be asked to attend a single session lasting approximately 90 minutes.

Who Can Take Part in the Research Study?

You can take part in this study if you are comfortable aiming and reaching with your right hand.

What You Will Be Asked to Do

Infra-red emitting diodes (IRED) which are small sensors, about the size of a lentil, will be placed on your right index finger, with medical tape, to track movement with the Optotrak Certus system. You will be asked to stand in front of a table, on it – a horizontal touch-screen computer screen. You will be asked to place your finger on a "home" location on the screen. There will be two potential locations where a target can appear and you will be reaching to touch the target as quickly and accurately as possible.

Possible Benefits, Risks and Discomforts

There are no direct benefits to participating in this study. Participating in the study might not benefit you, but we may gain insight into the brain's response selection efficiency.

Risks: There are minimal risks for participating in this study and they are similar to working with a tablet or iPad. You may experience some mental fatigue while completing the response selection task. Breaks will be provided in order to combat mental fatigue.

Compensation / Reimbursement

To thank you for your time compensation will be awarded in the form of 2.0 credits.

How your information will be protected:

All consent forms from the study will be kept in a locked cabinet in Dr. Heather Neyedli's faculty office in Dalplex 215F for 5 years after the publication of the results from the study.

We will describe and share our findings in papers and/or presentations. We will be very careful that no one will be identified. This means that ***you will not be identified in any way in our reports***. The people who work with us have an obligation to keep all research information private. Also, we will use a participant number (not your name) in our written and computer records so that the information we have about you contains no names. All your identifying information will be securely stored. All electronic records will be kept secure in an encrypted file on the researcher's password-protected computer.

If You Decide to Stop Participating

You are free to leave the study at any time. If you decide to stop participating at any point in the study, you can also decide whether you want any of the information that you have contributed up to that point to be removed or if you will allow us to use that information. You can also ask for your data to be removed from the study after it is completed; however, this will no longer be possible once data from the study have been analyzed. This typically occurs one week after you have participated.

How to Obtain Results

If you would like a copy of the study results please contact Jennifer Swansburg (902-449-5241 or j.swansburg@dal.ca)

Questions

If you have questions or concerns about your participation in this research study please contact Heather Neyedli (902-494-6786 or hneyedli@dal.ca) or Jennifer Swansburg (902-449-5241 or j.swansburg@dal.ca) at any time with questions, comments, or concerns about the research study.

If you have any ethical concerns about your participation in this research, you may also contact Research Ethics, Dalhousie University at (902) 494-1462, or email: ethics@dal.ca (and reference REB file # 2016-4000).

DALHOUSIE UNIVERSITY
Inspiring Minds

Signature Page

Project title: Measurement of Reach Trajectories to Two Targets

Lead researcher:
Dr. Heather Neyedli
Assistant Professor
School of Health and Human Performance
Phone: (902) 494-6786
Email: hneyedli@dal.ca

I have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I understand that I have been asked to take part in two sessions in the Cognitive and Motor Performance Lab at Dalhousie University. I agree to take part in this study. My participation is voluntary and I understand that I am free to withdraw from the study at any time, and my data can be withdrawn up until the point the data is published. All data will be published anonymously.

______________________________ ____________________________ ____________

Name Signature Date

☐ For SONA participants, please check this box if you wish to participate as an observer. As an observer, your data will not be used in the study as discarded upon completion of your participation

Appendix B

POST-DATA COLLECTION QUESTIONNAIRE

DALHOUSIE UNIVERSITY
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Project title: Measurement of Reach Trajectories to Two Targets

Lead researcher:

Dr. Heather Neyedli

Assistant Professor
School of Health and Human Performance
Phone: (902) 494-6786
Email: hneyedli@dal.ca
Funding provided by: National Science and Engineering Research Counsel of Canada (NSERC)

Questions to be asked by the researcher following completion of data collection, prior to the debrief session. Participants will not be given this questionnaire personally, questions will be asked and answers recorded by the researcher.

1. **Did you notice anything about the shapes?**
   If yes – What did you notice about the shapes?
   If no – see question 2

2. **Did you notice if any of the shapes were predictive?**
   If yes – Do you think you could identify which were predictive?
   Could you identify <u>what it was</u> they predicted?

3. **Can you guess which of these shapes were predictive?**

Appendix C

Debrief Form

Project title: Measurement of Reach Trajectories to Two Targets

Lead researcher:
Dr. Heather Neyedli
Assistant Professor
School of Health and Human Performance
Phone: (902) 494-6786
Email: hneyedli@dal.ca

Purpose and Outline of the Research Study

The specific goal of the study was to see if the pictures (symbolic cues) you saw before each movement affected how quickly you planed your movement, the trajectory of your movement and the side you chose to reach to. Some of the cues were highly predictive of where the target would appear. For instance after one cue the target would appear 80% of the time on the left and the other cue it would appear on the right 80% of the time. The other cue was non-predictive. The nature of the cues was left unknown to you in order to assess implicit vs. explicit learning. We asked you questions to help us identify how aware you were of the cues and if you identified which cues were predictive or non-predictive.

Even if you were not consciously aware that the cues were predictive, you may have been able to plan your action more quickly. You may also have made a more direct movement when the target appeared on the 'predicted side', but your movement trajectory might have veered in the opposite direction when the target appeared on the 'non predicted' side. This would indicate that you are using this symbolic information to partially pre-plan a movement before the target appears.

Questions

If after you leave today, you have questions or concerns about your participation in this research study please contact Jennifer Swansburg at 902-449-5241 or j.swansburg@dal.ca at any time with questions, comments, or concerns about the research study.

If you have any ethical concerns about your participation in this research, you may also contact Research Ethics, Dalhousie University at (902) 494-1462, or email: ethics@dal.ca (and reference REB file # 2016-4000).

Withdrawal of Data

As we stated in the consent form, you still have the opportunity to withdraw your data up until the point it is published. If you wish to do so after reading this debrief form please inform the experimenter verbally or you can also contact Jennifer Swansburg at 902-449-5241 or j.swansburg@dal.ca at a later date.

APPENDIX D

Participant	Ques. 1	Ques. 2	Ques. 3	Verbal Feedback
1	Yes	N/A	Correct	Second half was right, was initially wrong most of the time.
2	Yes	N/A	Correct	Noticed after the 2nd block, first thought it was random
4	No	No	Incorrect	Felt like the two triangles came up the most
7	No	No	Incorrect	Didn't notice which shape came up & which block was right Noticed the Right cue most*
11	No	Yes	Incorrect	Tried not to think too hard, would move too soon Noticed the Left cue most*
12	No	No	Incorrect	Movements influenced choice more than shapes Noticed the NT cue most*
13	No	No	Incorrect	Chose the side before the cue came up
14	No	No	Correct	Thought the order of trials was more predictive, not the shapes
17	No	No	Incorrect	Focused on the target & hitting it 2:1 pattern, left to right Reacted fastest to NT cue Tried to counterbalance choice based on previous choice
25	No	No	Incorrect	Weren't fast enough going to the left
26	No	No	Incorrect	Tended to go right for the first two blocks