



Symbolic, non-directional predictive cues affect action execution

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Abstract

Predictive cues may help us to plan an action in anticipation of what will come next. Some cues such as arrows contain directional information to orient the actor. Other cues, however, may contain no spatial information that directly orients the actor to the upcoming action. Non-directional predictive cues have been shown to increase performance in visual search tasks but have not been explored in the planning and execution of actions. The first aim of this study is to determine whether participants can implicitly learn to associate symbolic cues with an upcoming action target location. The second aim is whether this association leads to transient or sustained activation of the action associated with the predicted target location. High and low predictive cues preceded target appearance at long cue-target-onset asynchronies (1,100–2,000 ms). The trajectories of participants' reaching movements were analyzed depending on whether they aimed at the predicted or the non-predicted side within each of the cue type conditions. For the highly predictive cue, participants' trajectories veered further toward the opposite target location when participants aimed for the predicted target location compared to when they aimed for the non-predicted target location. These results indicate that participants can associate an upcoming action with non-directional predictive cues but the predicted response was inhibited in the long intervening time between the cue and target. This finding is similar to the response to peripheral-onset cues in inhibition of return type paradigms.

Keywords Inhibition of return · Perception and action · Goal-directed movements

Introduction

When interacting with our environment, there are often stimuli or cues that indicate a spatial location for an upcoming action. These cues often contain explicit directional information, for instance, an arrow directing you to look at a particular location. Peripheral onset cues, such as flashes of light or sound can also direct the actor to the location of the cue. There are also cues that are more symbolic, with a less obvious directional component. Take for instance approaching a yellow light at the intersection. If you are sufficiently far away from the intersection you should prepare to move your foot to the left to depress the brake; however, there is no directional

information indicating your foot should move leftward contained within this yellow cue.

The use of symbolic cues can be considered a form of contextual cueing where the visual context can guide and direct preferential processing for stimuli in the environment (Chun, 2000). For instance, a familiar global context could aid target detection in a visual search task (Chun & Jiang, 1998). 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).

Learned associations between stimuli are not restricted to global contexts. In a more traditional cue-target paradigm, Lambert, Naikar, McLachlan, and Aitken (1999) presented

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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 (100 ms) responses were faster at the predicted location compared to the non-predicted location; when the cue-target-onset asynchrony was long (600 ms) this pattern reversed with quicker responses to the non-predicted side. This finding is similar to inhibition of return type effects found with peripheral onset stimuli (Klein, 2000; Posner & Cohen, 1984). 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 (Kristjánsson, Mackeban, & Nakayama, 2001; Kristjánsson & Nakayama, 2003).

Participants can also associate symbolic information with an outcome. Specifically, Gozli, Moskowitz, and Pratt (2014) trained participants to associate a shape with a particular color outcome. During a subsequent test phase, a predictive shape cue was first displayed but was followed by an irrelevant color cue. When the irrelevant color cue had an incongruent association with the shape cue, there was no longer a response time benefit for valid over invalid shape cues, suggesting that the irrelevant feature of color, through learned association with a particular shape, could affect participants’ performance.

Taken together, it appears that participants can learn associations between both specific stimuli and invariant global contexts in visual search and cueing tasks. To date, however, most studies have focused on enhanced perceptual detection and identification. It therefore remains unclear how learned, non-directional cues affect how we plan and execute actions in our environment.

With regard to action, directional (Welsh, Pacione, Neyedli, Ray, & Ou, 2015) and peripheral (Buetti & Kerzel, 2009; Neyedli & Welsh, 2011; Tipper, Howard, & Houghton, 2000; Welsh & Elliott, 2004) spatial cues have been shown to affect reaching actions with the hand deviating towards or away from the cued location. These results are usually explained through action-centered theories of attention that state that we automatically plan the action associated with an attended stimulus. Critically, multiple actions can be activated in parallel in regions such as the premotor cortex (Cisek, 2007; Cisek & Kalaska, 2010). When reaching to the non-cued location the hand deviates towards the cued location if a competing action plan (i.e., toward the cued location) to the cue is still active, such as when the cue immediately precedes the target at short cue-target asynchronies. Conversely, the hand deviates away from the cued location at long cue-target asynchronies presumably because the competing action plan for the cued location has been inhibited (Neyedli & Welsh, 2011; Welsh & Elliott, 2004). These trajectory deviations occur even

when the cue is not predictive of the upcoming target location, further supporting that the cue stimulus *automatically* activates the associated action plan. Given that this pattern of early activation and late inhibition is similar to what was observed in classic peripheral-onset cue-target paradigms (e.g., Posner & Cohen, 1984) and the learned association cue-target paradigm (Lambert et al., 1999), the learned association between the symbolic cue and the predicted target location may similarly automatically activate the associated action plan.

Another possibility is that participants may use the learned association between the target location and the predictive symbolic cue to plan and execute the action in a more strategic manner. If the action plan remains active, even at longer cue-target-onset asynchronies in preparation for the upcoming target appearance, the reaching movement may be initiated more quickly to the predicted target. Recent research has suggested that participants can plan their movement trajectories in a more strategic manner in order to optimize task success (Wong & Haith, 2017). If participants are using the learned association between the target location and the symbolic cue in a more strategic nature, we would expect that when a target appeared at a non-predicted location the hand would deviate towards a predicted location because the action associated with that location would still be active.

The purpose of the study is first to determine whether participants can implicitly learn to associate symbolic cues with an upcoming action target location and, second, whether this association leads to transient activation or sustained activation of the action associated with the predicted target location. To test this purpose, on each trial participants were presented with a symbol followed 1,000–2,200 ms later by a target, which appeared at one of two potential target locations to the left or right of the symbol. Participants were required to reach out and touch the target as quickly and accurately as possible. Critically, half of the symbols were highly predictive of the target location where the target appeared at one location 78.5% of the time. The other half of the symbols were less predictive where the target appeared almost equally at each potential location following the symbol. Participants were not informed of the nature or purpose of the symbols.

We hypothesized that participants would implicitly learn to associate the predictive symbolic cues with a target location and this would lead to the activation of the movement associated with the predicted target location. If participants learned to associate the predictive cues with an upcoming target location, we would expect a difference between the movement trajectories when aiming for the predicted versus the non-predicted side following the predictive cue. More specifically, if the action plan is strategically sustained, the resulting movement should deviate toward the predicted target location when moving to the non-predicted location. If the action associated with the predicted target location is only transiently activated, the trajectory should deviate away from the predicted target

location when aiming for the non-predicted location, because the activity associated with the predicted action will have been suppressed given the long cue-target-onset interval. No such differences in deviations are expected between movements towards the predicted and non-predicted side following the low predictive cues.

Methods

Participants

Twenty-five right-handed individuals, 18–25 years of age, with normal or corrected-to-normal vision were recruited for participation using the Dalhousie Psychology Department’s Experimental Participation System. Written and informed consent was given prior to participation. Compensation was given in the form of two credit points toward their grade in an eligible course of their choosing.

Apparatus

Participants stood comfortably in front of a 75-cm tall table while reaching to targets that would appear on a touch screen (58 cm, 1,920 × 1,080 resolution) that was placed horizontally and at the closest edge of the table top. Two infrared emitting diodes (IREDS) were fixed to the participant’s right index finger. The Optotrak 3020 was used to record the kinematics of each reaching movement, at a sampling rate of 200 Hz. MATLAB (Mathworks Inc., Natick, MA, USA), was used to randomize the cue type assignment, trial

order within block, to record reaction time, and generate on-screen images.

Study design

Participants were asked to complete one session consisting of 448 trials, during which they were instructed to touch a target onscreen as quickly and accurately as possible while the kinematics of their reaching movements were recorded. Critically, before the target appeared, a symbolic cue was displayed. There were two cue types – high predictive (HP, with the target appearing on one side 78.5% of the time that cue was used) and low predictive (LP, with the target appearing on one side 53.5% of the time that cue was used). The cue types were balanced for both left and right sides: there was a high predictive cue for the left side, a high predictive cue for the right side, a low predictive cue for the left side, and a low predictive cue for the right side. A low predictive cue rather than a fully non-predictive cue (i.e., 50%) was used because it allowed for the designation of a predicted side and non-predicted side for analysis. Trials could be distinguished by whether the target appeared on the predicted side or the non-predicted side for all cue types, though for the low predictive cue, the predictiveness of the cue was close to chance.

The same four symbolic cues were used for each participant. The symbolic cues were selected to be left/right symmetric so bottom-up stimulus features would not bias the participant to a particular direction and that the participants would have no prior spatial association or connection with the cues. The assignment of each symbolic cue to type (HP-left, HP-right, LP-left, and LP-right) was randomized for each participant. An example of the cue assignment for one participant can be seen in Fig. 1.

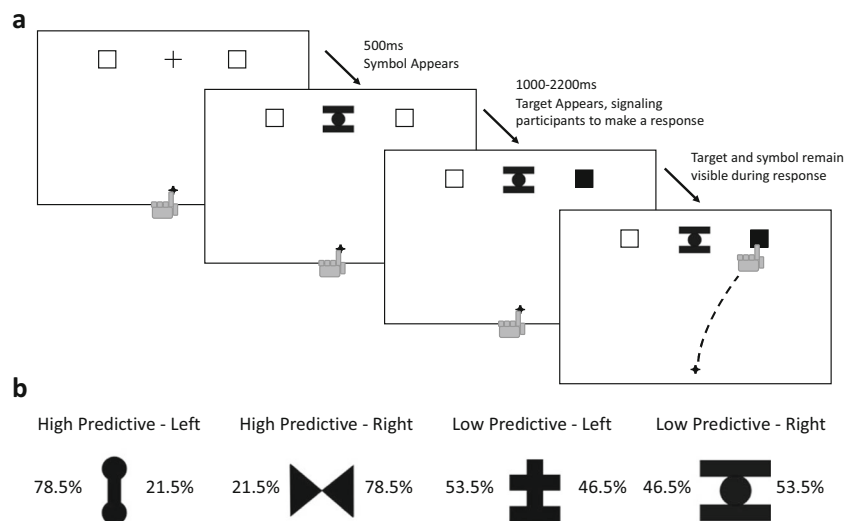


Fig. 1 (A) Trial progression. The trial initiated when participants put their finger on the home button at the bottom of the touch screen. (B) Four symbolic cues used in the experiment in the breakdown of potential target locations. The values next to each symbol represent the proportion of

trials for each cue-type, in which the target appeared on that side. Note that this is an exemplar symbol assignment. The symbols were randomly assigned to each cue type for each participant

The 448 trials were divided into four blocks of 112 trials. Each block had 28 trials for each cue type (e.g., high predictive-left).

Procedure

After the participants provided written, informed consent, the task was explained to participants while the IRED markers were fixed to their right index finger. Each participant was instructed to initiate a trial by placing their right index finger on a home button centered at the bottom of the screen. Upon initiating a trial, a fixation cross would appear (21 cm) above the home button and two potential target locations appeared 7.5 cm to the left and right of the fixation cross (Fig. 1). Participants were told to look at the fixation cross and to keep their finger on the home button until the target appeared (Fig. 1). After a brief pause (500 ms) one of the four symbolic cues (~4 cm × 3.5 cm) would appear in place of that fixation cross. Following one of four cue-target-onset asynchrony times (1,000 ms, 1,400 ms, 1,800 ms, or 2,200 ms) one of the potential target locations would turn black. Participants were told to reach and touch this target as quickly and accurately as possible. They were instructed to leave their finger on the target until it disappeared (after a maximum of 1,500 ms). Multiple cue onset asynchronies were used to reduce the predictability of target appearance and therefore reduce the possibility that the participant could predict the timing of when the target would appear.

Upon completion of all 448 trials, participants were asked a series of questions to determine if they gained explicit knowledge regarding the predictability of the cues. First, participants were simply asked: “Did you notice anything about the cues?” If they said yes, they were asked to explain what they had noticed. If they said no, they were then asked: “Did you notice if the images were predictive in any way?” Again, if they said yes, they were asked to expand on their statement. If participants again answered no, they were asked “If you knew at least one of the symbols was predictive, could you guess which symbols were predictive?” The experimenter then showed the participant the four cues and they were asked to guess which cues they thought were predictive.

Data processing and analysis

Kinematic data from the Optotrak was processed using a custom program (MATLAB, Mathworks Inc.). Data was first passed through a second-order, dual-pass Butterworth filter with a low-pass cut-off frequency of 12 Hz. Once filtered, the velocity profile of each trajectory was found by differentiating the positional data. Movement start was identified as the first of ten consecutive samples in which the velocity was greater than 30 mm/s. Movement end was identified as the first of ten consecutive samples in which the velocity fell below 30 mm/s.

Following movement selection, the movement profile of each trial was normalized with respect to movement amplitude. For each participant, the average trajectory along the x-axis (i.e., the horizontal axis along which target position varied) for each combination of Cue Type (high-predictive and low-predictive) and Target Side (predicted side and non-predicted side) and Block was calculated for movements to the right side and the left side. The average trajectories were integrated and the difference between movements to the left and right targets taken to calculate the area between reaches to the right and left side for each combination of conditions. A smaller area would indicate that the hand deviated towards the target location on the opposite side of the screen.

Reaction time was measured from the time when the target appeared to when the participant lifted his or her finger from the touch screen. Reaction times were averaged for each participant for each combination of Cue Type (high-predictive and low-predictive) and Target Side (predicted side and non-predicted side) and Block.

A 2 (Cue Type) × 2 (Target Side) × 4 (Block) repeated-measures analysis of variance (ANOVA) was used to analyze group-level comparisons for trajectory area and reaction time. If participants could associate the high predictive cues with an upcoming target location, we predicted a Cue Type × Target Side interaction would occur where there would be a difference in trajectory area and/or reaction time between movements to the predicted versus non-predicted side for the high predictive cue but no such difference for the low predictive cue. Bonferroni-corrected paired-samples t-tests were conducted as *post hoc* analysis for any significant interactions. The Greenhouse-Geisser correction was used to correct for violations of sphericity. To follow up on any significant effects on area, functional data analysis, specifically a functional ANOVA (fANOVA), was performed to determine at what points in the trajectory the conditions differed from one another (Gallivan & Chapman, 2014). fANOVA produces a functional *F*-statistic and the associated functional *p*-value across the normalized trajectory. The fANOVA treats the function as a single data object and therefore controls for multiple comparisons across the course of the trajectory.

Results

Trajectory area

The main effect of Block was significant, $F(1.94, 46.7) = 3.25$, $p = 0.049$, $\eta^2 = 0.12$. The significance of the main effect of Block is modified by higher order interactions. Neither of the main effects of Cue type, $F(1, 24) = 0.26$, $\eta^2 = 0.03$ or Target side, $F(1, 24) = 1.62$, $\eta^2 = 0.14$ were significant, $p > 0.10$ for each.

Critical for our hypotheses there was a significant interaction effect between Cue Type and Target Side, $F(1,24) = 13.7$,

$p = 0.001$, $\eta^2 = 0.36$ (Fig. 2A). As expected there was no significant difference in area between reaches to the predicted and non-predicted side for the low predictive cue, $t(24) = 0.48$, $p = 0.32$, $r = 0.98$. However, for the high predictive cue, the area between left and right trajectories was larger when aiming to the non-predicted side than when aiming to the predicted side, $t(24) = 3.35$, $p = 0.001$, $r = 0.97$. This finding indicates that participants' trajectories veered towards the opposite target location when they reached to the predicted side more so than when they reached to the non-predicted side.

The results from the fANOVA that compared reaching movements made to the predicted versus non-predicted side are shown in Fig. 3. Separate fANOVAs were used to compare the trajectories to the right and left targets, therefore Bonferroni-corrected p -values of 0.025 were used for these two analyses. The black bars in Fig. 3 represent regions in which there was a significant difference in x -axis deviation between movements to the predicted and non-predicted side. There was a significant difference between trajectories to the predicted and non-predicted side in both left and right aiming movements. These differences occurred early to midway through the movement in the high predictive cue condition. There were no such differences for the low predictive cue. Finally, none of the participants were able to correctly identify both of the cues that were highly predictive, even after they were told some cues were predictive and asked to guess which

cues were predictive. Note that participants were free to select as many cues as they believed might be predicted. We did not force participants to select two cues, which likely would have resulted in some participants guessing both highly predictive cues by chance.

The two-way interaction between Block and Target Side was also significant for Area, $F(3, 72) = 4.36$, $p = 0.007$, $\eta^2 = 0.15$ (Fig. 2B). *Post hoc* comparisons revealed that the only significant difference between reach trajectories to the predicted and non-predicted side is in Block 1, $t(24) = 3.39$, $p = 0.001$, $r = 0.92$. There was no significant difference between predicted versus non-predicted areas in blocks 2–4. This interaction was unexpected because it limited theoretical implications as it does not pertain to the predictiveness of the cue. Neither the two-way interaction of Block by Cue Type, $F(3, 72) = 1.00$, $p = 0.39$, $\eta^2 = 0.04$, nor the three-way interaction $F(3, 72) = 0.06$, $p = 0.98$, $\eta^2 = 0.002$, were significant, $p > 0.10$.

Reaction time

Four participants were excluded from the reaction time analysis due to a data recording error wherein the touch screen did not record reaction time, thereby reducing the sample to 21. With the remaining 21 participants, there were no significant main effects of Block, Cue Type, or Target Side on reaction

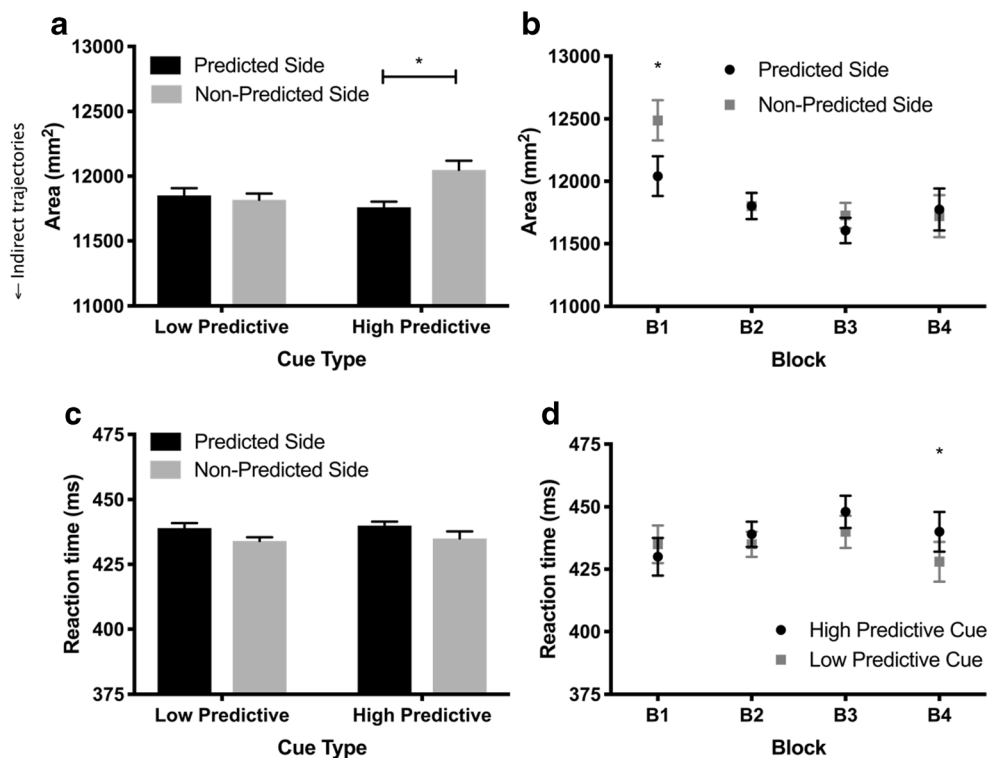


Fig. 2 (A) Significant interaction for the area between left and right reaches between Cue Type and Side. Note that indirect trajectories indicate that the trajectory veered more towards the opposite potential target location. (B) Significant interaction for the area between left and

right reaches between Block and Side. (C) No interaction for Cue Type \times Side for RT. (D) Significant interaction between Cue Type and Block for Reaction time. All error bars are within-subject standard error

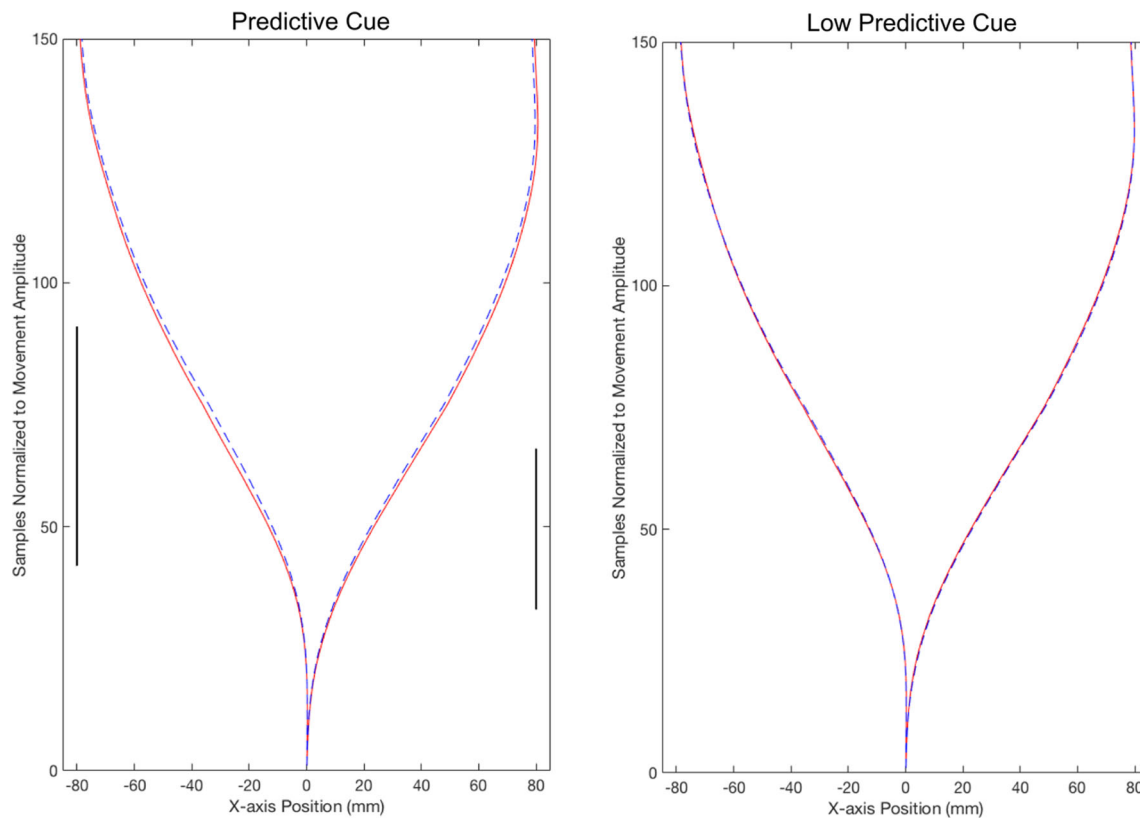


Fig. 3 Average trajectories for movements to the predicted (blue dashed line) and non-predicted side (solid red line) following the High Predictive (Left) and Low Predictive (Right) cue. Black bars represent where the functional p -value is less than .025

time. Of note, the theoretically relevant Cue Type \times Target Side interaction, $F(3, 57)=0.019$, $p=0.89$, $\eta^2=0.001$, had no significant effect on reaction time (Fig. 2C). There was a significant interaction between Block and Cue Type, $F(3, 57)=3.42$, $p=0.023$, $\eta^2=0.15$ (Fig. 2D). Visually, reaction times were faster following the high predictive cue in the first block, but slower than the low predictive cue in subsequent blocks. Bonferroni corrected t -tests ($\alpha=0.0125$) however, revealed that the difference in reaction times for cue type only approached significance in Block 4, $t(20)=2.42$, $p=0.013$, $r=0.99$, all other p -values $>.10$. Again, this effect was unexpected because it was not modified by which side the participant was aiming for (i.e., predicted vs. non-predicted side). The remaining two-way interactions of Block by Target Side, $F(3, 57)=1.53$, $p=0.22$, $\eta^2=0.071$, and the three way interaction was also not significant, $F(3, 57)=0.35$, $p=0.79$, $\eta^2=0.017$.

Discussion

The present study used predictive, symbolic cues with no prior spatial meaning or association to determine if participants could implicitly learn to associate a symbolic cue with an upcoming target location and to determine if this association

affected the motor planning process to the target. The reach trajectories were used to determine whether the activation of the motor plan to the predicted target location is transient in nature, or whether it could be sustained until target appearance.

For the high predictive cue only, the area between the trajectories for the trials in which the target appeared on the non-predicted side was significantly larger than the area between curves of those trials in which the target appeared in the predicted location. In other words, the participants deviated towards the opposite target location when aiming for the predicted location following a highly predictive cue and/or they deviated away from the predicted location when aiming for the non-predicted location. This result indicates that the activation of the motor plan to the predicted location likely was inhibited, resulting in a less direct trajectory towards the target location, a finding that will be discussed in more detail below. In contrast, it was hypothesized that if the learned association was used in a strategic manner their hand would deviate toward the predicted target location on trials in which the high predictive cue was followed by a target in the non-predicted location. Such a pattern of results would be characterized by the area between left and right trajectories being smaller for reaching movements to the non-predicted side compared to the predicted side, but this pattern of results was not observed.

Critically, there was no difference in the area between the trajectories to the predicted and the non-predicted side when the cue predicted the target location at near chance levels (i.e., the low predictive cues).

The factor of Block did not affect the magnitude of the critical Cue Type \times Target Side interaction. Given that participants needed to implicitly learn the cue meanings it might be expected that the Cue Type \times Target Side interaction would become more pronounced over the course of four blocks of trials. This lack of effect of Block may be due to the large number of trials (112) per block. Participants may have already implicitly learned the association between the cue and target location for the high predictive cues in the later stages of the first block. A finer grained analysis is not possible because, even with 28 trials per cue type (e.g., high predictive-left), in each block, there were only six trials per block that involved participants moving to the non-predicted location following the high predictive cue. Block did interact with Target Side in the trajectory area analysis and with Cue Type for the reaction time analysis. It is unclear what the theoretical relevance of these two-way interactions is because they do not modify the theoretically relevant Cue Type \times Target Side interaction. For reaction time, one possibility is that in the final block of trials there was a small inhibitory effect for the initiation of movement to the predicted side for the high predictive cue that did not manifest as a three-way interaction between block, cue, and side. However, there was only a 1-ms difference in average reaction time between movements to the predicted and non-predicted side for the high predictive cue in the final block of trials (419 ms and 420 ms, respectively). While speculative, it may be that by the end of the session participants were taking longer to react to the high predictive cues because of an increased interest in or processing of these relevant stimuli. Future work could include a longer exposure to the high predictive cues, which may reveal that participants would eventually become explicitly aware of the predictiveness of the cues.

The finding that the hand deviated away from the predicted location when aiming for the non-predicted side following a high predictive cue is consistent with the response activation model originally conceived using peripheral-onset cues (Neyedli & Welsh, 2011; Welsh & Elliott, 2004; Welsh, Neyedli & Tremblay, 2013). The symbolic cue may have led to the activation of the action associated with the predicted target location; however, given that long cue-target-onset asynchronies were used, this action was inhibited. This inhibition led to trajectories deviating away from the predicted target location when aiming for the non-predicted side and towards the non-predicted side when aiming for the predicted location (Fig. 3).

The time course of activation and inhibition may differ, however, between peripheral-onset cues and the central, symbolic cues used in the present study. At long cue-target-onset

asynchronies (1,100 ms) there was no significant difference between movement trajectories to cued compared to un-cued locations for peripheral-onset cues (Neyedli & Welsh, 2011). In the present study, long cue-target-onset asynchronies were used (1,000–2,200 ms) and inhibition-like effects were observed. It may be that the activation and inhibition processes associated with the symbolic cues are delayed in time given that greater interpretation of the symbolic cue may be necessary versus the stimulus driven nature of the peripheral-onset cues. Further, the present study did not include shorter cue-target-onset asynchronies because it was unclear whether participants would deviate toward or away from the predicted target location. Future work should include shorter cue-target-onset asynchronies to determine whether the hand would deviate towards the predicted location, so further comparisons can be drawn between the time courses for the two cue types, a suggestion that will be explored in further detail below. Another possibility for observing strategic activation of the predicted target location is to use a go-before-you-know paradigm, where the participant has to initiate the movement before they see the target location. Strong, strategic deviations to one target have been observed when selecting between two targets with no pre-cues during rapid movements in a go-before-you-know paradigm (Wong & Haith, 2017). A pre-cue, symbolic or otherwise, may bias participants to initially aim more often for the cued target location in a similar paradigm. Further, while it is unclear whether a strategic motor planning process would be conscious in nature, if participants were explicitly aware of the predictive nature of the cues, they may be more likely to deviate towards the predicted target location. Future research can examine these possibilities.

The current trajectory findings are also consistent with the inhibition-like effects observed with symbolic cues using a traditional key-press task (Lambert et al., 1999). One difference between the current study and Lambert et al. (1999) is the spatial location of the cue. In their task, the cue (a letter ‘S’ and ‘W’) would appear next to the potential target location, with the target appearing next to one letter the majority of time. This type of cueing is more similar to the global contextual cues seen in visual search tasks (e.g., Chun & Jiang, 1998) where the target appears next to the same stimuli over repeated trials. Thus, the location of the stimuli provides information about the location of the target. In contrast, the symbolic cues in the current study were presented centrally; the location of the cue did not indicate the upcoming target location nor did the location of the cue change across trials. Instead, participants implicitly learned to associate a particular shape with an upcoming target location.

Note that unlike previous work using both peripheral onset and symbolic cues, there were no theoretically relevant effects on reaction time (i.e., a cue type by target side interaction) in the current study. Lambert et al. (1999) observed a longer reaction time when the target appeared at the predicted

location compared to the non-predicted location at longer (600 ms) cue-target-onset asynchronies. This pattern of results is similar to inhibition-of-return (IOR)-like effects seen with peripheral-onset cues (Posner & Cohen, 1984; Klein 2000). One possible reason there was not a significant Cue Type \times Target Side interaction on reaction time was due to the loss of four participants' reaction time data due to a data-recording error. However, even with the full sample size it is unlikely the Cue \times Side interaction would have been significant due to the small effect size ($p=0.89$, $\eta^2=0.001$). Another reason for the lack of effect in reaction time may be that the previous studies used a simple keypress task rather than a more complex reaching movement. Presumably the reaching movement takes longer to plan, resulting in a longer reaction times across all conditions. Examining the trajectory deviations also may have provided a more sensitive measure of the cueing effect because trajectory information provides a richer data set for analysis. Further, reaction time data provides more insight into the detection processes whereas trajectories likely provide information on movement planning and execution.

IOR effects can be seen in both the reaction time (temporal) and the trajectory pattern (spatial) components of a reaching task in peripheral-onset cues (Neyedli & Welsh, 2011; Welsh, Neyedli & Tremblay, 2013). These previous findings, however, suggested that IOR effects for the temporal and spatial components of a reaching task follow different time courses. Specifically, inhibitory effects to the cued location occurred at shorter cue-target-onset asynchronies in reaction time (350 ms) compared to trajectory deviations (600 ms). This finding suggests that movement initiation and hand path planning and control can be dissociated, indicating that they may be controlled through separate processes. This dissociation may be one reason why trajectory effects were present in the current study but reaction time effects were not. It also suggests that symbolic cues may be processed differently than peripheral-onset cues where robust, inhibitory reaction time effects were observed.

As alluded to before, the potential temporal differences between cue types (central-symbolic vs. peripheral-onset) and the presence of IOR-like effects suggests future research should examine the effects of symbolic cues at varying cue-target-onset asynchronies. Long cue-target asynchronies were used for this initial work using symbolic cues with the motivation that the participant should have an extended period of time to look at the cue to ensure they had the opportunity to study and process the cue appearance. Now that it has been established that participants can implicitly associate a symbolic cue with an upcoming action target location, it would be interesting to see if the hand would deviate towards the cued location at very short cue-target-onset asynchronies (e.g., 100 ms); given that the hand deviates towards peripheral-onset cues (e.g., Welsh & Elliott, 2004, and Lambert et al., 1999, observed faster reaction times to the cued location at very

short cue-target-onset asynchronies for symbolic cues). It would also be interesting to determine if inhibition effects would occur at shorter cue-target-onset asynchronies (e.g., 600–750 ms) as seen with peripheral-onset cues.

Conclusion

The results of the study showed that participants implicitly associated a centrally presented, predictive symbolic cue with an upcoming target location; however, after the long cue-target asynchronies used in this study, the action to the predicted location was inhibited. There was no difference in trajectories between the predicted and non-predicted side when the cue predicted the target at near chance levels. These effects, however, were not observed in reaction time, therefore further research is needed using varying cue-target-onset asynchronies to explore the potential differences between reaction time and trajectory deviation effects.

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Open Practices The materials (stimuli, analysis scripts, etc.) for the experiments reported here are available upon request to the authors. The participants did not consent to having the data released so the data are not available. The experiment was not preregistered.

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