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**Preferential Reaching and End-State Comfort: How Task Demands Influence Motor
Planning**

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Abstract

Various factors (e.g., hand preference, object properties) constrain reach-to-grasp in hemispace. With object use, end-state comfort (ESC) has been shown to supersede the preferential use of one hand at the midline. To assess how location, size, and orientation of objects (dowel, mallet, cup) influence preferred-hand use and ESC (N=50; Mage = 20.83), three preferential reaching tasks were implemented. Object location influenced hand selection in all tasks, along with size (cups) and orientation (mallets). Object location and orientation influenced ESC, but only with dowels and mallets. When oriented away from the preferred hand in hemispace, there was a higher occurrence of non-preferred hand use to facilitate ESC. Overall, findings add to understanding of ESC and preferential reaching with varying task demands.

Keywords: Motor Planning; End-State Comfort; Preferential Reaching; Hand Selection; Hand Preference; Grasp Selection; Object Location; Object Orientation

Introduction

Human performance of complex, multi-articular tasks can be explained by ecological dynamics, where coordination and control are derived from the relationship between intentions, perceptions, and actions. This view of motor skill performance purports that the relationship between movement pattern stability (i.e., robustness of motor skills during disturbances/perturbations) and flexibility (i.e., ability to adapt) is continually constrained in a movement system (Araújo, Davids, & Passos, 2013; Davids et al., 2012; Seifert, Komar, Araújo, & Davids, 2016).

According to Gibson (1979), affordances are action opportunities based on individuals' perception of the environment; they are specified in a frame of reference unique to the action capabilities of each individual (Borghi & Riggio, 2015; Gibson, 1979; Lamb et al., 2017; Seifert, Komar, Araújo, & Davids, 2016). In reaching and grasping, coordination both between and within components of perception and action systems must be addressed (Kelso, 1995; Seifert, Komar, Araújo, & Davids, 2016). Movement selection is driven by the tendency to optimize certain criterion and exploit affordances within the environment, which minimizes the cost functions related to motor redundancy (Dounskaia & Shimansky, 2016) and provides flexibility of control (Dounskaia & Wang, 2014). Adaptive behaviours reflect flexibility to guarantee functional solutions to constraints, revealing stability against perturbations; stable movement systems are characterized by reproducible and consistent movement patterns over time (Seifert, Komar, Araújo, & Davids, 2016). Individuals exploit inherent affordances and task constraints in the movement system to achieve task goals (Seifert, Komar, Araújo, & Davids, 2016).

Hand selection during reaching tasks is a function of the level of control that can be attained by one hand compared to the other (Leconte & Fagard, 2006; Stins, Kadar, & Costall,

2001). According to the motor dominance hypothesis, if hand preference exists in motor planning and execution, then the preferred hand will be used to perform most unimanual tasks (Bryden et al., 1994; Scharoun, Scanlan, & Bryden, 2016). The preferred limb system achieves the most accuracy as a result of predictive control of limb and task dynamics (Pryzbyla et al., 2013; Sainburg, 2002); therefore, when both hands are in use, the preferred hand is chosen more often for precise control of movement and manipulation of an object, as the non-preferred hand is more adept at positioning.

When reaching into different regions of hemispace, the Kinesthetic Hypothesis outlines that biomechanical constraints on the preferred hand will lead to non-preferred hand use, especially in contralateral space, favouring proximity of the object and movement efficiency (Bryden & Huszcynski, 2011; Gabbard & Rabb, 2000; Rezae et al., 2010; Scharoun, Scanlan, & Bryden, 2016). The Kinesthetic Hypothesis, also referred to as the “comfort hypothesis” (Gabbard & Rabb, 2000, p. 181), argues that an individual does not necessarily consider an object’s location in hemispace, but will perceive the biomechanical constraints involved in the task to perform the task with the most efficient and comfortable response; the key factor for the Kinesthetic Hypothesis is that individuals will choose a movement based on their perception of the actions afforded to them, and choose the most efficient of those actions. (Gabbard & Rabb, 2000). Conversely, the Hemispheric Bias Hypothesis outlines the tendency for individual to use each hand in ipsilateral space in order to accommodate spatial compatibility (Bishop, Ross, Daniels, & Bright, 1996; Bryden & Huszcynski, 2011; Gabbard & Rabb, 2000; Leconte & Fagard, 2004; Scharoun, Scanlan, & Bryden, 2016). This bias reflects the ability of the hands to perform faster and more accurately in ipsilateral space; where each hand will perform better in its own region of hemispace (e.g., right hemispace-right hand, left hemispace- left hand). In

contralateral space, there is greater need for interhemispheric communication, which results in a loss of movement efficiency (Bryden & Roy, 2006; Gabbard & Rabb, 2000). Furthermore, reaching in ipsilateral space promotes optimal visual processing within a single visual hemifield (Leconte & Fagard, 2006). Both the Kinesthetic Hypothesis and the Hemispheric Bias Hypothesis are critical to understanding goal-oriented reaching tasks, as spatial information for reaching in hemispace is either driven by perceptions through the Kinesthetic Hypothesis or controlled through the Hemispheric Bias Hypothesis (Gabbard & Rabb, 2000).

The spatial location of the target object is a fundamental constraint on hand selection (Stins, Kadar, & Costall, 2001). Perihand space boundaries influence action planning and adjustments throughout the movement (Patane et al., 2018). In support of both the Kinesthetic and Hemispheric Bias Hypotheses, research has demonstrated the preferred hand is used almost exclusively in ipsilateral space, and less often in contralateral space (Bryden, Mayer, & Roy, 2011); there is a bias to use each hand in its own region of hemispace (i.e., ipsilateral space) where performance is both faster and more accurate than in contralateral space (i.e., reaching across the midline; Bryden & Roy, 2006; Coelho et al., 2013). A shift to the use of the non-preferred hand is demonstrated in contralateral space (Coelho et al., 2013; Helbig & Gabbard, 2013; Leconte & Fagard, 2004; Leconte & Fagard, 2006; Rezae et al., 2010; Scharoun, Scanlan, & Bryden, 2016). General findings have outlined that adults use the preferred hand most often in ipsilateral and midline reaches, although those with a strong right hand preference are likely to continue to use the preferred hand in contralateral space, despite the potential biomechanical inefficiencies (Bryden & Huszczynski, 2011; Mamolo et al., 2006).

When people demonstrate a strong hand preference, this hand tends to be used in a larger area in hemispace to accomplish a variety of tasks; when an individual is considered strongly

lateralized, they are highly consistent in their hand choice for tasks, while less strongly lateralized individuals are more likely to use their hands interchangeably to complete various tasks (Stins, Kadar, & Costall, 2001). Object characteristics also influence hand selection (Bryden, Mayer, & Roy, 2011). The use of tools has been shown to elicit greater preferred hand selection compared to objects that may be perceived as ecologically irrelevant, where the use of the tool leads to increases in preferred hand selection compared to grasping tasks (Bryden et al., 2011; Mamolo, Roy, Rohr, & Bryde, 2006; Scharoun, Scanlan, & Bryden, 2016). There is also an increase in preferred hand use when precision is needed for grasping and manipulation of the object, related to task complexity (Stone, Bryant, & Gonzalez, 2013). That said, people are more likely to choose the hand that matches the alignment of the object (for example, if the handle of a mug was oriented to the left, the individual would be more likely to choose their left hand) regardless of the starting position of the hands (Bryden & Huszczynski, 2011; Scharoun, Scanlan, & Bryden, 2016).

When manipulating the object is the goal, the movement is initiated in such a way that anticipates the future demands of that manipulation. The grasp used reflects planning for actions that contribute to aiming and precision (Herbort & Kunde, 2019; Rosenbaum & Sauerberger, 2019). First order planning involves consideration immediate task demands. In reach-to-grasp, this involves shaping grip aperture based on perceptual effects of object properties. The term *micro-affordance* has been used to describe how object characteristics (e.g., size, orientation) evoke a specific motor response (Ellis & Tucker, 2000). For example, Hermsdörfer and colleagues (2006) described the performance of individuals with apraxia to improve with actual tools compared to in pantomime, as “the affordances provided by the tool and the object may evoke a particular motor representation” (p. 1642).

Second-order planning, in comparison, includes consideration of both immediate and subsequent task demands, dependent upon task complexity and planning requirements (Rosenbaum et al., 2012). Second-order planning thus allows the individual to modify their behaviour in anticipation of secondary task demands (Rosenbaum et al., 2012; Scharoun, Gonzalez, Roy, & Bryden, 2018). According to the precision hypothesis, individuals favour grasps that promote end-state comfort, where having control at the end of the movement is critical, and assumes that the control requirements for placing an object are higher than those for grasping and/or lifting (Coelho, Studenka, & Rosenbaum, 2014; Herbort & Kunde, 2019; Rosenbaum et al., 1990; Rosenbaum et al., 1993; Rosenbaum & Sauerberger, 2019; Seegelke & Weigelt, 2018). The selected grasp for object manipulation is dependent upon the amount of control needed at various points throughout the movement; an object is typically grasped efficiently if control was needed at the beginning phase of the movement, and awkwardly if control is needed towards the end of the movement (Rosenbaum & Sauerberger, 2019).

From this perspective, it has also been argued that hand preference may be a malleable feature in movement control and may be less important compared to other performance variables, such as end-state comfort in grasping (Coelho, Studenka, & Rosenbaum, 2014). Support for this claim is derived from Coelho and colleagues (2014), who examined the bar-transport task in two conditions: (1) designated hand (left or right), with freedom to select initial grasp (overhand or underhand), and (2) designated initial grasp, with freedom to select hand. Participants prioritized ending in a comfortable position over using the preferred hand; therefore, indicating that end-state comfort was weighted as a greater constraint in action control. It is important to note that this research observed object manipulation at the midline.

Overall, it is understood that numerous factors influence the decision to select one hand (or the other) when reaching to grasp and manipulate objects in regions of hemispace (e.g., object location, object characteristics). Literature also reports that, when there exists an intention for use, objects are grasped in consideration of both immediate and secondary requirements, and thus result in a comfortable end-state posture. In such cases, the desire to end comfortably has been shown to supersede the preferential use of one hand. However, literature to date has generally examined the end-state comfort effect when object manipulation occurs at the midline. In such cases, object properties, such as size and orientation, often remain consistent (i.e., are not manipulated as a factor of inquiry). To garner additional insights regarding the interplay of hand preference and second-order planning when objects are located in different regions of hemispace, the current research assessed end-state comfort (i.e., trials where participants ended in a neutral posture that facilitates object use without further manipulation) and hand selection (i.e., preferred hand use within each task) within three preferential reaching tasks. Manipulations of object orientation (dowel/mallet handle) and size (cup) were included to garner a better understanding of how object properties and action intentions influence hand and grasp selection.

First, overturned cups were placed in five regions of hemispace; participants were asked to pick up a cup and pretend to pour water from a pitcher located at the midline. To examine the influence of object size, four sizes of cups were included. Subsequently, dowels (painted half black) and rubber mallets were placed in three regions of space; participants were required to: (1) pick-up and place a dowel on a tracing of the dowel at the midline, matching according to colour; and (2) pick-up a rubber mallet and hit a nail in a wooden block at the midline. To delineate whether orientation is influential, dowels and rubber mallets were oriented towards and away from, and to the left and right of the participant. Dependent measures included the proportion of

192 trials performed with preferred hand use and end-state comfort (i.e., ending a reach-to-grasp
193 movement in a neutral posture that facilitates object use without further manipulation).

194 It was hypothesized that a higher frequency of preferred hand selection would be displayed
195 in ipsilateral space and at the midline, but that the non-preferred hand would be used more often
196 in contralateral space; this hypothesis is in support of the kinesthetic hypothesis and hemispheric
197 bias hypothesis, where an individual is more likely to use each hand in their own region of
198 hemispace based on biomechanical constraints and spatial information (for example: Bryden &
199 Huszczynski, 2011; Gabbard & Rabb, 2000; Scharoun, Scanlan, & Bryden, 2016). It was also
200 hypothesized that participants would demonstrate end-state comfort regardless of object location,
201 size, or orientation; characterized by the finding that initial grasps would be uncomfortable or
202 awkward to facilitate comfortable end-state postures (for example: Herbot & Kunde, 2019;
203 Rosenbaum et al., 1990; Rosenbaum & Sauerberger, 2019; Seegelke & Weigelt, 2018). Finally,
204 it was expected that participants would prioritize a grasp that facilitated end-state comfort across
205 regions of space, over the decision to use the preferred hand (i.e., demonstrate end-state comfort,
206 albeit with the non-preferred hand). This hypothesis also supports the kinesthetic hypothesis
207 (Gabbard & Rabb, 2000), where an individual will use the non-preferred hand based on
208 perceived biomechanical inefficiencies (for example: Bryden & Huszczynski, 2011; Helbig &
209 Gabbard, 2013; Leconte & Fargard, 2006).

210 **Methods**

211 **Participants**

212 A convenience sample of 50 young adults between the ages of 18- and 26-years-old
213 (Mage = 20.83, SD = 1.78; 26 Female, 24 Male; 45 right-handers, 5 left-handers) from the
214 undergraduate and graduate student body agreed to participate. All participants were without any

known sensorimotor or cognitive impairments that may have influenced participation. To confirm eligibility, a statement regarding inclusion/exclusion criteria, which included a detailed list of disabilities and disorders that would disqualify the participant, was included in the information letter. Written informed consent was obtained, indicating that the participant: (a) was willing to participate in the research, and (b) permitted video recording.

Procedures

This research was reviewed and received ethics clearance from the University of Windsor research ethics board (REB#: 17-245). Data collection occurred in a laboratory space on the university campus. Participants were seated across from a researcher for the duration of data collection, which included a Waterloo Handedness Questionnaire (WHQ; Bryden, 1977), and a series of three preferential reaching tasks with overturned cups, dowels, and rubber mallets (Figure 2). The entire protocol lasted approximately 45 minutes. A video recorder was used to record performance within each individual task; videos were coded offline. Unfortunately, some of the video files were corrupted during file transfer; therefore, while all 50 participants completed the three tasks, we were unable to code all videos. The number of participants is stated in the data analysis section.

The WHQ asks participants to reflect on which hand they would use in a variety of unimanual tasks. The 20-item version was used in the current research. Response options include left always (-2), left usually, equal, right usually, and right always. Items are scored from -2 (left always) to +2 (right always), allowing for a total score (range: +/- 40) to be computed. It is expected that right-handers have positive scores, whereas left-handers have negative scores. Scores from the WHQ can also be used to identify the degree or strength of hand preference. For example, a score of +40 indicates a person strongly prefers the right hand; whereas a positive

score closer to zero, such as +4, indicates a weak right hand preference (Steenhuis & Bryden, 1989).

In the first preferential reaching task (Figure 1A), 5 overturned cups were placed in front of the participant at 0-, 45-, 90-, 135-, and 180-degrees (i.e., far left, near left, midline, near right, far right). Glasses were identical in size and shape, but differing in colour, to allow the researchers to refer to each cup by colour instead of location. A pitcher, with no handle, was located at the participant midline. Participants were asked to pick up a designated cup and demonstrate the action of pouring into the cup with the pitcher. To prevent instructions from guiding performance, nothing else was specified. It is important to note that the overturned glass task has revealed consistent results when implemented both with (Scharoun & Bryden, 2014) and without water (i.e., as if to pour water, e.g., Scharoun, Gonzalez, et al., 2016). Participants complete three trials with four cup sizes (4.7cm, 6.2cm, 7.2cm, and 8.4cm diameter; Figure 2), for a total of 60 trials. Trials were blocked by cup size; however, locations were randomized. Dependent measures included the proportion of trials with preferred hand selection and end-state comfort (i.e., ended the movement with a thumb-up grasp, with the wrist in a neutral position, and the cup reoriented for use).

[Insert Figure 1 about here]

[Insert Figure 2 about here]

In subsequent preferential reaching tasks (Figure 1B/C), objects (i.e., dowels painted half black or rubber mallets) were placed in front of the participant at 0-, 90-, and 180-degrees (i.e., left, midline, right). Objects were identical in size and shape, but each had a coloured band to allow the researchers to refer to each by colour instead of location. Participants were asked to pick up a dowel and place it on a designated location, such that the orientation of the dowel

matched a tracing of the dowel at the participants midline. Likewise, participants were asked to pick up a mallet and hit a nail in a wooden block at the midline using the black side of the mallet head. In both tasks, nothing else was specified, to prevent instructions from guiding performance. Participants completed three trials of each task with four orientations (black end of dowel/ mallet handle: towards, left, away, and right) for a total of 48 trials/task. Trials were blocked by handle orientation; however, the locations were randomized. Dependent measures included the proportion of trials with preferred hand selection and end-state comfort (i.e., ended the movement with the wrist in a neutral position to place the dowel or hit the nail).

Data Analysis

SPSS© statistical software (version 25) was used for data analyses. For the preferential reaching task with overturned cups, the two dependent measures (1: proportion of trials with preferred hand selection; and 2: proportion of trials with end-state comfort) were submitted to a location (5: far right, near right, midline, near left, far left) by cup size (4: 4.7cm, 6.2cm, 7.2cm, 8.4cm diameter) within-subject analysis of variance test with repeated measures. The Bonferroni correction was used for multiple comparisons. Data from 46 participants (Table 1) were included in analysis, 5 of whom (i.e., 10.87%) were left-handed (WHQ score = -25.80, SD = 7.56) and the remaining 41 right-handed (WHQ score = 27.07, SD = 7.04). Although representative of the general population, as right- and left-handed samples were not comparable in size, hand preference was not included as a between subjects' factor; therefore, separate analyses of the proportion of trials with preferred hand selection were performed for right- and left-handers. All participants were included in analysis of end-state comfort.

[Insert Table 1 about here]

Preferential reaching tasks with dowels and rubber mallets were analyzed separately. For both tasks the two dependent measures (1: proportion of trials with preferred hand selection; and 2: proportion of trials with end-state comfort) were submitted to a location (3: right, midline, left) by handle orientation (4: towards participant, left, away from participant, right) within-subject analysis of variance test with repeated measures. The Bonferroni correction was used for multiple comparisons. As the task was inherently different for left-handers, due to the orientation of the objects, only data from 43 right-handed participants ($M_{\text{age}} = 20.68$, $SD = 1.62$; 23 Female, 20 Male; WHQ Score = 27.47, $SD = 6.93$) were analyzed.

Results

Proportion of trials with preferred hand selection.

Overtured cups. Analysis of right-handed participants revealed a significant interaction between size and location ($F(12, 480) = 2.740$, $p = .001$, $\eta^2_p = .064$; Figure 3). Pairwise comparisons with a Bonferroni correction revealed that, for all cup sizes, there was no difference in preferred (i.e., right) hand selection in near and far locations (both right and left); however, all other locations were significantly different. In far right space, less preferred hand selection was displayed with the 6.2cm cup compared to the 7.2cm cup. In far left space, less preferred hand selection was seen with the 6.2 cup compared to the 8.4cm cup. Finally, at the midline, significantly less preferred hand selection was demonstrated with the 7.2cm cup compared to the 4.7cm and 8.4 cm cups. The main effect of location ($F(4, 160) = 141.145$, $p < .001$, $\eta^2_p = .779$; Figure 4) was consistent with the interaction. The effect of size was not significant ($F(3, 120) = 2.422$, $p = .069$, $\eta^2_p = .057$). Analysis of left-handed participants identified a main effect of location ($F(4, 16) = 14.035$, $p < .001$, $\eta^2_p = .778$; Figure 4); however, when adjusted for multiple comparisons using a Bonferroni correction, no differences were identified ($p > .05$). Neither the

effect of size ($F(3, 12) = 1.400, p = .291, \eta^2_p = .259$) nor interaction between location and size ($F(12, 48) = 1.391, p = .203, \eta^2_p = .258$) were significant.

[Insert Figure 3 about here]

[Insert Figure 4 about here]

Dowels. A significant effect of location ($F(2, 86) = 80.687, p < .001, \eta^2_p = .652$) revealed significantly greater preferred-hand (i.e., right-hand) selection in right-space ($M = 2.824, SE = 0.050$) compared to the midline ($M = 2.449, SE = 0.111$) and left-space ($M = 1.063, SE = 0.152$). The effect of orientation ($F(3, 129) = 2.381, p = .073, \eta^2_p = .052$) and interaction between orientation and location ($F(6, 258) = .300, p = .936, \eta^2_p = .007$) were not significant.

Rubber Mallets. The interaction between location and orientation was significant ($F(6, 258) = 19.654, p < .001, \eta^2_p = .319$; Figure 5), along with main effects of location ($F(2, 86) = 35.885, p < .001, \eta^2_p = .461$) and orientation ($F(3, 129) = 36.975, p < .001, \eta^2_p = .468$). In left-space, there was greater preferred-hand selection when the handle was oriented to the right and away from the participant, compared to when it was oriented to the left and towards the participant ($p < .001$). At the midline and in right-space, the frequency of preferred-hand selection was lowest when the handle was oriented to the left compared to all other orientations ($p < .001$). Also, in right-space, when the handle was oriented away from the participant, less preferred-hand selection was demonstrated compared to when oriented towards and to the right of the participant ($p = .024$). When the handle was oriented towards the participant, to the left or right, significantly less preferred-hand selection was demonstrated in left-space compared to the midline and right-space ($p < .05$). When the handle was oriented away from the participant, the frequency of preferred-hand selection was lower in left-space compared to right-space ($p = .041$). Overall, the frequency of preferred-hand selection was highest in right-space compared to the

midline and left-space ($p < .003$); likewise, when the handle was oriented to the right and away from the participant, compared to when oriented towards ($p < .001$) and to the left ($p < .001$).

[Insert Figure 5 about here]

Proportion of trials with end-state comfort

Overtured cups. Neither the interaction between size and location ($F(12, 528) = 1.342$, $p = .190$, $\eta^2_p = .030$), nor the main effects of size ($F(3, 132) = .702$, $p = .552$, $\eta^2_p = .016$) and location ($F(4, 176) = 1.630$, $p = .169$, $\eta^2_p = .036$) were significant. It is important to note that the frequency of end-state comfort was quite low in all regions of space (far right: $M = 1.01$, $SE = 0.17$, near right: $M = 1.04$, $SE = 0.17$, midline: $M = 1.12$, $SE = 0.17$, near left: $M = 1.11$, $SE = 0.17$, and far left: $M = 1.12$, $SE = 0.17$) compared to previous reports (e.g., Scharoun, Gonzalez, et al., 2016).

Dowels. The interaction between orientation and location ($F(6, 252) = 20.554$, $p < .001$, $\eta^2_p = .329$; Figure 6) and main effect of orientation ($F(3, 126) = 61.661$, $p < .001$, $\eta^2_p = .595$) were significant; however, the effect of location was not ($F(2, 84) = .437$, $p = .647$, $\eta^2_p = .010$). Overall, there was significantly more end-state comfort when the black end of the dowel was oriented towards and to the right of the participant compared to when it was oriented away ($p < .001$), and in all orientations when compared to the left ($p < .001$). In left space, there was significantly more ESC displayed when oriented to the right and away from the participant (which did not differ) compared to towards ($p < .05$), and in all orientations compared to when oriented to the left ($p < .001$). At the midline and in right space, the number of trials with ESC was greater when oriented towards and to the right of the participant (which did not differ) compared to when oriented away and to the left ($p < .001$). In right space, there was no difference when oriented away and to the left of the participant; however, at the midline, more

ESC was displayed when oriented away ($p < .001$). When oriented towards the participant, significantly more ESC was demonstrated in right space compared to the midline ($p = .009$) and left space ($p < .001$). When oriented to the right, significantly more ESC was displayed in right compared to left space ($p = .044$). When oriented away from the participant, significantly more ESC was demonstrated in left space compared to the midline and right space ($p < .001$), and at the midline compared to right space ($p = .001$).

[Insert Figure 6 about here]

Rubber Mallets. A significant interaction between orientation and location was revealed ($F(6, 252) = 7.038, p < .001, \eta^2_p = .144$; Figure 7), alongside a main effect of orientation ($F(3, 126) = 24.823, p < .001, \eta^2_p = .371$). Overall, significantly more ESC was displayed when the handle was oriented towards or to the right (which did not differ) compared to away from and to the left of the participant ($p < .001$; which did not differ). This was true regardless of the region of space ($p < .05$). When the handle was oriented to the right, significantly more ESC was demonstrated at the midline and in right space compared to left space ($p = .021$). When the handle was oriented away from the participant, significantly more ESC was displayed in left space compared to the midline and right space ($p < .001$). The main effect of location came up short of the cut off for statistical significance ($F(2, 84) = 3.018, p = .054, \eta^2_p = .067$).

[Insert Figure 7 about here]

Discussion

The current study assessed end-state comfort and preferred hand selection within three preferential reaching tasks; specifically, to examine reaching patterns related to object location, movement context, and task demands. Three main predictions were made: first, that use of the preferred hand would occur more often at midline and ipsilateral hemispace, and the non-

preferred hand more often in contralateral space, in support of the kinesthetic hypothesis and the hemispheric bias hypothesis, wherein the participant will use their preferred hand based on perceptions of spatial affordances and biomechanical constraints (Bryden & Huszczynski, 2011; Gabbard & Rabb, 2000; Scharoun, Scanlan, & Bryden, 2016). Such behaviours were considered important, as this study examined reaching from three perspectives: a bimanual reaching task (the overturned cups), a rotation task (the dowels), and a tool-based task (the rubber mallets); these tasks were chosen as progression through the different tests increased the demand on the use of the hands, which has been shown to elicit stronger hand preference ratings (Bryden, Mayer, & Roy, 2011; Scharoun, Scanlan, & Bryden, 2016). Second, it was hypothesized that participants would demonstrate ESC regardless of object location, orientation, or size; initial grasping behaviours typically reflect the anticipation of future demands of the manipulation (Herbort & Kunde, 2019; Rosenbaum & Saurberger, 2019). These demands favour end-state comfort when there is increased precision necessary within the movement, and assumes that the control requirements during these stages are higher than the requirements for grasping and/or lifting of the object (Herbort & Kunde, 2019). Finally, it was hypothesized that ESC would be prioritized higher than hand selection (Coelho et al., 2014), further supporting approaches to motor control and reaching in hemispace based on the kinesthetic hypothesis (Gabbard & Rabb, 2000). To allow for specific discussion, the following section will discuss the overturned cup task separately from the dowel and mallet tasks, followed by a general discussion.

Overturned Cups

Previous evidence for reaching and grasping during unimanual tasks in right-handed individuals demonstrated a preference for the right hand when picking up objects at the midline and in ipsilateral space, with increased likelihood of using the preferred hand in contralateral

space according to increases in task complexity (e.g., Bishop et al., 1996; Bryden and Roy, 2006; Mamolo et al., 2004, 2006; Scharoun, Scanlan, & Bryden, 2016). Results from the overturned cup task provide further evidence in support of hand selection based on object location in hemispace and task complexity.

Contradictory to previous research assessing ESC, which has demonstrated consistent patterns of ESC planning in the overturned cup task (e.g., Scharoun Benson et al., 2018), this pick-up and pour task with overturned cups demonstrated lower prevalence of ESC. There was a greater tendency for participants to assume a comfortable grasp at the beginning of the movement (e.g., hand covering the bottom of the cup; pinch between the thumb and first finger, and/or thumb and first two fingers) and complete the movement with the wrist in an awkward, supinated position. Fuelscher et al. (2016) found that there is a greater tendency for participants to adopt initial grasps that facilitate ESC when movements were simple (one-step) compared to more complex movements. As the cups task represented a multi-step movement, the results of the current study support the finding that lower ESC may be observed (Fuelscher et al., 2016).

In the current study, the jug was not filled with water and participants were not required to pour water into the cups, rather to mimic pouring and then return the cup to the overturned position; completion of the task did not necessitate the consideration of ESC during the pouring action (e.g., with the wrist in a neutral position), as the cup was being returned to the original position at the end of the movement. This could be further explained by the quasi-pantomime nature of the pick and pour task; pantomime tasks require greater cognitive processing, where an individual relies on their mental representation of the action throughout the movement (Bhoryoo et al., 2020; Fuelscher et al., 2016; Scharoun, Gonzalez, Roy, & Bryden, 2018; Stöckel &

Hughes, 2016). By removing the actual water from the movement, participants are using increased working memory to mimic manipulation of the jug and cups throughout the task.

The current results support the finding that individuals tend to grasp objects based on the intended action; where bimanual performance is constrained by the intended goal states (Seegelke & Weigelt, 2018). The participants grasped the cups based on the intention to return the cup to an overturned position, rather than the pouring action that was analyzed. There was a division of labour between the hands; the more an individual uses their preferred hand for manipulation and grasping tasks, the more they use the non-preferred hand for stabilization during those tasks (Coelho et al., 2013; Guiard, 1987; Pryzbyla et al., 2013; Scharoun, Scanlan, & Bryden, 2016; Stone, Bryant, & Gonzalez, 2013). Participants in the current study were required to manipulate the pitcher and cup by mimicking a pouring action with the empty jug. The movement required third-order planning (i.e., pick-up, pour, place) in order to accurately perform the task of holding the pitcher with one hand, picking up and supporting the cup with the other, and then returning the cup to an overturned position. It was expected that this task would represent second-order planning of movements (i.e., pick-up, pour), however, as participants were not required to pour water into the cup, the mimicking task influenced the initial grasp of the overturned cup. While the expected second-order planning allows the individual to plan behaviours based on the secondary task demands, participants in this study unexpectedly planned movement based on the tertiary demands of the movement (replacing the cup after the pouring action; see also Rosenbaum et al., 2012; Scharoun, Scanlan, & Bryden, 2016).

Dowels and Rubber Mallets

As expected, examination of hand selection and location in the dowel task revealed data that are congruent with previous research findings. The dowel task represented a pick-up and

place task combined with a rotation task, characterized by the need to rotate the dowel to ensure proper placement on the place marker. When the black end of the dowel was oriented opposite the place marker, participants adopted creative grasp and rotation solutions in order to assume ESC. Both the dowel and mallets task results are consistent with the finding that when engaged in object rotation tasks, participants will employ motor imagery techniques to mentally represent the movement to be completed and generate a forward model of the action (Barhoun et al., 2019)

During both the mallet and dowel tasks, the ending position with ESC (placing the dowel or hitting the nail) resulted in adopting a relatively similar neutral wrist position. This finding is consistent with previous research which details that an individual demonstrates more ESC when using the tool or object to complete a task (Bryden, Mayer, & Roy, 2011; Mamolo et al., 2006; Scharoun, Scanlan & Bryden, 2016). Interestingly, the dowel task required further exploitation of affordances than both the cups and the mallet tasks to account for rotation of the dowel to place it appropriately with ESC (e.g., Barhoun et al., 2019). This finding is consistent with Herbort and Kunde (2019), who found that when ESC was considered by participants there were improved object translations, rotations, manipulation times, and movement errors throughout the execution of the action.

As with previous research, object orientation influenced hand selection regardless of object location in hemispace (Bryden & Huszczynski, 2011; Chan & Hoffman, 2012; Scharoun, Scanlan, & Bryden, 2016). The mallet task in the current study provides supporting evidence for this trend in reaching and grasping literature. When the handle of the mallet was oriented away from the participants' preferred hand (in left hemispace and handle oriented away and to the left) the participant was more likely to use their non-preferred hand to reach for, and use the mallet to hit the nail. In this task, participants were also less likely to demonstrate ESC when they used

their non-preferred (left) hand. The combination of object orientation and hand selection with ESC demonstrates a combined influence of preference and comfort in tasks that require a use condition after reaching and grasping. Furthermore, the mallet task, in particular, supported previous findings that reaching behaviours differed when affordances for action were detected by the participants (Scharoun Benson, Bryden, & Roy, 2019; Scharoun Benson, Roy, & Bryden, 2018); mallets had clear handles that participants could afford a grasp to in order to hit the nail with the rubber head of the mallet, while the cups and dowels did not have handles or other markers that afforded a specific use (the coloured ends of the dowels were used to plan rotations to hit the target, neither end had a specific use).

Compared to the overturned cup task, the dowel and mallet data demonstrated support for previous research on preferential reaching and use of tools; when presented with a specific task, the use of tools is likely to elicit greater use of the preferred hand, overriding the potential biomechanical inefficiencies of reaching into contralateral space (Bryden, Mayer, & Roy, 2011; Scharoun, Scanlan, & Bryden, 2016).

General Discussion

In the proportion of trials related to hand selection and preferential reaching (a reach and grasp task), the data support the Kinesthetic Hypothesis, where object proximity and movement efficiency are taken into account when planning movements (Gabbard & Helbig, 2004). Participants were not asked to grasp any of the cups, dowels, or mallets in specific ways for the reach and grasp tasks; however, participants grasped the objects in ways that were congruent with previous research on reaching and grasping in hemispace. Reaches at the midline and in ipsilateral space were performed more often by the preferred hand, where reaches in contralateral space were performed more often by the non-preferred hand (Bryden & Huszczynski, 2011;

Bryden, Mayer, & Roy, 2011; Leconte & Fagard, 2004; Leconte & Fagard, 2006; Rezae et al., 2010).

Grasp selection for object manipulation combines habitual and goal-directed processing, where the habitual system demonstrates a stronger influence on grasp selection; motor planning for grasping tasks is most necessary when performing the movement for the first time, after which the individual is likely to use recall of motor plans in the habitual system to perform the task (Herbort, Mathew, & Kunde, 2016). The current study further demonstrates the importance of object location when determining hand selection in preferential reaching tasks; demonstrating increased use of the non-preferred hand in contralateral space in reach and grasp tasks (Bryden & Huszczynski, 2011; Bryden, Mayer, & Roy, 2011; Bryden, Pryde, & Roy, 2000; Calvert & Bishop, 1998; Mamolo, Roy, Rohr, & Bryden, 2006).

Task demands have been identified as a contributing factor to reaching preferences, where the greater the demand, the greater the likelihood of use of the preferred hand, even in contralateral space (Bryden, Mayer, & Roy, 2011; Cohelho, Studenka, & Rosenbaum, 2014; Steenhuis & Bryden, 1999; Scharoun, Scanlan, & Bryden, 2016). The intended action influences how objects are handled, while the grasp posture at the onset of the movement can help to determine how far in advance actions are planned (Scharoun, Gonzalez, Roy, & Bryden, 2018).

In summary, the present study provides additional support for reaching and grasping literature for unimanual tasks, where individuals will use their preferred hand more often in contralateral space according to task demands and despite the potential biomechanical inefficiencies. This study furthers existing literature on ESC in the dowel and mallet tasks through evidence of increased use of the non-preferred hand according to object orientation; participants used their non-preferred hand more readily when the handle was oriented away from

the preferred hand, promoting biomechanical efficiency with grasping for these tasks. Finally, the participants in this study demonstrated stronger evidence for third-order planning, compared to second-order planning in the cup task. This is likely attributed to task complexity and demands, where returning the objects to the start position was likely considered in the motor planning phase. Hand selection for grasping and manipulation is a variable and task dependent phenomenon; the task end-goal, task demands, biomechanical efficiency, and object location and orientation in hemispace influence preferential reaching and grasping behaviours (Helbig & Gabbard, 2013; Gonzalez, Flindall, & Stone, 2015). Together, the findings from the present study add to the reaching and grasping literature with a consideration for ESC, and provide further evidence for the influence of task demands on motor planning and execution in both unimanual and bimanual tasks. It is, however, important to note that this study did include a small number of left-handed participants, which is a clear limitation of this work. Future work assessing the performance of left-handed participants is recommended.

Disclosure Statement

The authors have no conflict of interest to disclose.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author (SMSB), upon reasonable request.

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700

Table

	Mean Age (SD)	Sex (Female:Male)	Mean WHQ (SD)
Total ($N = 46$)	20.83 (1.86)	26:20	21.33 (18.06)
Right-handers ($n = 41$)	20.78 (1.82)	24:17	27.07 (7.04)
Left-handers ($n = 5$)	21.25 (2.50)	2:3	-25.80 (7.56)

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702

703

Table Caption

704

Table 1. Participant demographics for preferential reaching task with overturned cups

705

706

Figures

Figure 1

Figure 2

Height (cm)	5.2	5.9	6.5	7.0
Diameter (cm)	4.7	6.2	7.2	8.4

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure Captions

Figure 1. Study set up with: (A) Overturned cups, (B) Dowels, and (C) Rubber Mallets

Figure 2. Cup dimensions

Figure 3. Analysis of right-handers revealed a significant interaction between location and cup size in analysis of preferred-hand selection with the overturned cups. Standard error bars are displayed.

Figure 4. A main effect of location was revealed for both left- and right-handers in analysis of preferred-hand selection with the overturned cups. Standard error bars are displayed.

Figure 5. Analysis of right-handers revealed a significant interaction between location and orientation in analysis of preferred-hand selection with the rubber mallets. Standard error bars are displayed.

Figure 6. Distinct differences in the frequency of trials with ESC were demonstrated in the interaction between orientation and location. Standard error bars are displayed.

Figure 7. Regardless of location, significantly more ESC was displayed when the handle was oriented towards or to the right compared to away from and to the left of the participant. Standard error bars are displayed.