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The influence of action execution on end-state comfort and underlying movement kinematics: An examination of right and left handed participants

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ABSTRACT

People typically move in an anticipatory manner, planning the intended action in advance to minimize the energy costs associated with producing the action (e.g., Rosenbaum et al., 2009). This is exemplified behaviorally in the end-state comfort effect, which is characterized by the selection of an uncomfortable initial posture to enable a comfortable posture upon completion of the movement (Rosenbaum et al., 1990). The main objective of this study was to further investigate the end-state comfort effect in left- and right-handers ($N = 20$). More specifically, to: (a) understand the influence of mode of action execution; and (b) delineate the role of handedness. The overturned glass task (Fischman, 1997) was used as means of assessment, where participants were asked to demonstrate picking up a glass to pour water in four modes of execution: (1) pantomime without a stimulus; (2) pantomime with image of the glass as a guide; (3) pantomime with glass as a guide; and (4) grasping the glass. End-state comfort was displayed regardless of mode of execution, hand used to complete the task or handedness group. However, kinematic analysis revealed distinct differences, highlighting how movement parameters are altered as a result the mode of action execution.

1. Introduction

Reaching for a glass to pour a drink of water may seem like a simple task. However, goal-directed movements are complex in nature as they involve a series of processing events (e.g., Elliott, Helsen, & Chua, 2001; Elliott et al., 2010). As an almost infinite number of movement options are available to complete any given task, of particular interest is how an individual plans and executes such movements in a specific way. The goal of this study was to investigate how left- and right-handers plan and control reach-to-grasp movements to an upright or overturned glass within four modes of execution: pantomime without a stimulus, pantomime with image or glass as a guide, and actual grasping.

A single goal-directed action generally proceeds with two-components (Woodworth, 1899): an initial adjustment phase, and a current control phase. However, the overall movement can be separated into a series of processing events (Elliott et al., 2001; Elliott et al., 2010). Prior to the signal to move exists a planning period, including processes specific to the goal of the actor and their environment (Elliott et al., 2010; Glover, 2004). It is generally understood that individuals reach for objects in an anticipatory manner, planning the intended action in advance to minimize the energy costs associated with producing the movement (e.g., Rosenbaum et al., 2009). Rosenbaum, Meulenbroek, Vaughan, and Jansen (2001) describe motor planning in light of Bernstein's (1967) degrees of freedom problem, such that the actor implicitly orders internal representations in a constraint hierarchy to plan a goal posture which offers the most cost-efficient movement. Cost-efficiency in grasp selection is determined by control; therefore, hand postures are planned by deriving a total cost from the weighted sum of movement velocity and endpoint variability (Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012). With practice, the performer gradually adjusts to refine their movement strategy. If a motor plan ends up costing the motor system, postures are re-assessed for future movement (Rosenbaum et al., 2001; Rosenbaum, Meulenbroek, & Vaughan, 2001; Rosenbaum et al., 2009), improving feed-forward processes to meet the necessary afferent and efferent requirements of the task (Elliott et al., 2010).

The ability to perform in such a way is dependent on the ability to perceive an object (or tool) according to its physical features and act upon it (Tucker & Ellis, 1998). The importance of this link is exemplified clinically in apraxia, a neurological disorder of skilled movement that cannot be explained by an underlying deficit in basic sensorimotor functions, verbal comprehension, or object recognition (Roy, Black, Stamenova, Herbert & Gonzalez, 2014). One factor in understanding deficits in apraxia relates to the modality, or mode of action execution.

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As demonstrated by Randerath, Goldenberg, Spijkers, Li, and Hermsdörfer (2011), accuracy of tool use performance of individuals with apraxia improves with more contextual information (pantomime, to movement with a tool, to movement with tool and object).

In light of these findings, and others (see Baumard, Osiurak, Lesourd, & Le Gall, 2014 for a review of tool use after left brain damage), it is argued that pantomime (i.e., performing an action associated with a tool without the use of the object) may serve to convey semantic information about an action, such that individuals are required to form and maintain a mental representation of the tool and action until the gesture is performed. In comparison, actual tool use reduces the cost on the working memory system, while also decreasing the degrees of freedom and likelihood of error (e.g., Baumard et al., 2014; Roy & Hall, 1992). As such, semantic tool information is only activated in a task when there is an intention to use the tool (e.g., Randerath, Li, Goldenberg, & Hermsdörfer, 2009; Roy & Hall, 1992; Roy et al., 2000). Spatial and temporal features of the movement are thus different when comparing pantomime and actual tool use in individuals with apraxia and healthy controls (e.g., Hermsdörfer, Hentze, & Goldenberg, 2006). More specifically, pantomime is characterized by less time to peak velocity, more time after peak velocity and higher peak velocity compared to actual tool use (Clark et al., 1994; Heath, Westwood, Roy, & Young, 2002; Hermsdörfer et al., 2006; Hermsdörfer, Li, Randerath, Goldenberg, & Eidenmüller, 2011).

The current study sought to further explore how the mode of execution influences reach-to-grasp movements with regards to the *end-state comfort effect* (Rosenbaum et al., 1990; see Rosenbaum et al., 2012 for a review). End-state comfort is characterized by the selection of an uncomfortable initial posture to enable a comfortable posture upon completion of the movement (Rosenbaum et al., 1990). For example, when asked to pick up an overturned glass, people are likely to assume an uncomfortable, thumb-down posture at the start of their movement to allow for a comfortable, thumb-up end-state posture, in which the glass is re-oriented for use. The *overturned glass task* (Fischman, 1997) was used as means of assessment in the current study.

In Fischman's (1997) original study, participants poured water in "glass held" (i.e., pickup overturned glass and measuring cup and pour), and "glass down" (i.e., pickup overturned glass, set it down, pick up measuring cup and pour) conditions. End-state comfort was evident when participants assumed an uncomfortable thumb-down grasp to start the movement, allowing for a comfortable thumb-up grasp at the end of the movement. Sensitivity to end-state comfort was seen in 48 of 53 participants in the "glass held", and 50 of 53 participants in the "glass down" condition. When the task allowed participants to set down the glass, 30 of 50 used the same hand to pick up the glass, and subsequently pick up the pitcher to pour water. When required to hold the glass, 39 of 50 used the same hand to pick up the glass as the "glass down" condition leaving the other hand to pick up the pitcher. Participants were sensitive to end-state comfort and also displayed a preference for performing with a particular hand (Fischman, 1997).

The notion that hand preference influences motor planning and control processes is prevalent in the literature. According to the *dynamic dominance hypothesis* (e.g., Sainburg, 2002, 2005), each hand is specialized for specific aspects of control. The preferred hand of right-handers is superior for precise control of limb dynamics and reliant on feedforward control (e.g., Wang & Sainburg, 2007). As such, higher peak velocities (Annett, Annett, Hudson, & Turner, 1979; Boulinguez, Nougier, & Velay, 2001; Heath & Roy, 2000), less error in the initial acceleration phase (Roy & Elliott, 1989), a shorter corrective period (Lavrysen, Elliott, Buekers, Feys, & Helsen, 2007; Roy, Kalbfleisch, & Elliott, 1994), better accuracy, and an overall shorter movement time (Annett et al., 1979; Elliott et al., 1993; Roy & Elliott, 1989) have been noted for the preferred hand. In comparison, the non-preferred hand is more adept at positional control and requires feedback control (e.g., Wang & Sainburg, 2007). The non-preferred-hand thus displays a planning advantage, evident in faster reaction time and shorter time to peak velocity (e.g., Roy et al., 1994).

A recent study (Lavrysen et al., 2012) investigated if left-handers also display preferred hand (i.e., left-hand) advantages. Similar to right-handers, peak velocity was reached earlier when moving with the left-hand (Lavrysen et al., 2012), thus suggesting results are independent of hand preference (Lavrysen et al., 2012). It has been suggested that the two hemisphere/limb systems are differentially specialized for complementary aspects of movement (Wang & Sainburg, 2007), where left handers and right handers display mirrored patterns of interlimb transfer; however differences between the limbs in smaller for left handers (Wang & Sainburg, 2006; Przybyla, Good, & Sainburg, 2012).

If a preference for one hand is evident from a kinematic perspective, it is logical to consider that differences may also exist behaviorally in motor planning; specifically, with respect to the end-state comfort effect. Between-hand differences have been investigated in both bimanual and unimanual tasks. Bimanual task assess whether symmetry or end-state comfort take precedence when manipulating one object with each hand (e.g., Hughes & Franz, 2008; Janssen, Beuting, Meulenbroek, & Steenbergen, 2009; van der well & Rosenbaum, 2010). In congruent trials, both are observed; however for incongruent trials sensitivity to end-state comfort has been shown to remain (Weigelt, Kunde, & Prinz, 2006), decrease (Janssen et al., 2009) be absent (Hughes & Franz, 2008), or favor a changing preference (van der Well & Rosenbaum, 2010). Janssen et al. (2009) and Janssen, Meulenbroek, and Steenbergen (2011) observed end-state comfort was present more often for the right hand in both right and left handers and therefore suggested that motor planning may be under left hemisphere control. This was in contrast to Weigelt et al. (2006), who noted both hands of right handers were sensitive to end-state comfort. Hughes, Reißig, and Seegelke (2011) also demonstrated that hand preference and the hand used to complete the task do not influence end-state comfort.

Similar findings were reported by Herbort and Butz (2011) and Coelho, Studenka, and Rosenbaum (2013) in unimanual tasks, where right handed participants completed the overturned glass task (Herbort & Butz, 2011) and bar transport task (Coelho et al., 2013). Herbort and Butz (2011) had participants complete the task with both hands. In comparison, Coelho et al. (2013) either specified the hand/grasp to use or enabled participants to select which hand/grasp to use, depending on the experiment. In all cases grasps that afforded end-state comfort were maintained (Coelho et al., 2013; Herbort & Butz, 2011). In a follow-up experiment, Coelho et al. (2013) asked participants to rate the comfort of each grasp, where hand-grasp combinations which afforded end-state comfort were identified as the most comfortable.

It is likely that the conflicting results can be attributed to differences in the tasks. As highlighted by Herbort and Butz (2011), an everyday task such as the overturned glass may involve little online planning (e.g., McCarty, Clifton, & Collard, 1999). Children begin to drink from cups from 8- to 20-months, where lids are typically removed by the second birthday (Carruth & Skinner, 2002). This task can therefore be considered over learned, to the point of being a habitual behavior (Herbort & Butz, 2011). Although bar-transport, for example is not a habitual movement, it is possible that the task also requires little online control, whereas tasks with uncommon grasps, such as the one used by Janssen et al. (e.g., Janssen et al., 2009, 2011) involve more extensive motor planning.

The current study aimed to extend the previous literature to examine whether differences in pantomime and actual tool use in healthy left and right handers would be evident in everyday object manipulation, within a commonly used end-state comfort paradigm (i.e., overturned glass task). Summarizing then, the main objective of this study was to analyze the effects of action execution and hand preference upon movement kinematics and sensitivity to end-state comfort