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Problems in planning bimanually incongruent grasp postures relate to simultaneous response specification processes

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ABSTRACT

The purpose of the current experiments was to examine whether the problems associated with grasp posture planning during bimanually incongruent movements are due to crosstalk at the motor programming level. Participants performed a grasping and placing task in which they grasped two objects from a table and placed them onto a board to targets that required identical (congruent) or non-identical degrees of rotation (incongruent). The interval between the presentation of the first stimulus and the second stimulus (stimulus onset asynchrony: SOA) was manipulated. Results demonstrate that the problems associated with bimanually incongruent grasp posture planning are reduced at SOA durations longer than 1000 ms, indicating that the costs associated with bimanual incongruent movements arise from crosstalk at the motor programming level. In addition, reach-to-grasp times were shorter, and interlimb limb coupling was higher, for congruent, compared to incongruent, object end-orientation conditions in both Experiment 1 and 2. The bimanual interference observed during reach-to-grasp execution is postulated to arise from limitations in the visual motor system or from conceptual language representations. The present results emphasize that bimanual interference arises from constraints active at multiple levels of the neurobiological–cognitive system.

1. Introduction

Many of our everyday activities involve using our two hands in a coordinated fashion. In some bimanual tasks, such as breaststroke swimming, the limbs produce very similar motor outputs. However, in other tasks (such as buttoning a shirt, or striking a match), the limbs perform markedly different actions. Interlimb coupling is a predominant constraint in both the spatial and temporal domains (see Franz, 2003 for a review). During tasks in which the left and right hands perform different actions (incongruent, e.g., circles paired with lines, or circles paired with squares) each hand tends to take on some of the spatial characteristics of the other hand (Franz, 2003; Franz, Zelaznik, & Mccabe, 1991). Another robust observation is that the individuals generally take longer to initiate and execute bimanually incongruent, compared to congruent, actions (Bingham, Hughes, & Mon-Williams, 2008; Hughes & Franz, 2008; Kelso, Southard, & Goodman, 1979; Kunde & Weigelt, 2005).

Over the years, researchers have sought to identify the source of interference during bimanually incongruent movements. One of the earliest explanations was that the increased motor planning and execution costs associated with bimanually incongruent movements arise from cross-talk during the specification of two unequal parameter values (Heuer, Spijkers, Kleinsorge, van der Loo, & Steglich, 1998; Spijkers & Heuer, 1995; Spijkers, Heuer, Steglich, & Kleinsorge, 2000). Evidence in support of the transient nature of coupling (i.e., transient programming coupling hypothesis, Heuer, 1986, 1993) at the motor programming level of bimanually performed amplitudes was provided by Spijkers, Heuer, Kleinsorge, and van der Loo (1997). In that study participants performed bimanual reaching movements to targets of same (10–10 cm, 20–20 cm) or different (10–20 cm, 20–10 cm) amplitudes. In addition, the interval between the presentation of the movement goals (precue signal) and the imperative signal was varied (0, 250, 500 and 750 ms in Exp 1; 0, 125, 250, 375, 500, 750 and 1000 ms in Exp 2). Spijkers et al. (1997) hypothesized that short precueing intervals would not afford sufficient time for complete parameter

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programming. Thus, programming would occur during the reaction time interval, resulting in longer reaction times for different than for same amplitude movements. In contrast, programming of same or different amplitudes could be completed at long precueing intervals, and as such there should be no reaction time difference between these two conditions. Consistent with their hypothesis, Spijkers et al. (1997) found that the reaction time difference between movements of same and different amplitudes decreased as a function of the preparation interval, indicating that the costs associated with bimanual incongruent movements arise from crosstalk at the programming level.

This account of bimanual interference was, however, challenged by a series of studies that manipulated the manner in which the movement end-goals were cued (Diedrichsen, Hazeltine, Kennerley, & Ivry, 2001; Diedrichsen, Ivry, Hazeltine, Kennerley, & Cohen, 2003; Hazeltine, Diedrichsen, Kennerley, & Ivry, 2003). Replicating previous work (Heuer et al., 1998; Spijkers et al., 1997), responses were initiated much faster during congruent compared to incongruent conditions when the targets were symbolically cued (e.g., visual representation of movement amplitude). However, when the targets were cued directly (e.g., a circular light that appeared to the side of the target), the planning and movement costs associated with bimanually incongruent movements were reduced or even eliminated. The authors argued that the advantage observed during congruent movements relates to processes involved in processing symbolic cues (e.g., stimulus identification, response selection), rather than the concurrent programming of two different actions.

Motivated by this corpus of work, research from our laboratories has investigated whether limitations in bimanual grasp posture planning share similar underlying mechanisms as those observed during bimanual aiming movements. In general, examinations of bimanual grasp posture planning have shown that participants are sensitive to bimanual spatial coupling (i.e., grasping objects with identical postures) as well as comfortable final postures (i.e., end-state comfort) (Hughes & Franz, 2008; Hughes, Haddad, Franz, Zelaznik, & Ryu, 2011; Hughes, Reissig, & Seegelke, 2011; Weigelt, Kunde, & Prinz, 2006). When the end-goals of both hands are congruent, participants will adopt grips that allow them to satisfy both end-state comfort and bimanual coupling (Hughes & Franz, 2008; Weigelt et al., 2006). However, when the end-goals for the two hands are incongruent, neither bimanual coupling constraint nor end-state comfort emerge as a predominant constraint (Hughes & Franz, 2008; Hughes, Haddad et al., 2011; Hughes, Reissig et al., 2011).

Our initial foray into this line of work examined whether limitations in bimanual grasp posture planning are also due to goal-selection conflicts (Hughes, Seegelke, Reissig, & Schütz, 2012). Motivated by the work of Diedrichsen and colleagues (Diedrichsen et al., 2001, 2003; Hazeltine et al., 2003), we manipulated the manner in which the action end-goals were cued (symbolic cueing vs. direct cueing). In accordance with previous work we expected that cueing the movement goals in a symbolic fashion would result in conflicts related to the translation of symbolic cues into response codes during incongruent conditions, whereas interference in goal-selection would be minimized for directly cued movement goals. However, contrary to our initial expectations, there was no advantage in grasp posture planning for the direct cueing condition, indicating that limitations in bimanual grasp posture planning do not arise from stimulus identification or response selection conflicts associated with the translation of symbolic cues into action responses.

The purpose of the current experiments was hence to examine whether the problems associated with grasp posture planning during bimanually incongruent movements are due to crosstalk at the motor programming level (i.e., during the specification of two unequal parameter values), as previously found in bimanual reaching movements. In accordance with previous studies from our laboratory, the task required participants to perform a bimanual grasping and placing task in which they were to grasp two objects from a table and place them onto a board to targets that required identical (congruent) or non-identical (incongruent) degrees of rotation. Similar to Spijkers et al. (1997) we manipulated the interval between the presentation of the first and the second stimulus (stimulus onset asynchrony: SOA). We hypothesized that participants would be less able to satisfy grasp posture planning constraints (i.e., bimanual spatial coupling and/or end-state comfort, depending on condition) when the stimuli were presented simultaneously or separated by short time intervals, but that crosstalk (at the programming level) would be reduced or absent at longer SOA durations. If this hypothesis is correct, then the grasp posture planning congruency difference (i.e., between congruent and incongruent object end-orientation conditions) should decrease as a function of SOA duration. This finding would indicate that the costs associated with bimanual grasp posture planning arise from crosstalk at the programming level.

During our investigations into bimanual grasping and placing, we have repeatedly reported a reduction in hand interlimb coupling values during the reach-to-grasp and grasp-to-place phases for movements to incongruent, compared to congruent, object end-orientation conditions (Hughes, Haddad et al., 2011; Hughes, Reissig et al., 2011; Hughes et al., 2012). The manipulation of SOA duration employed in the current study afforded the possibility to examine whether limitations in bimanual execution arise from transient parametric coupling. Indeed, if the decrease in hand interlimb coupling during the execution of bimanually incongruent movements arises from interference between concurrent processes of parametric specification, it would be expected that SOA duration would have a strong effect on interlimb coupling. Specifically, short precueing intervals would not afford sufficient time for complete programming parametric specification of either bimanually congruent or incongruent movements, and as such the hands would be less coupled during incongruent than congruent object end-orientation conditions. In contrast, participants should be able to program the individual parameters for the two hands at long precueing intervals, and as such there should be no interlimb coupling difference between conditions with congruent and incongruent object end-orientations.

2. Experiment 1: Methods

2.1. Participants

Eighteen individuals were recruited to participate in the experiment. The dataset from three participants were removed prior to analysis because the participants were not able follow the instructions to move bimanually. This left us with a sample of fifteen right-handed participants (mean age = 25.07 years, SD = 4.57, SD = 6.45, 7 men and 8 women). Participants had normal or corrected to normal vision, and did not have any known neuromuscular disorders. The methodology and consent form for this study were approved by the Bielefeld University Institutional Review Board, and conformed to the declaration of Helsinki.

2.2. Apparatus

Participants stood in front of a custom built placement board (1.5 m × 0.4 m) that was braced by two legs (Fig. 1a). The placing board was adjusted to shoulder height, and the center of the board was oriented so that it coincided with the midline of the participants. On each side of the board were four white target circles