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Brain and Cognition 57 (2005) 102–105

Brain and Cognition

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Manual asymmetries in bimanual reaching: The influence of spatial compatibility and visuospatial attention

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Accepted 12 August 2004

Abstract

The goal of the present investigation was to explore the possible expression of hemispheric-specific processing during the planning and execution of a bimanual reaching task. Participants ($N = 9$) completed 80 bimanual reaching movements (requiring simultaneous, bilateral production of arm movements) to peripherally presented targets while selectively attending to either their left or right hand. Further, targets were presented in spatially compatible (ipsilateral to the aiming limb) and incompatible (contralateral to the aiming limb) response contexts. It was found that the left hand exhibited temporal superiority over the right hand in the response planning phase of bimanual reaching, indicating a left hand/right hemisphere advantage in the preparation of a bimanual response. During response execution, and consistent with the view that interhemispheric processing time (Barthelemy & Boulinguez, 2002) or biomechanical constraints (Carey, Hargreaves, & Goodale, 1996) generate temporal delays, longer movement times were observed in response to spatially incompatible target positions. However, no hemisphere-specific benefit was demonstrated for response execution. Based on these findings, we propose lateralized processing is present at the time of response planning (i.e., left hand/right hemisphere processing advantage); however, lateralized specialization appears to be annulled during dynamic execution of a bimanual reaching task.

Keywords: Manual asymmetries; Bimanual reaching; Spatial compatibility

1. Introduction

The study of manual asymmetries provides an opportunity to examine the contributions of the cerebral hemispheres to the control of goal-directed movement. Research in this area has indicated a functional dissociation between the hand/hemisphere system responsible for response planning, and that responsible for response execution. Indeed, amongst right hand dominant individuals it has been repeatedly shown that the left hand/right hemisphere system elicits a reaction time advantage over the right hand/left hemisphere system. This finding has been taken as evidence of a right hemisphere advantage for movement parameterization (e.g., Barthelemy & Boulinguez, 2002). Conversely, the right hand/left hemisphere system exhibits an advantage for the execution of a reaching movement. As such, the right hand exhibits faster movement times and decreased endpoint error and variability relative to reaches performed by the left hand. Presumably, the right hand advantage reflects left hemisphere efficiency/effectiveness in specifying neuromuscular synergies and/or processing response-produced visual feedback (see Elliott & Chua, 1996 for review).

Interestingly, however, a paucity of research has directly examined whether or not those factors influencing

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0278-2626/$ - see front matter
doi:10.1016/j.bandc.2004.08.041

hemisphere-specific processing advantages in unimanual reaching contexts similarly influence bimanual reaching movements (i.e., when movement of both limbs is executed simultaneously). Seminal findings of Kelso, Southard, and Goodman (1979) report temporal entrainment between effectors during bimanual movement—suggesting the absence of hemisphere-specific processing advantages. This coupling, potentially mediated by a number of subcortical and/or spinally mediated interactions, signifies a preferred organization of constituent movement elements and a highly 'phased' execution of coordinated multi-limb actions. In contrast, we (Heath, Binsted, & Polun, in press) have recently shown a robust left hand advantage for reaction time in a bimanual reaching task; however, evidence of a right hand temporal advantage for response execution was not observed. This finding was interpreted as evidence that manual asymmetries are expressed during the response planning (i.e., left hand/right hemisphere processing advantage) but not response execution (i.e., null hemisphere-specific processing advantage) stage of a bimanual response.

To further explore the expression of hemisphere-specific processing in bimanual reaching, the current study sought to determine whether or not the spatial complexity associated with a bimanual response might permit expression of a lateralized effect during response execution. Specifically, we directed participants to orient visuospatial attention to a specific hand—either left or right—while completing a bimanual response to targets in spatially compatible (targets in ipsilateral space) and incompatible (targets in contralateral space) response contexts. Based on unimanual reaching literature, if greater online monitoring of the limb is required in a spatially incompatible response context, then participants should exhibit faster movement times, when orientating visuospatial attention to their right limb. That is because this context favors the right hand/left hemisphere system; a system that is thought to processes response-produced visual feedback more effectively than the left hand/right hemisphere system (e.g., Woodworth, 1899). In contrast, if bimanual movements are coupled in terms of their temporal organization, then our experimental manipulations should not impact entrainment of the limbs.

2. Methods

2.1. Participants and apparatus

Nine undergraduate students from the Department of Kinesiology, Indiana University, participated in this experiment. Participants were head free and sat in front of a normal table-top. Discrete bimanual reaching movements were executed to small (1.5×1.5 cm) and large (3×3 cm) targets printed in white ink on a black background. The targets were located 35.5 cm anterior to two telegraph keys which served as the home position for all movements. Targets and telegraph keys were 19 cm apart ($-10°$ and $+10°$ relative to the sagittal axis) providing a common orientation of both limbs at the start of a reaching movement. The orientation of the limbs at the home position was $\sim$80° of shoulder abduction and $\sim$135° of elbow flexion in the frontal plane. Vision of the aiming environment was manipulated via liquid-crystal shutter goggles (PLATO Translucent Technologies, Toronto, ON, Canada), and position of the left and right index finger was measured by attaching infra-red emitting diodes (IREDs) to the nail of each. Spatial position of the IREDs was sampled at 200 Hz for 2 s following an auditory initiation tone via an OPTOTRAK 3020 motion analysis system (NDI, Waterloo, ON, Canada).

2.2. Procedure

Participants completed bimanual reaches in two attentional contexts. In the first context, reaching accuracy of the left or right hand was emphasized, and the hand moving to that target was designated the bimanual-attended (B-A) limb. Because aiming accuracy was emphasized for one limb, the second attentional context involved in the within-trial performance of the limb in which response accuracy was not emphasized (i.e., the bimanual-unattended (B-U) limb). Attentional context was factorially combined with a condition in which reaches were completed in ipsi- or contralateral space (i.e., spatially compatible or incompatible). Ipsilateral reaching movements entailed spatially compatible mapping between start and target location (i.e., left hand to left target, right hand to right target), whereas, contralateral reaching movements involved spatially incompatible mapping between start and target location, that is, crossing the body midline to touch a target located in contralateral space (i.e., left hand to right target, right hand to left target).

The start of each trial began once participants depressed the home position telegraph keys. That action inverted the shutter-goggles to their transparent state for a 2 s visual preview phase during which time participants were requested to orient their visuospatial attention to either the left or right hand. Following preview, an auditory tone signaled participants to "initiate movements of both hands simultaneously following an auditory tone." If the condition involved optimizing accuracy for the left hand in an ipsilateral condition, then participants were instructed to emphasize accuracy of the left hand moving to the left target. In this condition, movement accuracy of the right hand moving to the right target was not emphasized. If the condition involved emphasizing accuracy of the left hand in a contralateral condition, then participants were instructed to emphasize accuracy of the left hand moving to the right target. In this condition, movement accuracy of the right hand moving to the left target was not emphasized. In addition to the examples outlined above, homologous response sets emphasizing right hand accuracy were also examined.

Each participant performed four blocks of 20 trials. Two of these trial blocks involved an accuracy emphasis for the left hand (i.e., left hand ipsilateral, left hand contralateral). The remaining two trial blocks involved an accuracy emphasis for the right hand (i.e., right hand ipsilateral, right hand contralateral). The order of the trial blocks was randomized and the presentation of target (small or large) occurred in a pseudo-randomized fashion, with the caveat that each target appeared on 10 occasions within a block of trials.

2.3. Kinematic analysis

Displacement data were filtered using a second-order dual-pass Butterworth filter (low-pass cut-off frequency 15 Hz). Instantaneous velocities (from displacement) were calculated using a two-point central finite difference algorithm. The criterion for movement onset and offset was 50 mm/s. Dependent variables included reaction time (RT, time from response cueing to movement onset) and movement time (MT, time from movement onset to offset).

3. Results

Dependent measures were examined via 2 (hand: left, right) by 2 (attentional context: B-A, B-U) by 2 (movement space: ipsilateral, contralateral) by 2 (target: small, large) fully repeated measures analysis of variance (alpha = .05).

The results for RT yielded an effect for hand ($F_{1,8} = 95.37$, $p < .001$): RTs for the left hand (260 ms) were faster than the right (283 ms). The analysis of MT yielded significant effects for attentional context ($F_{1,8} = 42.32$, $p < .001$), movement space, ($F_{1,8} = 38.16$, $p < .001$), and target ($F_{1,8} = 12.04$, $p < .01$). MTs for B-A reaches (425 ms) were faster than B-U reaches (435 ms), whereas ipsilateral reaches (400 ms) were faster than contralateral reaches (460 ms). In accord with Fitts Law, reaches to the large target (424 ms) were faster than reaches to the small target (436 ms, see Fig. 1 for summary of MT data).

4. Discussion

In this investigation, we examined the expression of lateralized function for movement production within the context of bimanual reaching. Based on the extant unimanual reaching literature, it was hypothesized that hand/hemisphere dissociations should be present as a function of movement phase (planning versus control) and task constraints (e.g., visuospatial orientation of attention and/or ipsilateral versus contralateral response). Conversely, the bulk of bimanual aiming literature suggest nullification of hemisphere-specific processing advantages due to dynamical limb entrainment.

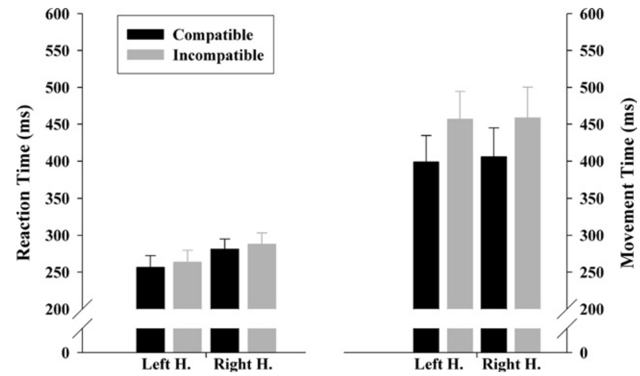

Fig. 1. Reaction time (ms: left figure) and movement time (ms: right figure) as a function of hand and movement space.

4.1. Response planning

The left hand exhibited temporal superiority over the right hand in the response planning phase of bimanual reaching. As we have demonstrated previously (Heath et al., in press), this advantage cannot be attributed to lateralized orientation of visuospatial attention. That is becuase the left hand RT advantage was expressed not only when accuracy was directed to the left hand, but also when accuracy was directed to the right. Moreover, the present results demonstrate that the left hand advantage was elicited when the response entailed spatially compatible (ipsilateral response) or incompatible (contralateral response) mapping between start and target location. Taken as a whole, it is proposed that limb entrainment is absent or incomplete at the time of response planning thereby permitting expression of a left hand/right hemisphere temporal advantage. Such a proposal is consistent with the unimanual aiming literature's view that peripheral factors (i.e., visuospatial orientation of attention, movement direction) do not ameliorate the left hand advantage for response planning (e.g., Barthelemy & Boulinguez, 2002).

4.2. Response execution

Derived from the unimanual reaching literature, it was anticipated that movement time of the right hand would be faster than that of the left hand—particularly, when attention was devoted to the right hand in a spatially incompatible response set. Presumably, that is, because a response set entailing right hand accuracy in a complex movement environment (i.e., reaching across the midline of the body) would permit enhanced expression of the purported right hand/left hemisphere temporal advantage for processing response-produced visual feedback (see Elliott & Chua, 1996). Conversely, the majority of the bimanual literature would predict temporal entrainment of the limbs regardless of the requirements of the motor output (e.g., Kelso et al., 1979). The present investigation failed to unequivocally support either hypothesis. The movement time results showed that the effect of attentional context and movement space was additive, but did not interact with one another. More specifically, B-A reaches were faster than their B-U counterparts, whereas ipsilateral reaches (spatially compatible) were faster than their contralateral (spatially incompatible) counterparts.

As we have expressed previously (Heath et al., in press), the enhanced movement times of B-A trials most likely reflects the fact that orienting attention to a specific limb selectively primes that hand/hemisphere system to effectively integrate online feedback. As a result, movement of the "primed" effector unfolds more rapidly than the limb for which attention—and online control processes—is not selectively primed. In terms of the effect of spatial compatibility, the longer movement times associated with reaches completed across the body midline (i.e., contralateral space) is consistent with the view that interhemispheric processing time (Barthelemy & Boulinguez, 2002) or the biomechanical constraints on contralateral movements (Carey et al., 1996) are computationally more complex, and thus elicit longer movement times. Importantly, the fact that our results did not yield a consistent right hand advantage speaks to the notion that the right hand advantage for response execution classically noted in the unimanual aiming literature (e.g., Woodworth, 1899) is not similarly expressed in a bimanual reaching task.

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