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Hemispheric Competition in Left-Handers on Bimanual Reaction Time Tasks

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ABSTRACT. The authors examined possible differences in left- and right-handers on bimanual reaction times to centralized visual stimuli. Eighty participants ($n = 40$ in each group of left- and right-handers) were tested on unimanual and bimanual reaction time (RT) tasks. Consistently across the 2 groups, the dominant-hand RT was faster, on average, than the nondominant-hand RT, and unimanual RTs were faster than bimanual RTs. However, RT differences between hands revealed a higher percentage of dominant-hand-led trials in right-handers than in left-handers, despite similar absolute RT differences in the 2 groups. On the basis of those findings, the authors conclude that hand dominance does not generally determine which hand leads in a bimanual task and that left-handers have stronger between-hemisphere competition than right-handers do.

Key words: bimanual, handedness, hemisphere dominance, temporal coupling

Recent researchers have focused on similarities and differences in the motor planning and performance of left- and right-handers by using unimanual and bimanual tasks. A specific aim in our own studies is to elucidate those properties of bimanual representation, planning, and attention processes that are similar in left-handers and right-handers and those properties that distinguish the two groups. One set of studies was motivated by previous research on the task of bimanual circle drawing (Carson, Thomas, Summers, Walters, & Semjen, 1997; Semjen, Summers, & Cattaert, 1995; Stucchi & Viviani, 1993; Swinnen, Jardin, & Meulenbroek, 1996). Franz, Rowse, and Ballantine (2002) examined the performances of left- and right-handers on a task of bimanual circle drawing to determine whether the dominant hand always leads the nondominant hand. Consistent with the findings of previous studies, the dominant hand tended to lead the nondominant hand when the bimanual task was performed in a mirror-symmetrical manner (Amazeen, Amazeen, Treffner, & Turvey, 1997; Franz, 2000a, 2000b, 2003, 2004; Swinnen et al.; Wuyts, Summers, Carson, Byblow, & Semjen, 1996; Treffner and Turvey, 1996; for related studies in which attentional manipulations were used, see Franz, 2004; Temprado, Zanone, Monno, & Laurent, 2001). However, further analyses on our own data revealed that the average signed phase difference was larger in right-handers than in left-handers, not because of group differences in the absolute magnitude but because of different numbers of trials led by each hand. In right-handers, the right hand tended to be the lead hand on nearly 78% of trials; whereas in left-handers, the left hand tended to be the lead hand on only approximately 56% of trials. We computed that measure of phase lag as the average instantaneous difference between hands computed across 8 continuous seconds of circle drawing across time.

Given that circle drawing involves spatial representations, among other planning properties that might be lateralized (Franz, 2000a, 2000b, 2003), as well as feedback processes, it is important to examine patterns of hand lead in simple bimanual reactions if one aims to isolate specific influences of hand dominance on bimanual planning and coupling. Studies in which simple reactions were used have typically been performed only on right-handed participants, and, to our knowledge, there have been no studies on simple bimanual reaction times in equivalent sample sizes of right-handers and left-handers. Because one can use the interpretation of reaction time effects to develop and examine theories of psychological and neural processes, it seems essential that data on left-handers be considered in more detail.

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A number of theoretical models have been proposed to account for hand lead effects on the basis of differences between the left and the right hands' performance on unimanual and bimanual reactions in predominantly right-handers. One theoretical view that has received some support is that there is in the right hemisphere an integrator of the left and right hands' bimanual reaction time responses (Taniguchi, 1999a, 1999b). In those studies, 58 healthy right-handed participants demonstrated shorter reaction times with stimuli presented to the left hemifield in both unilateral and bilateral conditions, suggesting that the unifying center for simultaneous bilateral responses is located in the right hemisphere. One could argue, however, that that conclusion does not describe bimanual data specifically. Further analysis disclosed slower responses during the bimanual condition than in the unimanual condition (Taniguchi, 1999a, 1999b).

A second possibility is that the left hemisphere is dominant for bimanual responses, as suggested by symmetrical circle-drawing tasks in which the right hand generally leads (Stucchi & Viviani, 1993). In the hemisphere-dominance model, it would be predicted that the right hand receives motor commands before the left hand does, given that the left hand's motor command would take longer to arrive from the left cerebral hemisphere than would the right hand's motor command. A third view is that neither hemisphere is dominant and that each functions the same for the bimanual case as for the unimanual case, but in parallel. An integrator process that does not reside in either hemisphere (perhaps at a subcortical locus) has been posited to perform the integration of movement signals associated with the two hands. That view has received some support from studies in which other types of bimanual tasks were used, including drawing of complex figures and continuous tapping, based primarily on the finding that without an intact corpus callosum (callosotomy), patients demonstrate normal coupling in the movement onset of repetitive productions of a bimanual movement (Franz, Eliassen, Ivry, & Gazzaniga, 1996; Ivry & Hazeltine, 1999).

The hypotheses just outlined are based primarily on data from right-handed individuals. However, our data on circle drawing provide a potentially interesting clue concerning effects of handedness; namely, that left-handers produce stronger evidence of a mixed hand lead than right-handers do. If that finding were to generalize to reaction time, then we would expect a dominant-hand lead on a higher proportion of trials in right-handers than in left-handers. In other words, the tendency for the right hand to lead in right-handers would be larger than the tendency for the left hand to lead in left-handers. Although we currently know of no framework presently in the literature for handling that type of result, we propose a hemisphere-competition model as a plausible account. According to the model, left-handers have stronger between-hemispheres competition than right-handers do, with the latter group characterized primarily as being left-hemisphere dominant. It follows that rather than showing a more pure tendency for the dominant hand to lead, the increased competition in left-handers results in a higher proportion of fast presses by the less dominant hand. In other words, the less dominant hand presses the key before the more dominant hand on a larger proportion of trials in left-handers than in right-handers. In the present study, we aimed to investigate whether support for a hemisphere-competition model can be found in the simplest case of bimanual reaction times to centralized stimuli or whether other proposed models account better for data obtained in both left-handers and right-handers.

Method

Participants

Participants were 80 undergraduates at the University of Otago who participated either as part of their coursework or in exchange for $8.50 compensation for their time. The age range was 18–56 years with a mean age of 29.5 years. Forty of the participants were self-declared right-handers and 40 were self-declared left-handers. We also assessed hand dominance in the two groups on the basis of an abbreviated Edinburgh Handedness Inventory (Oldfield, 1971). Based on hand preferences given on a battery of common tasks on the inventory, handedness scores ranged from −1.00 (*strongly left handed*) to 0.30 (*least left hand dominant*) for the left-hander group (with a mean score of −0.63), and from 0.20 (*least right hand dominant*) to 1.00 (*strongly right-handed*) for the right-hander group (with a mean score of 0.79). Note that 15 people in the left-handed group had scores that overlapped with those of the right-handed group. Thus, the analyses (reported later) that revealed differences between groups were quite conservative. However, we also analyzed all data on the basis of high versus low handedness scores (redistributing left- and right-handers into two groups on the basis of handedness scores alone), and the pattern of findings for high versus low was virtually the same as the pattern of findings for right-handers versus left-handers, respectively. Those findings revealed that participants in the overlapping portion of the two groups did not differentially influence our results (although we kept those data to increase statistical power).

Apparatus

We used a personal computer with millisecond timing routines to measure the reaction times for the left and the right hands in both the unimanual and bimanual tasks. The visual stimuli appeared on a 14-in. computer monitor. A fixation point (1 cm × 1 cm on the screen) was presented on each trial, followed by a green dot (1.5 cm diameter) on each trial. Participants were to respond by pressing one response key on unimanual trials and both response keys on bimanual trials, with the appearance of the green dot. A loud tone was presented for anticipatory responses (those that occurred before presentation of the green dot).

Design

The experiment consisted of three conditions: left hand alone (unimanual left), right hand alone (unimanual right), and both hands together (synchronized bimanual). Each of the three condition types was run four times in blocked fashion, in a randomized order of blocks, except that no 2 consecutive blocks were of the same condition type. Within each of the 12 blocks, there were 36 trials, yielding a total of 432 responses including unimanual and bimanual conditions. For statistical analyses, we used a mixed design, with the between-groups comparison of left- versus right-handers and with the within-participants factors of type (unimanual vs. bimanual) and hand (dominant, nondominant).

Procedure

We gave participants general information about the experiment and asked them to sign an informed consent form approved through the University of Otago ethical committee. We read the activities in the handedness inventory aloud one by one, and asked participants to state verbally which hand was preferred to perform the activity. Participants were then invited to a soundproof booth and they sat on a height-adjustable chair in front of the table, with the computer monitor 57 cm away. We asked them to rest their hands on a response board, with the left index finger on the left key and the right index finger on the right key. For unimanual tasks, they used only one index finger and the other hand rested on their lap. A modified keyboard used as the response board was situated in front of midline so that the left hand produced responses in the space just left of midline (by approximately 4 cm) and the right hand produced responses in the space just to the right of midline (by approximately 4 cm). The participants' arms were bent at the elbows so that they used only the fingers to respond.

Because condition varied from block to block, we reminded participants about which hand or hands to use at the beginning of each block of trials. On a given trial, we presented the fixation cross in white on a black background in the center of the monitor for a delay that varied randomly from 500 to 1,000 ms. The cross then disappeared and was replaced by a green filled circle that remained on the screen for 1,200 ms, or until participants made one response (unimanual blocks) or responded with both hands (bimanual blocks), whichever came first. Following the response on unimanual trials, or the second of two responses on bimanual trials, an intertrial interval of 1,000 ms occurred before the next trial. If a response was produced before the appearance of the green stimulus, an error tone (400 Hz, 50-ms duration) sounded. We emphasized speed of responding, but we also warned participants not to respond before seeing the green dot. We logged anticipations, incorrect responses, or no responses as errors. An experimental session began with 36 practice trials of each condition. The experiment took approximately 40 min per participant. After all 12 blocks were tested, we debriefed the participants.

Data Analysis

We report the between-participants factor of group (left-handers vs. right-handers) and within-participants factors of condition type (unimanual vs. bimanual) and the hand of performance (dominant vs. nondominant). Before data analysis, we rejected reaction times that exceeded 450 ms or those less than 100 ms. The total number of rejected trials comprised 1.8% of the data, and those trials were approximately equally distributed across the condition types.

We computed the mean and the standard deviation for each hand across each block and, in addition to the between-hands reaction time (RT) difference, the absolute value of the between-hands RT difference for bimanual trials. We calculated the signed between-hands RT difference to determine which hand led on each bimanual trial by subtracting the RT of the left hand from the RT of the right hand. A positive value indicated a faster left hand RT. A negative value indicated a faster right hand RT. The absolute value of the RT difference was computed on a trial-by-trial basis as a measure of the magnitude of the hand lead or the degree of synchronization of the two hands. A large value indicated that the performance of the two hands was not in close synchrony. In contrast, a value close to zero indicated that the two hands were tightly coupled (i.e., both the left and the right hands pressed the keys at approximately the same time).

Results

As predicted from earlier RT research, there was a highly significant main effect of condition on RT, revealing longer RTs for bimanual than for unimanual responses, $F(1, 78) = 74.18$, $p < .001$. Bimanual RT ($M = 266$ ms, $SE = 6.7$) was 13 ms longer, on average, than unimanual RT ($M = 253$ ms, $SE = 5.8$). Of novel importance, given that this task has not been tested in left-handers, is that there was no hint of an interaction of condition with group, indicating that the unimanual versus bimanual difference was not reliably different for the two groups, $F < 1$. The nondominant hand produced longer RTs than the dominant hand by approximately 6 ms, $F(1, 78) = 19.46$, $p < .001$. Most important, that effect also did not interact with group, revealing that the dominant hand tended to lead in each handedness group when we took both unimanual and bimanual conditions into account, $F < 1$. The mean RTs for each condition for the two groups appear in Table 1.

An unexpected result was a significant interaction between condition and hand that revealed a smaller between-hands RT difference on bimanual trials than on unimanual trials (3 ms vs. 7 ms), $F(1, 78) = 5.98$, $p = .017$. The nondominant hand produced a slower RT than the dominant hand in both unimanual and bimanual conditions, but the bimanual RTs were more closely coupled than would be predicted from the unimanual RTs.

To further evaluate the bimanual trials, we performed an analysis of signed RT difference. Of interest to the hypotheses examined was a highly significant main effect of group that revealed that the dominant hand led by a larger amount in right-handers than in left-handers, $F(1, 78) = 12.93$, $p < .001$, Cohen's $d = .80$, Effect size $r = .37$ (see Table 2). Note that the 95% confidence intervals were –0.945 to 2.695 for left-handers, and –5.595 to –1.955 for right-handers, with negative values indicating a right hand lead. We then computed the absolute value of the RT difference, following logic outlined recently in studies on bimanual circle drawing (Franz, 2004; Franz & Packman, in press; Franz et al., 2002). Because the signed RT difference can be positive or negative depending on which hand leads, those values will cancel one another during averaging. If the absolute value computation yields a similar average value as the signed computation does, then one can conclude that one hand responds faster than the other consistently across trials. Alternatively, if the absolute value computation yields significantly larger average values than the signed computation does, then one can conclude that there is a mixed hand lead in which one hand leads on some trials and the other hand leads on the remaining trials.

Most interesting, there was no hint of a difference between left-handers and right-handers on the absolute value of the RT difference, as revealed by the very similar values shown in Table 2 ($F < 1$). Moreover, when analyzing RT difference with signed versus absolute as a variable, we found a highly significant difference between the two types of RT difference , as expected, $F(1, 78) = 85.9$, $p < .001$. RT difference also interacted significantly with handedness group, also as expected, because the signed RT difference differed in the two groups but the absolute RT difference was not reliably different, $F(1, 78) = 8.07$, $p = .006$. Taken together, those results reveal that left-handers must have produced more of a mixed hand lead than right-handers did. In other words, the dominant-hand lead in right-handers occurred on proportionately more trials than did the dominant-hand lead in left-handers. A frequency analysis further supported that finding. As shown in Table 3, left-handers demonstrated less of a tendency for a dominant-hand lead than right-handers did, an effect that was highly significant, $F(1, 78) = 7.48$, $p = .008$.

Discussion

In this study, we examined simple RTs to centrally presented stimuli under unimanual and bimanual response conditions in a group of 40 right-handers and a group of 40 left-handers. Those handedness groups were operationally defined on the basis of reported hand preferences on an inventory of common tasks (Oldfield, 1971). Thus, we divided the group on the basis of behavioral handedness. Our primary purpose was to establish whether there are unimanual and bimanual differences in RT in the two handedness groups so that we could reevaluate theoretical approaches to the study of movement planning that were based primarily on right-handed participants. As implied by the term *hand dominance*, on average the right hand responded faster than the left hand in right-handers and the left hand responded faster than the right hand in left-handers. That effect was found for the average of all unimanual and bimanual trials. Also consistent with recent studies on right-handers (Taniguchi, 1999a, 1999b), bimanual RTs were generally longer than unimanual RTs. Although that additional processing might be related to the assignment of effectors from both hands in the bimanual as compared with the unimanual case, it is unclear what other organizational properties are necessary in the bimanual task, given that all other parameters should be equal for the two hands.

TABLE 1. Mean Reaction Time and Standard Deviation (in ms) for Each Hand in Unimanual and Bimanual Conditions in Left- and Right-Handers

	Unimanual				Bimanual			
	Left hand		Right hand		Left hand		Right hand	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Left-handers	252	45	260	58	269	57	270	57
Right-handers	252	56	246	52	264	62	260	63

TABLE 2. Average (and Standard Error) Signed and Absolute Reaction Time Differences (in ms) for Bimanual Trials of Left- and Right-Handers

	Absolute		Signed	
Group	*M*	*SE*	*M*	*SE*
Left-handers	5.93	.52	0.88	.91
Right-handers	5.74	.52	–3.78	.92

TABLE 3. Proportion of Total Trials With Left Hand Lead, Right Hand Lead, and Perfect Synchrony in Left- and Right-Handers

Group	Left hand lead	Right hand lead	Synchrony
Left-handers	48%	43%	9%
Right-handers	26%	69%	5%

The RT difference between hands was larger in unimanual comparisons than in bimanual between-hands comparisons. Thus, although the organization of bimanual responses takes time, the final outcome is a more coupled response than would be expected on the basis of unimanual responses. According to dynamical perspectives on action, in-phase movements of the left and right hands are the most stable mode of coordination, and the stable mode is maintained with increases in oscillation frequency. In the dynamical perspective, which is inspired by theories of self-organization of complex systems, it is generally assumed that patterns of stability result from neural, muscular, and vascular variables (Haken, 1983; Schöner & Kelso, 1988). Bimanual RT tasks differ markedly from the continuous tapping tasks used in dynamical frameworks, although it is possible that the close coupling inherent in in-phase bimanual movements accounts, at least in part, for the between-hands coupling found in the speeded RT tasks of the present study. However, that does not appear to be the whole story.

Our primary finding, that the dominant hand responded faster than the nondominant hand in both groups but that the proportion of bimanual trials on which that occurred was larger in right-handed than in left-handed participants, poses some challenges to theoretical perspectives of bimanual movement planning and coordination while supporting others. The simple theory that an integrator process is responsible for group differences (see introductory comments) would hold only if the integrator itself differs between left-handers and right-handers. It seems highly unlikely that a separate process such as a subcortical integrator of responses would differ depending on handedness. Recall that the RT difference between the unimanual responses of the two hands was not different in magnitude in the two handedness groups; thus, the novel effect of a larger RT difference in right-handers than in left-handers is unique to bimanual responses.

The present findings also pose challenges to theoretical models based on traditional hemispheric-dominance arguments, according to which the hemisphere opposite the dominant hand is the primary arbiter in each handedness group. Indeed, that appears to be the case for unimanual responding but not necessarily for bimanual responding. It is commonly accepted that the left hemisphere is dominant in the motor actions of right-handers. That account is consistent with the findings that the right hand tends to respond faster than the left hand in unimanual and bimanual responses. If left-handers have opposite dominance, then the right hemisphere would be expected to elicit faster responses (of the left hand) both in unimanual and bimanual responses. The finding that the signed RT difference was approximately zero for bimanual responses in left-handers strongly challenges that view, given that the prediction would be a more consistent left hand lead across trials. Although the left-hemisphere-dominance hypothesis is not entirely challenged by the results of right-handers, it would seem that even their dominant-hand lead should be more consistent across trials if the traditional view of hemisphere dominance were the whole story (see also Franz & Rowse, 2003).

We propose that the hemisphere-competition model outlined in the introductory comments captures the primary effects reported here. Specifically, we propose that the left and right hemispheres compete to respond when the task involves both hemispheres, as in a bimanual response to a centralized stimulus, and that the competition is greater in left-handers than in right-handers because of more balanced hemisphere dominance in left-handers. The primary evidence in favor of that novel view comes from the direct comparison between the signed and absolute values of RT difference in the bimanual trials. Despite the similarity in the average absolute RT difference values across groups, the magnitude of the signed RT difference was significantly larger in right-handers than in left-handers. In other words, participants from both groups produced evidence of a mixed hand lead in responding on bimanual trials, but that tendency was more pronounced in left-handers (see Tables 2 and 3). We further predict that the hemisphere competition does not ensue in the unimanual case, given that our study involved blocked performance of unimanual and bimanual conditions. We are presently testing a mixed block design to verify that prediction.

It has been posited in dynamical perspectives on coordination that a symmetry parameter accounts well for asynchrony between hands on continuous-tapping tasks (Temprado, Zanone, Monno, & Laurent, 1999), although the neural or psychological basis of that parameter is unclear. A variant of the just-mentioned account is that symmetries (and asymmetries) relate to the attentional distribution of the tasks. Indeed, changes in the patterns of between-hands asynchrony have been demonstrated with manipulations of attention to one hand or the other in continuous bimanual circling tasks (Franz, 2004; Swinnen et al., 1996; Wuyts et al., 1996) and in pendula moving tasks in which attention was manipulated by the use of targets located over the left or right hand (Amazeen et al., 1997). Generally, attention to one hand increases the phase lead of that hand. Applying those principles to bimanual RT tasks of the type used in the present study, we may assume that attention is distributed more evenly across the two hands when the task is bimanual. In contrast, when the task is unimanual, attention might be primarily focused on the responding hand. That could account for the finding that bimanual RTs are more closely coupled than would be predicted from unimanual RTs.

Our competition model seems to apply if we consider that attention distribution interacts with built-in forms of hemisphere dominance. With bimanual preparation to respond, we would expect that attention is more evenly distributed between the two hands (Franz, 2004; Miller & Franz, in press). The distribution of attention enables flexible allocation of dominance between hemispheres at any given time (see later discussion). In right-handers, the strong built-in hemispheric dominance would result in a left-hemisphere bias, on average. In contrast, in left-handers (in whom the hemisphere biases might not be as strong), that built-in bias would be more balanced between hemispheres. Attention enables dominance to shift between hemispheres. Accordingly, when presented with a centralized stimulus that requires a bimanual response, the left-handed group undergoes more transient shifts between hemispheres during the interval of bimanual preparation because the two hemispheres are already quite closely balanced. That close balance would also account for the higher proportion of synchronous bimanual trials in left-handers than in right-handers (see Table 3). But note that perfect synchrony is an exception to the rule (see Miller & Franz), given that all participants in the present study responded with one hand before the other on the majority of bimanual trials. In right-handers, a slight left-hemisphere bias would remain even with an equal distribution of attention between hemispheres because the built-in dominance is already strong. In sum, the effect of the transient shift of balance between hemispheres in left-handers would result in the nearly equal apportionment of hand lead responses for the two hands.

Consistent with the view just outlined, other findings from our laboratory strongly suggest that the corpus callosum is involved in the flexible allocation of task dominance at any given time. On the continuous circle-drawing task, people with completely severed callosi (callosotomy or *split-brain*) or a congenital absence of the callosum (callosal agenesis) adopted a preferred mode of drawing (in-phase or out-of-phase) depending on their hemisphere dominance; moreover, they were unable to intentionally switch between in-phase and out-of-phase modes even at slow movement speeds without the direct guidance of vision or excessive practice on the task (Franz, 2000a, 2000b). Those findings are consistent with our hypothesis that hemisphere biases (or built-in forms of dominance) determine the predominant mode of responding when the flexible allocation of attention between hemispheres is not possible (Franz, 2000a, 2000b, 2003; see Franz et al., 2002, for a review of that idea). Note that, in contrast to situations involving continuous feedback-dependent movement tasks, such as bimanual circling, previous findings demonstrated that when the stimuli for discrete tasks are presented to the two hemispheres simultaneously, accurate responses can be produced bimanually even when the callosum is severed (Franz et al., 1996; Franz, Waldie, & Smith, 2000). Moreover, because one cannot monitor feedback from the two hands simultaneously, the hands can become uncoupled temporally during feedback-dependent circle drawing, both in normal participants and in people with callosotomy (Franz, 2000a, 2000b; see also Kennerly, Diedrichsen, Hazeltine, Semjen, & Ivry, 2002).

In summary, the claim that the dominant hand generally responds faster than the nondominant hand was supported by the present findings. With respect to the two handedness groups, right-handed controls produced faster responses with their dominant right hand and left-handed controls produced faster responses with their dominant left hand. With respect to hand lead on bimanual trials, however, left-handers showed nearly an equal proportion of trials led by the dominant and the nondominant hands, whereas right-handers revealed a higher proportion of trials led by the dominant right hand than by the less dominant left hand. We conclude that hand dominance alone does not generally determine which hand leads in a bimanual task, and that behavioral left-handers have stronger between-hemisphere competition than behavioral right-handers do because of an interplay of hemisphere dominance and attention.

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