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RESEARCH NOTE

Shift of manual preference by lateralized practice generalizes to related motor tasks

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Abstract Previous investigation (Teixeira and Teixeira in Brain Cogn, in press, 2007) has evidenced a persistent shift of manual preference for a particular motor task following lateralized practice. In the present study, we assessed the extent to which shift of manual preference is generalizable to related motor tasks. Twenty right-handers were assigned to an experimental or to a control group. The former were provided with practice on a particular sequence of finger movements with their left hand only, while the latter remained inactive. Participants were assessed on manual asymmetry, indexed by movement time, and manual preference for the practiced and for other two sequences of finger movements (transfer tasks). Assessment was made before, immediately after, and 30 days following (retention) practice sessions. Results showed that lateralized practice led to significant bilateral reduction of movement time, maintaining the symmetric performance observed before practice following task acquisition. Regarding manual preference, before task acquisition, all participants in the experimental group were right-handed for the main task; immediately after practice their predominant manual preference shifted to the left hand, a profile that was maintained in retention. This persistent shift of manual preference was also observed for one of the transfer tasks requiring the same sequence of transitions between finger movements. Indices of correlation between manual asymmetry and manual preference were non-significant across tasks and phases, suggesting that manual preference was not defined by lateral asymmetry of performance. We propose that manual preference is established by automatic sensorimotor processing and/or increased confidence on a single hand from previous experiences.

Keywords Handedness · Lateralization · Manual asymmetry · Generalization · Motor training

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Introduction

Lateralization of human motor function has been proposed as a dynamic and multifaceted process contingent upon individual related determinants (Serrien et al. 2006). One such individual determinant of human lateralization has been shown to be systematic motor experiences using a single limb, heretofore named lateralized practice (LP). Research has indicated that LP has a role in shifting manual preference (preference of a single hand to perform motor tasks). Evidence has been presented that as right-handed children (Singh et al. 2001) and adults (Teixeira 2007) advance in age, their preference for the right hand becomes stronger. Furthermore, left-handed children are frequently enforced to shift their manual preference to the right hand (Zverev 2006), and in many cases this environmental pressure is successful. Meng (2007) reported that in a large group of left-handed children, social effort to shift manual preference produced the desired effect in approximately 60% of the cases (see also Porac et al. 1986). Both strengthening of manual preference in right-handers and shift of manual preference in left-handers seem to be due to extensive lateralized motor experiences in different activities, modulating previous tendencies of use of the hands. In agreement with this interpretation, Mikheev and colleagues (2002) showed that judo athletes prefer more frequently than other individuals to perform certain movements with their left hand, although overall right-handed. This observation suggests that learning is able to shift manual preference for particular motor tasks in right-handers also, who usually are more consistent in the use of the preferred hand than left-handers (Healey et al. 1986).

Direct evidence from controlled experimental investigation of the effect of LP on the establishment of lateral preference in right-handers has been presented recently. Teixeira and Teixeira (2007) evaluated the effect of LP of sequential finger movements of the nonpreferred left hand on manual asymmetry and preference. The results revealed a noticeable shift of manual preference for the experimental task following practice, with some participants shifting from the original consistent right hand preference to consistent left hand preference. That was an enduring effect, since 1 month following the end of practice, shift of manual preference for the experimental task was still observable (cf. McGonigle and Flook 1978, for analogous findings in animals). Additional aspects in these results deserve further attention. First, following practice of the nonpreferred left hand, no significant difference between performance of the right and the left hand (manual asymmetry) was observed. Thus, it was shown that the symmetric performance between the hands, as usually observed in complex sequential finger movements[1] in adults (Teixeira and Paroli 2000; Hausmann et al. 2004) and children (Denckla 1974; Fagard 1987), is not significantly changed by the amount of LP employed in the study. Second, the results pointed out incongruence between manual asymmetry and manual preference. This point was detected in the group analysis, with no significant correlation between magnitude of manual asymmetry and strength of manual preference, and in the large number of individual cases of divergence between manual preference and manual asymmetry. These results are contradictory to the assumption that manual preference for a given task is a function of the relative proficiency between the right and the left hand (Bishop 1989), and suggest that manual preference and manual asymmetry are affected differently by LP.

Incongruence between manual preference and manual asymmetry in Teixeira and Teixeira's (2007) study has been explained by proposing that an important component of manual preference arises from increased confidence on a single limb as a result of LP, rather than from performance advantage of one hand. On the basis of this conceptualization, an individual becomes more confident on that hand used most in previous opportunities to perform a motor task, and this increased confidence on a single hand would enhance its chance of been chosen to perform that task in future situations. If this proposition is correct, shift of manual preference following LP for a particular motor task should generalize to motor tasks requiring similar movements, independent of performance asymmetries between the hands. This hypothesis was scrutinized in the present study by assessing immediate and enduring effects of practice with the nonpreferred left hand of sequential finger movements on manual asymmetry and manual preference. This analysis was conducted for the practiced task and for variations of it, focusing on the relationship between preference and performance.

Materials and methods

Participants

Thirteen male and seven female university students (age range 17–46 years, $M = 23.45$, $SD = 7.92$) participated in the study. All participants were right-handers, as indicated by the Edinburgh manual dominance inventory (Oldfield 1971), with median score equal to 4.5 on a 5-point scale. Ethical approval for this study was granted by the Institutional Review Board and all procedures were in accordance with the standards established in the Declaration of Helsinki.

Task and equipment

The main experimental motor task consisted of sequentially touching the thumb with the other four fingers in the following order: index, ring, middle, and little finger. One trial consisted of performing this sequence (cycle) of finger movements three times without interruption. The aim of the task was to complete a trial in the shortest period of time. Two other sequences of finger movements were used in a transfer situation. One task (serial) consisted of modification of the sequence of the main task by touching the thumb with the other fingers in the following order: little, ring, middle, and index finger. As in the main task, one trial consisted of performing three cycles of between-finger touching movements. The other task (repetitive) consisted of keeping the overall sequence of movements as for the main task, but performing three repetitive touches with each finger before starting another triplet of touches. Thus, each trial in this task was performed by making consecutive triplets of touches to the thumb with the index, then the ring, middle, and last the little finger.

Participants performed the main and transfer tasks while sitting on a chair, having the elbow of the active hand upheld on a table. The forearm was kept stable by the participants without physical constraints in a predominant

[1] See the effect of task complexity on manual asymmetry in Hausmann et al.'s (2004) results, with increased symmetry of performance in more complex sequential finger movements in contrast to advantage of the preferred hand in repetitive finger tapping.

vertical orientation, slightly bent forward, with the active hand pronated. Movements were filmed using a digital camera (SONY, DV-500), and images were analyzed at 60 Hz in order to measure movement time (MT) on each trial.

Experimental design and procedures

Experimental procedures were initiated by assessing overall handedness and then specific manual preference for the experimental tasks. Manual preferences for the main and for the two transfer tasks were assessed by asking participants about their manual preference for those particular tasks. Overall handedness and specific manual preferences were assessed on a five-point continuous rating scale: 1 = left always, 2 = left usually, 3 = indifferent, 4 = right usually, and 5 = right always. In the sequel, participants were provided with instructions about the task, and then with familiarization trials. Familiarization consisted of three trials performed slowly, followed by another set of three trials performed at a fast rate. This procedure was employed for both hands immediately before initial evaluation of manual asymmetry.

For experimental treatment, participants were pseudorandomly assigned to one of two groups: experimental ($n = 10$; 6 males, 4 females), or control ($n = 10$; 7 males, 3 females). The experiment was divided into four phases: pretest, practice (or rest), posttest, and retention. In the pretest, performance of both hands was assessed on the experimental task only. Participants performed three trials for each hand in sequence, having order of hands counterbalanced across participants. There were regular intervals of approximately 10 s between trials, and the interval between assessments of each hand was 1 min approximately.

Following pretest, the experimental group were provided with practice for the left hand on the main task, while the control group had no activities other than those usually performed on their daily living duties. Practice trials were divided into three sessions, conducted on different days, completed within a period of 1 week. In each session, the experimental group performed five blocks of 20 trials, with rest intervals of a few seconds self determined by the participants. Thus, at the end of this phase participants had performed 300 trials, corresponding to 900 cycles of finger movements. In order to increase motivation to improve performance, participants trained the task in couples. During each session of practice, while one participant performed the task, the other in a couple registered the time spent to complete each trial with a stopwatch. Movement time was informed to participants after every trial, and they were asked to improve their performance across training sessions. Practice trials were performed under supervision of the laboratory staff. One (posttest) and 30 (retention) days following the end of practice, manual preference for the main and transfer tasks, and manual asymmetry for the practiced task were evaluated by repeating the procedures employed in the pretest. In the sequence, participants were assessed on manual asymmetry in the serial and repetitive transfer tasks, with the same procedures as for the main task. Sequence of evaluation of transfer tasks was counterbalanced across participants. During pretest, posttest, retention and transfer trials no feedback was provided about movement time. Trials with any sequencing errors or interruption of finger movements (approximately 7% of the trials) were aborted and repeated immediately.

Measurement of movement time was made as a function of number of frames (17 ms each) in the video analysis. Movement time in a trial corresponds to the interval between the moment of visually detectable initiation of closure between the index finger and the thumb in the first cycle of movements and the moment at which no further displacement was detected in the closure between the little finger and the thumb in the last cycle of movements. Measurement of movement time across experimental phases and participants were made by a single rater. In order to estimate reliability of movement time measurement, a sample of 30 trials (10 from each experimental phase) were evaluated twice by the rater with a period of 1 week between measurements. The rate of perfect coincidence (proportion of agreements) between the two measurements was 67%, while in 27% of the trials a discrepancy of one frame was found, and in 6% of the trials there was a discrepancy of two frames.

Results

Manual asymmetry

Assessment of manual asymmetry for the main task was conducted through a three-way 2 (group) × 2 (hand) × 3 (phase) analysis of variance with repeated measures on the last two factors. The results showed significant main effects of group, $F_{(1,18)} = 5.63$, $P < 0.05$, and phase, $F_{(2,36)} = 39.94$, $P < 0.0001$. The main effect of group is due to shorter MTs for the experimental group ($M = 2.45$ s) in comparison with controls ($M = 3.07$ s), while the main effect of phase is due to longer MTs in the pretest ($M = 3.32$ s) in comparison with posttest ($M = 2.46$ s) and retention ($M = 2.50$ s), which did not differ from each other. No other main effect or interaction was detected. This result indicates a similar reduction of MT for the right and the left hand in the posttest and retention (Fig. 1a). As an advantage was detected favoring the experimental group across all phases, an additional analysis taking values of pretest as a covariate was made. Given that no significant main effect of hand or associate

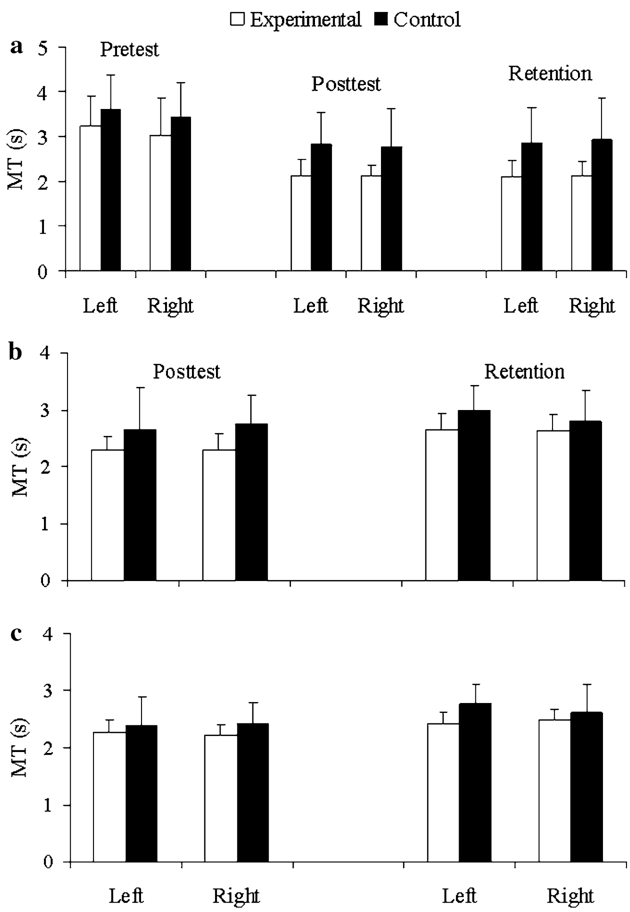

Fig. 1 Movement time (s) of the right and left hands for the experimental and the control group across phases for the main (**a**), and for the serial (**b**) and repetitive (**c**) transfer tasks; SD represented by *vertical bars*

interaction were detected in the primary analysis, the statistical model employed was a two-way 2 (group) × 2 (phase: posttest × retention) analysis of covariance with repeated measures on the second factor. Results indicated a significant main effect of group, $F_{(1,17)} = 9.34$, $P < 0.01$, indicating that practice per se accounts for a significant part of the difference of performance observed between groups in the latter experimental phases.

Assessment of manual asymmetry in the transfer tasks were performed through three-way 2 (group) × 2 (hand) × 2 (phase: posttest vs. retention) analyses of variance with repeated measures on the last two factors. For the serial transfer task, analysis showed significant main effects of group, $F_{(1,18)} = 4.40$, $P = 0.05$, and phase, $F_{(1,18)} = 14.15$, $P < 0.005$ (Fig. 1b). The same profile was found for the repetitive transfer task, with significant main effects of group, $F_{(1,18)} = 4.24$, $P = 0.05$, and phase, $F_{(1,18)} = 8.96$, $P < 0.01$ (Fig. 1c). In both analyses, the main effects of group are due to shorter MTs in the experimental ($M = 2.47$ and 2.34 s, respectively) as compared with the control ($M = 2.80$ and 2.55 s, respectively) group, while the main effects of phase are due to increment of MT from posttest ($M = 2.50$ and 2.32 s, respectively) to retention ($M = 2.77$ and 2.57 s, respectively).

Manual preference

Statistical analysis of manual preference for the main and transfer tasks was made by comparing the preference scores across experimental phases separately for each group. This analysis was initially conducted through Friedman's rank test, followed by Wilcoxon's matched pairs signed-ranks test to make follow-up contrasts. The results indicated a significant phase effect for the experimental, χ^2_F =14.77, $P < 0.001$, but not for the control, χ^2_F =2.33, $P > 0.3$, group. Paired comparisons between phases for the results of the experimental group showed significant reduction of the manual preference score in the posttest, $Z = 2.66$, $P < 0.01$, and retention, $Z = 2.52$, $P < 0.02$, in comparison with the pretest, while the difference between the two latter experimental phases did not reach significance.

Analysis of the serial transfer task did not detect a significant phase effect either for the experimental or for the control group (Ps > 0.05), while analysis of the repetitive transfer task revealed similar effects in comparison with the main experimental task. Friedman's rank test indicated significant differences between phases for the experimental, χ^2_F =10.69, $P < 0.005$, but not for the control, χ^2_F =2.00, $P > 0.3$, group. Paired comparisons between phases for the results of the experimental group showed a significant reduction of the manual preference score in the posttest, $Z = 2.37$, $P < 0.05$, and retention, $Z = 2.20$, $P < 0.05$, in comparison with the pretest, with no significant difference between the latter two phases.

Complementary analysis was made by comparing scores of manual preference between groups across tasks and phases through Mann–Whitney U test. For the main task, the results indicated significantly lower scores in the experimental group as compared with the control group in the posttest, $Z = 3.33$, $P < 0.001$, and retention, $Z = 2.14$, $P < 0.05$. For transfer tasks, analysis indicated significantly lower scores in the experimental group only for the serial task in the posttest, $Z = 2.43$, $P < 0.05$. Figure 2 presents the median scores of manual preference observed at each phase for the experimental (panel a) and the control group (panel b). Ranges of variation (extreme scores) are represented by vertical bars.

Correlation between the scores of manual asymmetry and manual preference was estimated by applying Spearman rank order analysis. Manual asymmetry was calculated by subtracting MT of the left hand from MT of the right hand, and then dividing the product by their sum. The higher the value, the larger was the difference of performance between

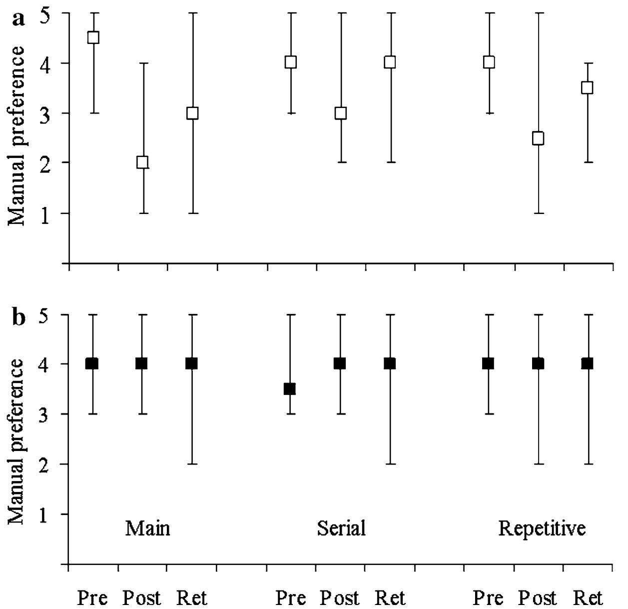

Fig. 2 Median scores of manual preference for the experimental (**a**) and for the control (**b**) groups across phases for the main, and for the serial and repetitive transfer tasks; range of scores across participants are represented by *vertical bars*

the hands. This analysis was applied separately for each group by task by phase. The analysis did not detect any significant correlation between scores of manual asymmetry and manual preference either for the main (r_s range: −0.27 to 0.54, P values > 0.05) or for transfer (r_s range: −0.44 to 0.61, P values > 0.05) tasks.

Discussion

Consistent with previous findings (Teixeira and Teixeira 2007), the results showed that practice of the left hand on the main task did not modify the symmetric performance observed before practice, with similar improvement of performance between the right and the left hand. This finding is conceived to be related to the neural network engaged to control actions of this nature. Previous studies have demonstrated that performance of complex sequential finger movements, by either hand, is featured by cerebral activation of bilateral cortical areas (Solodkin et al. 2001), with prominence of the premotor (Hlustik et al. 2002), primary motor (Verstynen et al. 2005), and parietal (Haaland et al. 2004) cortices of the left hemisphere. Haaland et al. (2004) have proposed that the left dorsal premotor and parietal areas are engaged when advance planning is necessary to perform complex sequences of movements requiring selection of different effectors and abstract organization of the sequence, regardless of the performing hand. More intense activity of the left primary motor cortex specifically in the execution of complex movements (Verstynen et al. 2005), in addition, suggests that the left hemisphere has a role not only in planning but also in the execution of complex movements by either hand. As a corollary, it is apparent that both the right and the left hand share an important part of the neural ensemble employed to control sequential movements, leading to symmetric performance between the hands and to equivalent improvement as a result of unimanual practice.

Manual preference for a given motor task has been proposed to be established as a function of superior performance of one hand in comparison with the other (Bishop 1989). From this proposition, larger manual asymmetries would lead to stronger manual preference for the advantaged hand, while symmetric performance between the hands would result in indifferent manual preference. Our results discredit such a proposition. Conversely, the present findings suggest that manual preference and manual asymmetry of performance are independent dimensions of behavior. Before LP of the nonpreferred left hand, all participants declared right hand preference for the practiced and transfer tasks, which is in agreement with a more general trend toward consistent right hand preference, as indicated by the Edinburgh inventory of manual dominance. Following LP, a significant shift of manual preference for the main experimental task was found, with a number of cases of conversion from right to left hand preference. Of particular interest for the purposes of the present study was the finding that such shift of manual preference to the left hand was observed to be generalizable to a transfer task.

Interestingly, generalization of manual preference was not equivalent between the two transfer tasks, although both the serial and repetitive tasks required fast sequences of finger movements. This differential effect between tasks is apparently related to the order of the movements required by each task. While for the serial task a simpler sequence of movements from the little to the index finger was required, in the repetitive task, triplets of finger movements had to be performed in the same order of the practiced task. As LP of sequential motor actions has been shown to lead to changed activation of cerebral areas associated with planning of the sequential order of movements (Grafton et al. 1998, 2002; Hlustık et al. 2002; Haaland et al. 2004; Parsons et al. 2005), neural adaptability at that neural component by learning a particular sequence of transitions between finger movements might be related to conversion from right to left manual preference in the repetitive transfer task. Supporting this proposition, Parsons and colleagues (2005) have shown that increased cortical activity in transfer tasks following extensive practice of sequential finger movements correlated with increased reaction time, but not with increased movement time. This result suggests that the transfer tasks interfered with the neural representation of plans for the sequential movements, but not with processes controlling their implementation. Thus, it is apparent that changing an extensively practiced sequence of movements requires resources from higher order levels of processing, in order to specify a new sequence and inhibit the learned ones, making movement control less automatic. Requirement of a more controlled execution of the sequence of finger movements leads to a context similar to performing a new motor task, potentially reducing the preference of the practiced hand in the transfer task. From this interpretation, we hypothesize that sequence of transitions between fingers, rather than dexterity in moving individual fingers, was the main factor determining a significant shift of manual preference for repetitive but not for the serial task.

Persistence of a shifted manual preference for the main and for the repetitive transfer task after 30 days of rest demonstrates that LP had an enduring effect (cf. Teixeira and Teixeira 2007). As indicated by non-significant values of correlation between scores of manual asymmetry and manual preference, such shift of manual preference was found not to be due to asymmetrization of performance favoring the left hand (cf. Dassonville et al. 1997). Even though manual asymmetry can not be disregarded as a factor contributing to definition of manual preference in motor tasks featured by expressive manual asymmetry favoring one hand, lack of association between manual asymmetry and manual preference in the main and transfer tasks in this study requires alternative explanations other than performance asymmetry for the observed variation of manual preference.

Investigating functional brain activation following practice of the preferred right hand on a visuomotor task, Floyer-Lea and Matthews (2004) observed that the initial, attentionally demanding stage of learning was associated with greater activity in predominantly cortical regions, including prefrontal, sensorimotor, and parietal cortices. As performance improved with extensive practice, cortical activity decreased (cf. Morgen 2004), giving place to enhanced activity in subcortical motor regions (cf. Floyer-Lea and Matthews 2005; Puttemans et al. 2005). These findings suggest that as a task is progressively automated by means of learning, subcortical circuits become dominant, making movement control attentionally less effortful. In line with these results, we propose that shift of manual preference might be a consequence of a more automatic processing of sensorimotor information required to maintain accurate motor output. Lateralized practice would lead then to a less effortful processing when the task is performed by the practiced hand, with a more comfortable execution of the motor act, a situation potentially leading to its selection.

An alternative explanation for shift of manual preference as a result of LP, although not incompatible with the automatization of sensorimotor processing hypothesis, has been presented by Teixeira and Teixeira (2007). According to that proposition, an important component defining manual preference is conceived to be an increased confidence on a single hand developed on the basis of the recent history of differential use of the limbs on a motor task. From this conceptualization, an individual becomes more confident on that hand used more frequently in previous opportunities to perform a motor task. This increased confidence would influence the choice of the hand to perform the practiced and related motor tasks in future instances. Findings of generalizable shift of manual preference, thus, are in agreement with expectations from the proposition of establishment of manual preference from increased confidence on the practiced limb.

In conclusion, our findings represent direct evidence for the effect of learning on human laterality, supporting the notion of handedness as a dynamic aspect of motor behavior (cf. Provins 1997; Serrien et al. 2006). Worth noticing in this regard is the fact that the reported modifications of manual preference took place in right-handers, some of whom declared to have become consistent left-handers for those experimental tasks after practice. Further, demonstration that manual preference was not related with manual asymmetry leads to the notion that general manual preference might be the precursor of manual asymmetries in a number of motor tasks rather than the prevalent point of view that manual preference is determined by manual asymmetry. Generalization of manual preference forged by unimanual experiences on a single task to related motor actions may be a key point to understand why one hand is consistently preferred for execution of voluntary movements even when that hand is not superior in performance.

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