THE EFFECT OF LONG-TERM BIMANUAL TRAINING ON ARM SELECTION DURING REACHING TASKS

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Abstract:

Handedness is viewed either as a preference or an asymmetry in sensorimotor performance. It has been shown that there is a relation between sensorimotor performance and hand selection. This relation is affected by the manipulation of sensory feedback, suggesting an effect of task condition on hand selection, and by a unimanual athletic training. Thus, in the current study, the aim was to find out if arm selection and symmetry were affected by a long-term bimanual practice with respect to motor performance. Right-handed rowers and non-rowers were tested on sensorimotor performance for both arms and its correspondence to plausible changes in the pattern of hand selection during a reaching task. EZ Kinetics KineReach System (2014) was used for data collection. It was hypothesized that the rowers would express less interlimb asymmetry compared to the non-rowers, which in turn, would lead them to display a different pattern of hand selection. Consistent with the hypothesis, the rowers improved their relative performance for both arms, thus performance appeared to be more symmetrical for the rowers than for the non-rowers. Symmetric performance for the rowers led them to have more symmetrical hand choices compared to the non-rowers. Arm selection resulting from interlimb performance differences can be affected by a long-term bimanual practice.

Key words: *arm selection, motor asymmetry, lateralization, rowers, bimanual training*

Introduction

Approximately 90% of the population is right-handed (Caliskan & Dane, 2009; Jung & Jung, 2009; Perelle & Ehrman, 1994; Vuoksimaa, Koskenvuo, Rose, & Kaprio, 2009) and prefer to use their dominant hand as they reach for an object. While one may choose non-dominant, dominant or both hands depending on task requirements, hand preference is generally assumed an invariant, biologically based trait. However, several studies have contested this view by demonstrating that other factors such as object location and attentional information related to task demands can influence hand preference (Gabbard, Tapia, & Helbig, 2003; Gabbard & Rabb, 2000; Helbig & Gabbard, 2004; Leconte & Fagard, 2006; Mamolo, Roy, Bryden, & Rohr, 2004). On the other hand, when the task dependency is minimized, if not eliminated, the right hand selection bias has been attributed to hand preference.

To identify factors that may influence hand preference for reaching tasks, researchers noticed that strongly lateralized right-handers used their dominant hand to cover approximately 60% of the frontal space (Gabbard & Rabb, 2000). The midline of reaching frequency was skewed to the left by approximately 20 degrees in reference to the midline of the body (Helbig & Gabbard, 2004). This midline shift of the right hand reaches was also confirmed in a more recent study (Przybyla, Coelho, Akpinar, Kirazci, & Sainburg, 2013). Removal of visual feedback resulted in fewer dominant arm reaches that decreased the dominant arm's breach across the midline. Kinematic analysis revealed that under conditions with no visual feedback, interlimb differences in hand path straightness were reduced and the non-dominant arm was actually more accurate than the dominant arm. In turn, this change in motor performance could have contributed to more non-dominant arm reaches. Another study comparing interlimb differences between hands showed that more frequent dominant arm reaches might be responsible for their higher efficiency (Coelho, Przybyla, Yadav, & Sainburg, 2013). For reaching toward midline targets, the dominant arm movements involved greater contributions from interaction torques generated by the shoulder, which reduced overall muscle torques at the shoulder and elbow of the dominant arm. The mentioned studies suggest that more frequent dominant arm reaches may be attributed to a higher efficiency of the dominant arm than the non-dominant arm in terms of accuracy and better coordination patterns.

Other researchers have also suggested that hand preference can be influenced by intensive training (Mikheev, Mohrb, Afanasiev, Landis, & Thut, 2002). There are some reports stating that a relatively large number of adult left-handers have experienced attempts to switch writing hand to the right side (Porac & Searleman, 2002; Porac & Martin, 2007). In some countries such as China and Japan, left-handed people have historically and still currently been forced from childhood to use their right hands for tasks such as eating and writing (Sato, Demura, Sugano, Mikami, & Ohuchi, 2008).

In line with this proposition, some researchers reported that motor preferences, as well as the cortical representations of body are not predetermined entities and can be adapted through experience such as sport or musical practice (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995). A recent study by Maeda, Souza, and Teixeira (2014) also showed a shift of manual preference between kung fu experts and amateurs indicating a weaker strength of right hand preference across kung fu experts when compared to the hand preference of amateurs. The authors also found a decreased intermanual performance asymmetry in some kung fu specific movements for the kung fu experts but not for the amateurs. Moreover, it has been more recently examined if participation in a unimanual sport (fencing) would modify performance asymmetries and, therefore, hand preference (Akpinar, Sainburg, Kirazci, & Przybyla, 2015). The results displayed substantially less interlimb asymmetry in the performance of arm reaching for the fencers compared to the non-fencers. This less interlimb asymmetry resulted in a shift of arm selection, which was in accordance with the impedance and predictive control stated in the dynamic model of motor lateralization (Sainburg, 2002, 2005; Yadav & Sainburg, 2014). The findings of the mentioned studies suggest that extensive practice can cause a shift in hand preference. However, studies conducted to find the effect of practice on hand preference are limited in a number of ways, such as utilization of qualitative data and focus only on the practiced task. The aforementioned study by Akpinar et al. (2015) focused on the effects of extensive unilateral training on arm preference, but there was nothing about the effects of bilateral training on arm preference.

In the current study, therefore, the effects of a long-term bimanual practice on motor performance and subsequent arm selection choices were examined. Interlimb performance asymmetry and arm selection patterns were compared between rowers and non-rowers. Rowing was chosen as an activity that requires both-sided coordination of both the lower and upper limbs. Rowing is based on propelling a boat on water using oars. The oars are used to push against the water to generate a force that moves the boat. Although physical strength and endurance are crucial parameters in rowing, it is imperative rowers have a high level of technique and skill to be able to perform the cycling movements efficiently (Hoffmann, Filippeschi, Ruffaldi, & Bardy, 2014). In this respect, the rowers' dominant and non-dominant arm need to work together to perform rowing strokes; therefore a high level of interlimb coordination is mandatory. As rowing includes mainly bimanual coordinated movements, it has been hypothesized that extensive practice with both arms should increase motor performance of both arms and decrease the interlimb difference among rowers. The decreased interlimb difference should lead to the increased usage of the non-dominant arm as compared to the arm preference in the non-rowers. To test this hypothesis, a task was implemented requiring reaching a target with either hand and aimed at investigating whether there is an effect of bimanual athletic training on the interlimb differences in sensorimotor performance and on the patterns of arm selection.

Methods

Participants

Eight healthy young rowers (4 females), aged between 18-24 years (M=21.4, SD=1.5), and eight healthy young non-rowers (4 females), aged between 18-23 years (M=21.1, SD=1.5), voluntarily participated in this study. All the participants signed the consent form approved by the Institutional Review Board of the Pennsylvania State University, which was in accordance with the Declaration of Helsinki as amended by the World Medical Association Declaration of Helsinki (World Medical Association, 2013). Rowing experience ranged between 5-10 years (M=6.6, SD=1.9) and it included experience in both the sweep and sculling techniques. The rowers were all at a competitive level and they practised at least 5 days a week and twice daily. The non-rowers did not participate in any sports. The data used for the non-rowers were gathered from the previously published study by Akpinar et al. (2015). All the participants reported right-handedness and scored above 90% on the extended 35 items handedness questionnaire (Hull, 1936), which is similar to the widely known Edinburgh Inventory (Oldfield, 1971).

Experimental design

EZ Kinetics KineReach System (2014) was used for data collection in this study. This system provides an interactive game-like situation for the participants. As the participants try to reach the target, electromagnetic sensors attached to the lower and upper arm record their arm movements (six-degree-of-freedom Flock of Birds tracking system, Ascension Technology, USA). This system has an accuracy rate of 1.4 mm root mean square (RMS) and 0.5 degrees RMS. Thus, this system is valid and reliable to measure human movements in both 2D and 3D. This setup measured reaching movements in the 2D horizontal space in front of the participant. Participants' arms were covered by a mirror onto which one cursor, one start position for each hand, and targets were projected from a 55" flat screen TV, which displayed a virtual reality interface. The participants sat in an adjustable chair with each arm supported against the effects of gravity and friction by an air sled to minimize possible effects of fatigue during the course of the task performance.

Three experimental sessions were organized for the participants. Each session was separated from each other by at least a two-week interval to avoid potential interlimb transfer. Each session consisted of reaches performed by the dominant arm only, by the non-dominant arm only, and by either the non-dominant or dominant arm as selected by participants. The first two conditions were named as the non-choice conditions and were designed to determine interlimb difference. The last condition was the choice condition and designed to determine hand preference pattern. These conditions were counterbalanced across participants.

The matrix of 32 targets located in the frontal space was displayed to the participants (Figure 1). These targets were arranged to each individual with respect to participant's arms size and initial joint angles. The locations of the starting position were identified for each participant based on the initial joint angles with the shoulder external and elbow internal angles being 25 and 75 degrees, respectively. In order to avoid any visual and spatial asymmetry between targets, the location of starting positions in parasagittal planes were averaged across the left and right hands and maintained through experimental sessions. The lines of targets in the transverse plane corresponded to 25, 40, 55 and 70% of the maximum distance measured between the starting position and the tip of the index finger when the arm was fully extended. The lines of targets in parasagittal planes were spaced symmetrically from the midsagittal plane into the left and the right hemispace by a quarter of the distance between the starting positions. This design aimed at achieving dense sampling of frontal space.

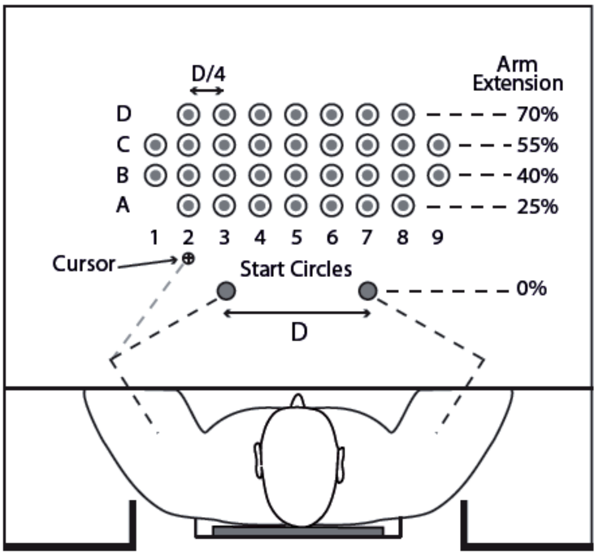

Figure 1. The distribution of the matrix of 32 targets.

Experimental task

Participants were asked to perform 320 reaching movements (10 per target) from the start circles (2 cm in diameter) that represented the starting positions to targets (3.5 cm in diameter), which were presented in pseudo-randomized order. The size of both the starting and target circles was taken from the previous study by Akpinar et al. (2015), which examined optimal starting circle and target size for the KineReach System.

The participants were instructed to reach displayed targets rapidly while maintaining accuracy and to stop on the target with no additional corrections. Trials were one second in duration and were initiated with a beep signal after both cursors (1.25 cm in diameter cross hair) were held in the start circles for the duration of 0.3 s. One target was displayed prior to the trial initiation giving a participant as much time as required for movement planning. Thus, the participants had unlimited time for planning reaching movement in both the non-choice conditions and to arm selection in the choice condition. Accuracy was rewarded with 10, 3 and 1 point for landing within 3.5, 4.5 and 5.5 cm diameter from the center of the target, respectively. These points were provided to motivate the participants throughout the experiment.

Data processing and statistical analysis

Displacement data were collected at 130 Hz and processed using 8 Hz dual pass fifth order Butterworth filter. In order to determine interlimb differences in movement performance, two dependent measures were quantified to examine movement accuracy (Final Position Error = FPE) and movement quality (Hand Path Deviation from Linearity = HPDL). The FPE was defined as the Euclidian distance between the center of the target and the 2D final position of the tip of the index finger represented by the cursor. The HPDL was defined as the ratio between the minor and the major axis of the movement path of the index finger (hand path). The major axis was defined as the farthest distance between any two points given on the hand path, and the minor axis was defined as the farthest distance perpendicular to the major axis from any given point on the hand path.

Means of these individual dependent measures of task performance (FPE and HPDL) and distribution of reaching frequency were analyzed using a 3-way mixed model ANOVA, with arm (dominant or non-dominant) and regions of space (right, middle and left) as the within-subject factors, and group (non-rowers or rowers) as the between-subject factor. Two different mixed model ANOVAs were conducted to investigate whether FPE and HPDL were different between the non-rowers and rowers for the dominant and non-dominant arm in three regions of space. Note that the right, middle, and left regions included targets to the right of the midline of the body (see Figure 1A, columns: 6-9), on the midline of the body (column 5), and to the left of the midline of the body (columns: 1-4), respectively.

In order to examine arm selection patterns in the choice condition, similar to the FPE and HPDL, the total of the dominant and the non-dominant arm reaching frequency across three regions for the rowers and non-rowers were quantified (Please see 4C), and then a 3-way mixed model ANOVA was conducted. For all the analyses, the participants were treated as a random factor and statistical significance was tested using an alpha value of .05 and *post-hoc* analysis was conducted using Bonferroni adjustment. Please note that movement speed was matched between both groups and across conditions, thus there was no effect on the dependent measures.

Results

The results of this study are presented in two parts. The first part presents interlimb differences between the rowers and non-rowers. The second part presents pattern of hand preference towards targets spanning entire workspace for the rowers and non-rowers, and investigates if these limb choices can be predicted with motor performance variables.

Interlimb differences between the rowers and non-rowers

Final position error (FPE):

Figure 2 presents average value of final position error (FPE) for each target with each arm for (a) non-rowers and (b) rowers. Standard error bars for the three regions (left, middle, right) are presented in Figure 2c for each of the 4 groups (rowers/non-rowers × dominant/non-dominant). Overall, the rowers were considerably more accurate than the non-rowers, and the dominant and non-dominant arms of the rowers showed lower difference in movement accuracy. On the other hand, the dominant arm of the non-rowers was substantially more accurate than their non-dominant arm. A 3-way mixed model ANOVA with regions (left/middle/right) and arms (dominant/non-dominant), as within-subject factors, and groups (rowers/non-rowers), as between-subject factor, revealed a main effect of group, $F_{(1,14)}$=20.25, p=.0005, η^2=.59. This main effect revealed that the rowers' arm movements were significantly more accurate than that of the non-rowers. A 2-way interaction between region and arm ($F_{(2,28)}$=16.65, p=.00001, η^2=.54) indicated that FPE varied differently for the two arms between regions. *Post-hoc* analysis revealed that the non-dominant arm performed significantly worse than the dominant arm in the right region of space. Overall, the rowers performed reaching movements significantly more accurately, with a similar performance of their both arms (non-dominant arm = 0.013±0.001 m and dominant arm = 0.013±0.002 m), compared to the non-rowers (non-dominant arm = 0.022±0.006 m and dominant arm = 0.018±0.005 m).

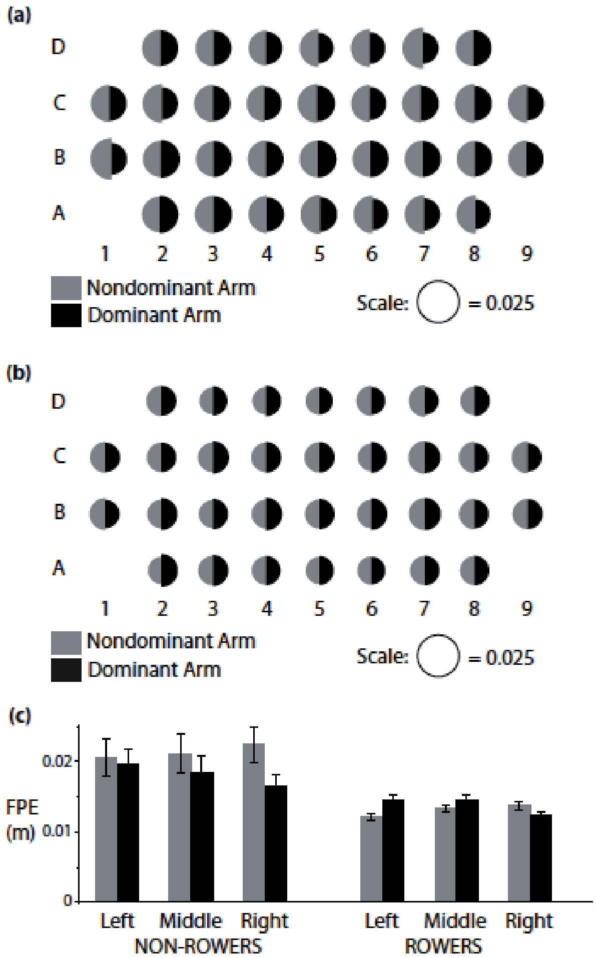

Figure 2. Final Position Error (FPE): (a) The magnitude of the FPE averaged across non-rowers for each target for the dominant (black half circle) and non-dominant arm (grey half circle); (b) The magnitude of the FPE averaged across rowers for each target for the dominant (black half circle) and non-dominant arm (grey half circle), the scale for each semicircle was 0.025m; (c) The non-rowers and rowers averaged across target regions and arms.

Hand Path Deviation from Linearity (HPDL): The other dependent variable depicting interlimb difference was hand path deviation from linearity (HPDL). Figure 3 shows HPDL averaged for each target across the non-rowers (Figure 3a) and rowers (Figure 3b). Similar to the presentation of FPE, the dominant arm's performance is shown like black half circles and the one of the non-dominant arm as grey half circles. For the statistical analysis, similar to FPE, targets were placed into three regions (left, middle, and right). HPDL measures were subjected to a 3-way mixed model ANOVA (3 regions × 2 arms × 2 groups). The average values representing this 3-way model are shown in Figure 3c. The result of the statistical analysis showed a significant main effect of arm ($F_{(1,14)}$=7.76, p=.01, η^2=.36) and significant region × arm interaction ($F_{(2,28)}$=24.58, p=.000001, η^2=.64). The main effect of arm revealed straighter reaching movements of the dominant arm compared to the non-dominant arm. *Post-hoc* analysis for region and arm interaction revealed that the non-dominant arm had a significantly larger HPDL than the dominant arm in the middle and right regions (p<.01). Moreover, statistical analysis also showed a significant main effect of region ($F_{(2,28)}$=4.35, p=.02, η^2=.24) and group x region interaction ($F_{(2,28)}$=4.53, p=.02, η^2=.24). The main effect of region revealed that movements to the right region were significantly straighter than movements to the middle region. The *post-hoc* analysis for the interaction between group and region displayed that the rowers had significantly straighter movements to the left region compared to the non-rowers. In fact, the rowers' reaching movements of both arms were very similar (non-dominant arm = 0.057±0.003 and dominant arm = 0.055±0.002) in terms of HPDL to the left region of space, but this was not the case in the non-rowers (non-dominant arm = 0.076±0.027 m and dominant arm = 0.066±0.016). Even though the rowers had substantially straighter movements of their non-dominant arm compared to the non-rowers, the main effect of group did not reach level of significance ($F_{(1,14)}$=3.80, p=.07, η^2=.07).

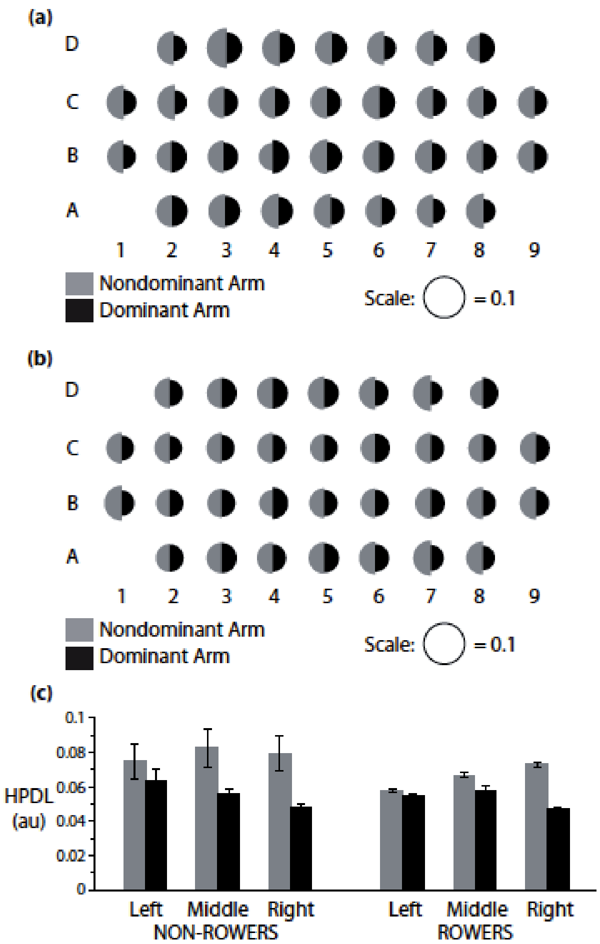

Figure 3. Hand Path Deviation from Linearity (HPDL): (a) The magnitude of the HPDL averaged across non-rowers for each target for the dominant (black half circle) and non-dominant arm (grey half circle); (b) The magnitude of the HPDL averaged across rowers for each target for the dominant (black half circle) and non-dominant arm (grey half circle), the scale for each semicircle was 0.1; (c) The non-rowers and rowers averaged across target regions and arms.

Overall, the results for the non-rowers were similar to the findings of previously published studies (Coelho, et al., 2013; Przybyla, et al., 2013), whereas improved performance, especially for FPE, observed in the rowers as a group probably resulted from a long-term bimanual practice. In fact, the rowers showed more improvement in their non-dominant arm than their dominant arm for both FPE and HPDL. As recent studies with non-athletes (Przybyla, et al., 2013) and fencers (Akpinar, et al., 2015) showed modulation of arm selection with respect to changes in sensorimotor performance, it was predicted that changes in motor performance in the rowers would modulate the pattern of arm selection and result in a more frequent usage of their non-dominant arm in reaching tasks. Moreover, as the rowers displayed significantly better HPDL in the left region of space compared to the non-rowers, arm selection pattern should differ between the two groups in that region.

Arm selection pattern of the rowers and non-rowers

Figures 4a and 4b display the distribution of reaching frequencies, averaged across participants for each target and for either group (non-rowers and rowers). Each pie chart in those figures reflects the percentage of total reaches made by either the non-dominant (light grey) or the dominant arm (black). Both groups used their dominant arm almost exclusively to reach the targets located on the right and middle regions (Figures 4a and 4b). Consistent with previous studies (Mamolo, et al., 2004; Przybyla, et al., 2013), the non-rowers chose their dominant arm more than the non-dominant arm for some of the targets located on the left region of the space

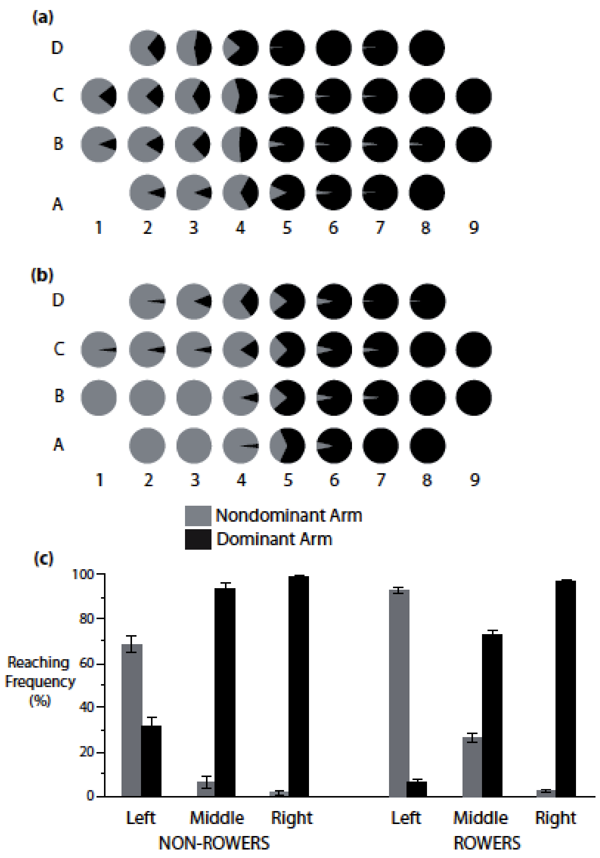

Figure 4. Reaching Frequency % (RF): (a) The magnitude of the RF averaged across non-rowers for each target for the dominant (black color) and non-dominant arm (grey color); (b) The magnitude of the RF averaged across rowers for each target for the dominant (black color) and non-dominant arm (grey color), scale for the circle was 100%; (c) The non-rowers and rowers averaged across target regions and arms.

(targets C4 and D4 in Figure 4a). Interestingly, this pattern was not observed in the rowers whose dominant arm reaches were reduced in the left region. The statistical analysis for reaching frequency displayed a three-way interaction ($F_{(2,28)}$=20.41, p=.0001, η^2=.59). The *post-hoc* analysis revealed that each arm was used significantly more frequently on its own region for both the rowers and non-rowers. However, the rowers used their non-dominant arm significantly more frequently in the left and middle region than the non-rowers (left region: rowers = 93% vs. non-rowers = 68%, middle region: rowers = 26.5% vs. non-rowers = 6.5%). Overall, the pattern of hand selection was different between the non-rowers and rowers.

Discussion and conclusions

Sensorimotor performance asymmetries between the dominant and the non-dominant arm have been shown to predict patterns of hand selection for reaching movements across horizontal space in front of subjects (Przybyla, et al., 2013; Coelho, et al., 2013). Moreover, changes in sensorimotor performance in response to visual feedback conditions, e.g. performing reaching movements with vision vs. no vision, had predictable effect on the pattern of hand selection (Przybyla, et al., 2013). Studies also reported that not only unimanual practice with the non-dominant arm (Teixeira & Okazaki, 2007; Teixeira & Teixeira, 2007), but also bimanual practice (Maeda, et al., 2014; Mikheev, et al., 2002; Stockel & Weigelt, 2012) increased the usage of the non-dominant arm for certain tasks. In a very recent study it has also been found that unimanual athletic training predominantly with the right arm can modulate the arm selection pattern (Akpinar, et al., 2015).

In the current study it was questioned whether a long-term professional bimanual athletic training can change the sensorimotor performance and thus alter the pattern of hand selection. The first question was whether a long-term bimanual practice changes the sensorimotor performance asymmetries. Overall, it has been generally accepted that athletes have better performance in some motor tasks, like balance (Davlin, 2004), strength (Sleivert, Backus, & Wenger, 1995), and speed than non-athletes. Moreover, superior performance of athletes as a result of the long-term practice has also been observed in some perceptual motor skills, like reaction time (Chan, Wong, Liu, Yu, & Yan, 2011; Di Russo, Taddei, Apnile, & Spinelli, 2006). Besides scoring better on perceptual motor skills, athletes also displayed better sensorimotor performance in comparison to non-athletes (Akpinar, et al., 2015; Ramsay & Riddoch, 2001). The effect of long-term practice on sensorimotor performance has also been observed in musicians (Rodrigues, Loureiro, & Caramelli, 2013). Based on the aforementioned studies, the first and the very basic prediction was that the rowers would change sensorimotor performance, most likely by improving, in comparison to performance of the non-rowers in the same task. More importantly, one of the main interests was to identify whether interlimb differences in sensorimotor performance persisted and/or were they been altered in response to long-term bimanual practice. One would expect to see an improved performance of both arms in the rowers compared to both arms of the non-rowers, as the former mainly perform bimanual tasks in their practice. Confirming this idea, data from the non-choice conditions showed that the rowers performed more accurate reaches with their both arms than did the non-rowers using the corresponding arm. Moreover, the rowers displayed less interlimb asymmetry compared to the non-rowers for FPE. The scores of the non-rowers were, generally, very similar to those in recent studies (Coelho, et al., 2013; Przybyla, et al., 2013).

In rowing, optimal technique is essential not only for performance improving, but also for minimizing injury risks (Jones, Allanson-Bailey, Jones, & Holt, 2010). A rowing stroke consists of drive and recovery phases. It is important a rower performs efficiently these phases with his/her both arms. Therefore, both arms should coordinately work together to perform the technique efficiently. Also, consistent performance of both arms is also required. In a study, it has been found that elite rowers, in ergometer rowing, demonstrated similar and consistent technique at all stroke rates; junior rowers performed similar to elite rowers with some deviations, and between non-rowers' technique varied across the examined stroke rates (Cerne, Kamnik, Vesnicer, Gros, & Munih, 2013). Thus, performing skillful strokes consistently requires expertise, and precondition for effective bimanual control of the arms. In this respect, decreased interlimb difference found in the current study in rowers may be a requirement for skillful performance for both the sculling and sweep techniques in rowing. Symmetrical performance of both body sides has also been found in taekwondo (Čular, Miletić, & Miletić, 2010). Taekwondo athletes displayed similar performance of the left and the right side of their body in some tests of motor abilities (flexibility, strength and explosive leg strength) and performance quality test of two basic taekwondo techniques. This may imply that athletes need to improve both body sides to acquire proficiency in their sports.

Superior performance of any athlete can be linked to some neurophysiological characteristics. The brain of an athlete needs to adapt to various types of behavior when performing skilled movements under different conditions and in changing environments (Nakata, Yoshie, Miura, & Kudo, 2010). These neural brain activations can include perception, decision-making, motor preparation, and execution of movements. In fact, some studies reported changes and shifts in brain activation as a result of a long-term practice among both musicians (Ridding, Brouwer, & Nordstrom, 2000) and athletes (Pearce, Thickbroom, Byrnes, & Mastaglia, 2000). Thus, the brain demonstrates plasticity in the reorganization following long-term skill acquisition; this may also improve performance when executing another skill or movement, like the one observed in the current study. Through the long-term bimanual practice, the cortical activation in both brain hemispheres may improve. These improved neural activations may result in a superior performance of perception, decision-making, motor preparation, and execution of movements for both arms in rowers compared to non-rowers. Moreover, it has also been stated that bimanual training is beneficial to improving the interlimb coordination in rehabilitation (Sleimen-Malkoun, Temprado, Thefenne, & Berton, 2011). The beneficial effect of bimanual training was also found in the virtual tracking arm reaching (Trlep, Mihelj, & Munih, 2012). Bimanual training improved both a single limb performance with the dominant arm and performance of bimanual movements. In this study, rowing training improved both arms' performance of reaching movements. However, the results of the study could have been affected by other factors, such as subjects' personal motivation or competitiveness, particularly because of the comparison between the rowers and non-rowers. For future studies, it would be good to examine similar traits among athletes of a similar skill level across sports that do not require bimanual activity.

As the rowers showed superiority in FPE as a group and in HPDL in the left region of space, it was expected that their arm selection should be more symmetrical compared to the non-rowers. In order to assess the effect of a long-term bimanual practice on the pattern of arm selection, the participants in both groups were instructed to choose an arm to aim at one of the thirty-two targets on each trial. Generally, hand preference studies showed that strongly lateralized right-handers use their dominant arm to cover approximately 60-68% of the frontal space in reaching movements (Coelho, et al., 2013; Przybyla, et al., 2013). However, this pattern of hand preference could be affected by manipulating the sensory information (Przybyla, et al., 2013), via the non-dominant arm practice (Teixeira & Teixeira, 2007; Teixeira & Okazaki, 2007), or by the participation in sports requiring unimanual (Akpinar, et al., 2015) and bimanual performance (Maeda, Souza, et al., 2014; Mikheev, et al., 2002). Thus, it is possible to shift the pattern of hand preference. The current data from the non-rowers is consistent with previous studies; however, the pattern of arm selection is different for the rowers. Namely, the rowers used their dominant arm less on the contralateral region than the non-rowers. It is still important to point out that the dominant arm is selected more than the non-dominant arm in both groups. The important difference in the limb selection pattern between the rowers and non-rowers was the point where the participants switched from using mostly dominant arm to mostly non-dominant arm (no target was reached to with more than 50% frequency by the dominant arm in the left region for the rowers). This switching point is further away from the body midline for the non-rowers compared to the rowers. This shift is mostly due to the effect of a long-term bimanual practice. Judo (Mikheev, et al., 2002) and kung fu (Maeda, et al., 2014) athletes were found to display more non-dominant left arm preference compared to non-athletes, which was measured via the assessment of a number of handedness items. Their results indicated that the athletes preferred to perform certain motor tasks more frequently using their left hands than the non-athletes, although overall they were right-handed. The result with arm selection in the current study is consistent with the findings in Mikheev et al. (2002), Maeda et al. (2014), and Akpinar et al. (2015). The rowers in the current study manifested better motor performance of both arms and, thus, preferred to use more their non-dominant arm in the left space compared to the non-rowers. In fact, both sensorimotor performance asymmetries and the arm selection pattern found in this study with rowers displayed the similar pattern with the previous study by Akpinar et al. (2015). Even though it has been previously stated in some studies that the effect of a short-term unimanual and bimanual practice on motor performance of both arms can be different (Mutha & Sainburg, 2009), it looks like a long-term unimanual or bimanual sport participation can improve both arms' performance in the case of reaching movements. Even though reaching accurately to targets is not a specific task performed in rowing, it is distinct, and practicing with both arms is biasing hand selection in distinct tasks. Future studies should focus on whether a reduced motor performance asymmetry and thus reduced asymmetry in arm selection can be observed in different practice types, like playing musical instruments. It would be good for rowing talent identification that coaches examine lateralization of potential participants and encourage those who exhibit decreased lateralization to participate in professional rowing or other bimanual activities. In addition, longitudinal studies should also be conducted to investigate if the decreased interlimb difference in rowers is a result of a long-term bimanual practice, or whether it has already existed before starting the sport.

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