



OPEN ACCESS

EDITED BY
Gregory Siy Ching,
Fu Jen Catholic University, Taiwan

REVIEWED BY
Selcuk Akpinar,
Nevşehir Hacı Bektaş Veli
University, Turkey
Sheilla Trajera,
University of St. La Salle, Philippines

*CORRESPONDENCE
Qun Fang
2020910112@qqdu.edu.cn

SPECIALTY SECTION
This article was submitted to
Educational Psychology,
a section of the journal
Frontiers in Psychology

RECEIVED 28 August 2022
ACCEPTED 24 October 2022
PUBLISHED 07 November 2022

CITATION
Fang Q, Xia Y, Zhang X and Huang F
(2022) Asymmetry of interlimb transfer:
Pedagogical innovations in physical
education. *Front. Psychol.* 13:1029888.
doi: 10.3389/fpsyg.2022.1029888

COPYRIGHT
© 2022 Fang, Xia, Zhang and Huang.
This is an open-access article
distributed under the terms of the
Creative Commons Attribution License
(CC BY). The use, distribution or
reproduction in other forums is
permitted, provided the original
author(s) and the copyright owner(s)
are credited and that the original
publication in this journal is cited, in
accordance with accepted academic
practice. No use, distribution or
reproduction is permitted which does
not comply with these terms.

Asymmetry of interlimb transfer: Pedagogical innovations in physical education

Qun Fang*, Yuhang Xia, Xiaochao Zhang and Fang Huang

School of Physical Education, Qingdao University, Qingdao, China

KEYWORDS

interlimb transfer, asymmetry, hemispheric lateralization, physical education, pedagogical innovation

Introduction

Interlimb transfer has long been identified in motor learning, with the consensus that the first research can be traced back to 1894 (Scripture et al., 1894). Effects of unilateral practice transfer to the contralateral limb, resulting in skill improvement of the untrained side (Green and Gabriel, 2018). Research evidence based on the neuroimaging technique suggests that interlimb transfer is more than a phenomenon at the behavioral level. In fact, it is associated with strengthened neural correlates within the motor network (Dirren et al., 2021). A noticeable feature of interlimb transfer is the asymmetrical pattern which indicates greater transfer in one direction than that in the other (Wang and Sainburg, 2004, 2006). Asymmetry of interlimb transfer has been well-documented in a number of motor learning research on manual performance (Sainburg and Wang, 2002; Lavrysen et al., 2003; Teixeira and Caminha, 2003; Galea et al., 2007). The typical design induces learning experience during the experiment by means of visuomotor rotations (Wang and Sainburg, 2004, 2006). Participants initially performed an aiming task by moving a cursor from a start point to a target over a tablet. The cursor displayed the location of the finger directing the cursor. After practices under normal circumstances, visual perturbations were assigned by 30° counterclockwise rotation. In the visuomotor rotation experiment, motor learning represents conscious and progressive corrections for perceived movement errors due to the distorted visual feedback (Taylor et al., 2014).

Theories on the asymmetrical interlimb transfer have been developing over the past decades. The proficiency model is an early hypothesis to provide insights into the asymmetrical transfer. Dominant hemisphere/hand is more proficient than non-dominant hemisphere/hand in motor learning. Practice on the dominant side results in more motor information available for transfer to the non-dominant side. Therefore, the model suggests greater transfer to the non-dominant limb performance following the dominant limb practice (Laszlo et al., 1970). On the other hand, the callosal access model predicts an opposite transfer direction which favors the dominant limb performance (Taylor and Heilman, 1980). According to this model, motor information is stored in the dominant hemisphere, thus facilitating learning and performance of the dominant limb due to the direct access to the stored information. While interpreting the asymmetrical transfer to some extent, the two models still show major limitations

as each model only covers one direction of interlimb transfer. Based on critical analysis of the limitations, Parlow and Kinsbourne (1989) proposed cross activation model with a particular emphasis on bilateral adaptations. This model is based on the observation that unilateral movement activates both contralateral and ipsilateral motor cortices (Dai et al., 2001; van Duinen et al., 2008). Unilateral training over time leads to neural adaptations in both hemispheres, and the neural adaptations in the untrained hemisphere enhance performance of the untrained limb (Ruddy and Carson, 2013).

The limitations of previous models called for more inclusive perspectives on the asymmetrical transfer in motor learning. Sainburg and Wang (2002) provided evidence that transfer direction was specific to task features. In the same arm reaching task, opposite transfer directions were observed in different kinematic measures. Greater contralateral transfer was identified in the initial direction of right arm movements under the rotated visual conditions. On the other hand, right arm training resulted in greater improvement in the final position accuracy of left arm movements. The findings suggest complex mechanisms underlying interlimb transfer, leading to further investigations on the functional specialization in left and right hemispheres.

Dynamic-dominance hypothesis assumes distinct neural mechanisms for particular movement features (Bagesteiro and Sainburg, 2002). While the dominant system is responsible for the regulation of dynamic characteristics of movement (i.e., control of trajectories and force production), the non-dominant system processes visual-spatial information of movement (i.e., control of final positions and targeted precision) (Sainburg, 2002; Stöckel and Weigelt, 2012). Hemispheric specialization for different motor control mechanisms has been shown to influence directions and magnitude of interlimb transfer (Sainburg et al., 2016). With the increasing understandings of hemispheric lateralization and interlimb transfer, the model of specialized processing and transfer was proposed with an essential hypothesis that practice involving the specialized hemisphere-effector system induces a larger transfer of learning than the non-specialized, less efficient hemisphere-effector system (Stöckel et al., 2011). Recent research provided evidence for the model of specialized processing and transfer. In a grooved pegboard task, right-handed participants showed greater transfer after right hand practice than that after left hand practice whereas left-handed participants performed the task with comparable magnitude of transfer after practice on each hand (Wang et al., 2020). Handedness is reflective of hemispheric asymmetry. The different transfer directions between right- and left-handed individuals suggest the impact of hemispheric asymmetry on interlimb transfer. Additionally, hemispheric activations tend to become less asymmetrical in response to increased task complexity. Asymmetrical transfer has been reported in simple tasks during which hemispheric activation is lateralized. On the other hand, complex tasks stimulate bilateral activations, leading to symmetrical interlimb

transfer associated with the reduced hemispheric lateralization (Wang et al., 2022). Therefore, the findings of handedness and task complexity suggest that the model of specialized processing and transfer can provide valid interpretations on asymmetry of interlimb transfer during motor learning.

Motor learning research has been conducted to expand understandings of the neural mechanisms. However, existing research with the purpose of applying neuroscience knowledge and principles to enhance motor learning is still limited. An interesting speculation can be reached about the feasibility to enhance teaching and learning in physical education (PE) by taking advantage of the asymmetrical phenomenon in interlimb transfer. So far, interlimb transfer has been mainly investigated by simple motor actions such as finger tapping and pegboard tasks. It is reasonable to examine whether the asymmetrical pattern observed in the laboratory settings can be extended to the practical conditions in PE classes. The current study proposed the opinion that asymmetry of interlimb transfer may contribute to pedagogical innovations in PE by facilitating the process of teaching and learning sport skills. PE class is the primary affordance for students to learn a novel sport skill (Stöckel et al., 2011). Research on asymmetrical interlimb transfer implies practical value in developing effective teaching strategies to enhance sport skill acquisition.

Pedagogical innovations in PE

Asymmetry of interlimb transfer is indicative of hemispheric functioning. Neuroimaging evidence has shown adaptations in neural circuits associated with improved performance of the untrained limb after unilateral training (Oosawa et al., 2019). Childhood and adolescence are critical periods during which the nervous system is highly plastic (Shaw et al., 2006; Ismail et al., 2017). PE class design in consideration of neural functioning may enhance sport skill acquisition. In recent years, neuroscience is characterized by prominent progress in improving the teaching and learning process for many subjects (Baena-Extremera et al., 2021). Research on asymmetrical interlimb transfer may provide a promising approach to integrate neuroscience into class design and organization, leading to pedagogical innovations in the field of PE.

Class design based on asymmetrical interlimb transfer

While improved performance of the trained limb indicates the principle of specificity, it is also necessary to notice the transfer effects which enhance performance of the untrained limb. Because interlimb transfer is asymmetrical in direction and magnitude, PE teachers and practitioners should consider practicing the side that results in larger transfer effects. For

a specific sport skill, if the right limb practice benefits both right and left limb performance whereas the left limb practice only produces positive effect on the left limb performance, a reasonable selection is to practice the skill with emphasis on the right side. Haaland and Hoff (2003) designed a soccer training program in which the experimental group performed skill practice by non-dominant (left) foot and the control group practiced with no particular demand on which side to use. The experimental group enhanced both left and right foot performance, whereas the control group only improved right foot performance. Between-group comparisons indicated that practice on the non-dominant foot resulted in superior left foot performance and comparable right foot performance to the control group. The findings warrant implementing non-dominant foot practice in acquisition of basic soccer skills.

Whether dominant or non-dominant limb practice produces greater transfer depends on the inherent motor components of the task (Sainburg and Wang, 2002). For the skills involving the visual-spatial information which specializes in the right hemisphere/left limb, particular emphasis on the left limb should be given during the practice. Additionally, dynamic characteristics of movement are processed in the left hemisphere/right limb system. Greater transfer effects can be achieved by the right limb practice on the skills involving the regulation of movement dynamics.

Evidence in accordance with the hypothesis was provided in a study which examined two types of throwing skills with particular demands on accuracy and force production (Stöckel and Weigelt, 2012). The training program lasted 8 weeks during which participants began the training with one hand in the first 4 weeks and then switched to the other hand practice in the last 4 weeks. In the task with an emphasis on throwing accuracy, initial practice on the non-dominant hand enhanced performance of both hands to a greater extent than the opposite order. In contrast, participants with initial practice on the dominant arm showed larger beneficial transfer than their counterparts with initial practice on the non-dominant arm when performing the throwing task with an emphasis on maximum force.

The throwing tasks with a particular demand on accuracy involves visual-spatial processing (e.g., trajectory control) in the right hemisphere/left limb system. Practice on the left hand is in line with the specialized hemisphere-effector system, thus resulting in greater transfer effects. Same rules can be applied to the task with a demand on throwing force. The left hemisphere/right hand system specializes in regulation of movement dynamics such as force production (Serrien et al., 2006). Practice on the dominant hand establishes a better representation of the specialized left hemisphere/right hand system in motor skill acquisition, leading to larger transfer from the right hand practice to the left hand performance.

Additional evidence was provided by 6-week fencing training sessions which were developed in accordance with the hemispheric lateralization hypothesis (Witkowski et al.,

2018, 2020). The ratio of non-dominant (left) side to dominant (right) side practice was 3:1, as each drill repeated three times on the left limb associated with one practice on the right limb. The control group, on the other hand, implemented practice only with the dominant side. Although fencing is a unilateral sport, bilateral practice resulted in greater improvement in hitting accuracy of the dominant hand than that after unilateral practice. Because the right hemisphere/left limb system specializes in spatial characteristics of movement, training with an emphasis on the left side enhances the specific neural network, producing transfer effects to the dominant hand performance. Therefore, evidence from the existing research implies promising applications of asymmetrical transfer to PE. Class design in accordance with asymmetry of interlimb transfer would promote time efficiency of teaching and learning.

Framework for future endeavors

Despite the promising applications of interlimb transfer, direct evidence with respect to pedagogical practice is still limited, which warrants future research on the relevant topic. A four-phase framework to guide subsequent research work is provided in this section.

Successful application of asymmetrical interlimb transfer to PE underlies the link between the trained limb and the specialized hemisphere-effector system in skill learning. The initial phase should classify individual sport skills (e.g., passing and dribbling) into corresponding hemisphere-effector systems. The fundamental work is to identify the skills which are dominantly processed by the right hemisphere/left limb system and those mainly processed by the left hemisphere/right limb system. The second phase involves conducting experimental studies to testify efficacy of the existing models in predicting and explaining the effects of applying asymmetrical transfer to sport skill acquisition. Marinsek (2016) provided a valid study design to examine lateral asymmetry in dribbling skill practice. Participants were randomly allocated to dominant limb practice group, non-dominant limb practice group, or bilateral practice group. Outcomes in relation to each teaching strategy were examined by within- and between-group comparisons. The third phase, after the study design and implementation, aims to interpret the results by available theoretical models. The findings may be inconsistent with the hypothesis that practice on the specialized hemisphere-effector system induces a better transfer of learning across limbs. Indeed, inconsistent findings have been reported by the existing literature. For the dribbling practice in soccer, some studies identified better learning outcomes associated with non-dominant limb practice (Haaland and Hoff, 2003; Teixeira et al., 2003), while evidence also indicated favorable transfer effects after dominant limb practice (Marinsek, 2016). The magnitude and direction of transfer may be influenced by

various factors such as age of participants (Marinsek, 2016) and types of sport skills (Stöckel and Weigelt, 2012). It is possible that the existing models may be inadequate to interpret all research findings, thus leading to the fourth phase of refining the models if necessary. With the cumulative understandings of the mechanisms underlying interlimb transfer in sport skill acquisition, principles of neuroscience and motor control can be better applied to enhance teaching and learning effects in PE classes.

Conclusion

The current study highlighted asymmetry of interlimb transfer as a potential contribution to pedagogical innovations in the field of PE. Asymmetrical transfer is considered a reflection of functional lateralization in left and right hemispheres. Taking advantage of this interlimb phenomenon may enhance time efficiency of teaching and learning a novel sport skill. The basic rule to guide teaching practice can be summarized in the statement that practice involving the specialized hemisphere-effector system induces greater transfer effects, thus facilitating acquisition of sport skills. The empirical evidence implies high practical value for PE class design and implementation, which warrants future research work on the relevant topic. Accordingly, a four-phase framework was proposed to guide following research and pedagogical practice. The current study calls for more attention to the innovative teaching strategy which indicates a promising combination between neuroscience and PE.

References

- Baena-Extremuera, A., Ruiz-Montero, P. J., and Hortigüela-Alcalá, D. (2021). Neuroeducation, motivation, and physical activity in students of physical education. *Int. J. Environ. Res. Public Health* 18, 2622. doi: 10.3390/ijerph18052622
- Bagesteiro, L. B., and Sainburg, R. L. (2002). Handedness: dominant arm advantages in control of limb dynamics. *J. Neurophysiol.* 88, 2408–2421. doi: 10.1152/jn.00901.2001
- Dai, T. H., Liu, J. Z., Sahgal, V., Brown, R. W., and Yue, G. H. (2001). Relationship between muscle output and functional MRI-measured brain activation. *Exp. Brain Res.* 140, 290–300. doi: 10.1007/s002210100815
- Dirren, E., Bourgeois, A., Klug, J., Kleinschmidt, A., van Assche, M., and Carrera, E. (2021). The neural correlates of intermanual transfer. *Neuroimage*. 15, 118657. doi: 10.1016/j.neuroimage.2021.118657
- Galea, J. M., Miall, R. C., and Woolley, D. G. (2007). Asymmetric interlimb transfer of concurrent adaptation to opposing dynamic forces. *Exp. Brain Res.* 182, 267–273. doi: 10.1007/s00221-007-1069-y
- Green, L. A., and Gabriel, D. A. (2018). The cross education of strength and skill following unilateral strength training in the upper and lower limbs. *J. Neurophysiol.* 120, 468–479. doi: 10.1152/jn.00116.2018
- Haaland, E., and Hoff, J. (2003). Non-dominant leg training improves the bilateral motor performance of soccer players. *Scand. J. Med. Sci. Sports* 13, 179–184. doi: 10.1034/j.1600-0838.2003.00296.x
- Ismail, F. Y., Fatemi, A., and Johnston, M. V. (2017). Cerebral plasticity: windows of opportunity in the developing brain. *Eur. J. Paediatr. Neurol.* 21, 23–48. doi: 10.1016/j.ejpn.2016.07.007
- Laszlo, J. I., Baguley, R. A., and Baird, P. J. (1970). Bilateral transfer in tapping skill in the absence of peripheral information. *J. Mot. Behav.* 2, 261–271. doi: 10.1080/00222895.1970.10734884
- Lavrysen, A., Helsen, W. F., Tremblay, L., Elliott, D., Adam, J. J., Feys, P., et al. (2003). The control of sequential aiming movements: the influence of practice and manual asymmetries on the one-target advantage. *Cortex* 39, 307–325. doi: 10.1016/S0010-9452(08)70111-4
- Marinsek, M. (2016). Lateral asymmetry as a function of motor practice type of complex upper- and lower-limb movement in young children. *Laterality* 21, 267–281. doi: 10.1080/1357650X.2015.1127253
- Oosawa, R., Iwasaki, R., Suzuki, T., Tanabe, S., and Sugawara, K. (2019). Neurophysiological analysis of intermanual transfer in motor learning. *Front. Hum. Neurosci.* 13, 135. doi: 10.3389/fnhum.2019.00135
- Parlow, S. E., and Kinsbourne, M. (1989). Asymmetrical transfer of training between hands: implications for interhemispheric communication in normal brain. *Brain Cogn.* 11, 98–113. doi: 10.1016/0278-2626(89)90008-0
- Ruddy, K. L., and Carson, R. G. (2013). Neural pathways mediating cross education of motor function. *Front. Hum. Neurosci.* 7, 397. doi: 10.3389/fnhum.2013.00397

Author contributions

QF and YX prepared the draft. XZ and FH worked on revision and approved the submitted version. All authors collaborated in preparing the manuscript. All authors contributed to the article and approved the submitted version.

Acknowledgments

The authors appreciate the practical insights provided by physical education teachers, Xiaodong Luo from Xiliu Rd. Elementary School, Zibo, China, and Zhe Wang from Qingdao Middle School, Qingdao, China.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

- Sainburg, R. L. (2002). Evidence for a dynamic-dominance hypothesis of handedness. *Exp. Brain Res.* 142, 241–258. doi: 10.1007/s00221-001-0913-8
- Sainburg, R. L., Schaefer, S. Y., and Yadav, V. (2016). Lateralized motor control processes determine asymmetry of interlimb transfer. *Neuroscience* 334, 26–38. doi: 10.1016/j.neuroscience.2016.07.043
- Sainburg, R. L., and Wang, J. (2002). Interlimb transfer of visuomotor rotations: independence of direction and final position information. *Exp. Brain Res.* 145, 437–447. doi: 10.1007/s00221-002-1140-7
- Scripture, E. W., Smith, T. L., and Brown, E. M. (1894). On the education of muscular control and power. *Stud. Yale Psychol. Lab.* 2, 114–119.
- Serrien, D. J., Ivry, R. B., and Swinnen, S. P. (2006). Dynamics of hemispheric specialization and integration in the context of motor control. *Nat. Rev. Neurosci.* 7, 160–166. doi: 10.1038/nrn1849
- Shaw, P., Greenstein, D., Lerch, J., Clasen, L., Lenroot, R., Gogtay, N., et al. (2006). Intellectual ability and cortical development in children and adolescents. *Nature* 440, 676–679. doi: 10.1038/nature04513
- Stöckel, T., and Weigelt, M. (2012). Brain lateralisation and motor learning: selective effects of dominant and non-dominant hand practice on the early acquisition of throwing skills. *Laterality* 17, 18–37. doi: 10.1080/1357650X.2010.524222
- Stöckel, T., Weigelt, M., and Krug, J. (2011). Acquisition of a complex basketball-dribbling task in school children as a function of bilateral practice order. *Res. Q. Exerc. Sport* 82, 188–197. doi: 10.1080/02701367.2011.10599746
- Taylor, H. G., and Heilman, K. M. (1980). Left-hemisphere motor dominance in righthanders. *Cortex* 16, 587–603. doi: 10.1016/S0010-9452(80)80006-2
- Taylor, J. A., Krakauer, J. W., and Ivry, R. B. (2014). Explicit and implicit contributions to learning in a sensorimotor adaptation task. *J. Neurosci.* 34, 3023–3032. doi: 10.1523/JNEUROSCI.3619-13.2014
- Teixeira, L. A., and Caminha, L. Q. (2003). Intermanual transfer of force control is modulated by asymmetry of muscular strength. *Exp. Brain Res.* 149, 312–319. doi: 10.1007/s00221-002-1363-7
- Teixeira, L. A., Silva, M. V., and Carvalho, M. (2003). Reduction of lateral asymmetries in dribbling: the role of bilateral practice. *Laterality* 8, 53–65. doi: 10.1080/713754469
- van Duinen, H., Renken, R., Maurits, N. M., and Zijdevind, I. (2008). Relation between muscle and brain activity during isometric contractions of the first dorsal interosseus muscle. *Hum. Brain Mapp.* 29, 281–299. doi: 10.1002/hbm.20388
- Wang, J., and Sainburg, R. L. (2004). Interlimb transfer of novel inertial dynamics is asymmetrical. *J. Neurophysiol.* 92, 349–360. doi: 10.1152/jn.00960.2003
- Wang, J., and Sainburg, R. L. (2006). Interlimb transfer of visuomotor rotations depends on handedness. *Exp. Brain Res.* 175, 223–230. doi: 10.1007/s00221-006-0543-2
- Wang, Y., Zhao, J., Inada, H., Négyesi, J., and Nagatomi, R. (2022). Impact of handedness on interlimb transfer depending on the task complexity combined with motor and cognitive skills. *Neurosci. Lett.* 10, 136775. doi: 10.1016/j.neulet.2022.136775
- Wang, Y. F., Zhao, J., Negyesi, J., and Nagatomi, R. (2020). Differences in the magnitude of motor skill acquisition and interlimb transfer between left- and right-handed subjects after short-term unilateral motor skill practice. *Tohoku J. Exp. Med.* 251, 31–37. doi: 10.1620/tjem.251.31
- Witkowski, M., Bojkowski, Ł., Karpowicz, K., Konieczny, M., Bronikowski, M., and Tomczak, M. (2020). Effectiveness and durability of transfer training in fencing. *Int. J. Environ. Res. Public Health* 17, 849. doi: 10.3390/ijerph17030849
- Witkowski, M., Bronikowski, M., Nowik, A., Tomczak, M., Strugarek, J., and Króliczak, G. (2018). Evaluation of the effectiveness of a transfer (interhemispheric) training program in the early stages of fencing training. *J. Sports Med. Phys. Fitness* 58, 1368–1374. doi: 10.23736/S0022-4707.17.07556-9