cortex 46 (2010) 264–267

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/cortex

Discussion forum

Practice makes bimanual interference imperfect – On the way to the generation of bimanual motion primitives

*Ronen Sosnik**

The Gonda Brain Research Center, Bar Ilan University, Ramat-Gan, Israel

Simultaneously manipulating the two hands is central to human daily life, from a simple action such as tying one's shoes to the proficiency of building and using tools. While using both hands in order to reach a common goal does not require extensive effort and is even done automatically, the concurrent generation of two independent movements with different spatiotemporal patterns results often in an increased time to initiate the movements (reaction time – RT) compared to conditions in which only one movement is performed at a time (Walter and Swinnen, 1990; Heuer, 1996; Vangheluwe et al., 2004). Furthermore, when different spatiotemporal patterns must be simultaneously produced, such as drawing a circle with one hand and drawing a rectangle with the second hand, spatial similarity effects take place between the two trajectories (Kelso et al., 1983; Konzem, 1987; Swinnen and Walter, 1998). The phenomenon was termed bimanual interference and was studied extensively over the last three decades. Psychological and imaging studies conducted on split brain patients (Franz et al., 1996; Eliassen et al., 1999; Kennerley et al., 2002) have shown that interference based on the spatial characteristics of the movements arises through callosally mediated interactions suggesting that the spatial goals are established at a high, cortical level. Studies employing discrete incompatible actions for the two hands, such as pointing in different directions and/or different amplitudes have shown that bimanual interference could be reduced when the target movements were cued directly by the onset of the target locations rather than symbolically by letters (Diedrichsen et al., 2001; Hazeltine et al., 2003). This finding indicates that directly cued actions can be programmed in parallel for the two hands, challenging the hypothesis that the cost to initiate non-symmetrical movements derives from spatial interference at the motor-programming stage. Rather, the cost appears to be related to stimulus identification, processing of symbolic cues and selection of an appropriate response, or both.

Another way to reduce bimanual interference is practice, as shown recently by Albert and Ivry (2009). Although several studies have previously shown that bimanual practice can suppress directional interference (Swinnen et al., 1991; Schumacher et al., 1999; Puttemans et al., 2003) the study of Albert and Ivry, based on a drawing task first introduced by Franz et al. (1996), is unique as it calls for the bimanual generation of sequential discrete movements rather than a continuous movement, which allows the assessment of bimanual interference and its modulation by practice both by the analysis of the reaction time needed to plan each segment and the characteristics of the spatiotemporal attributes of the trajectories generated by each hand. Thus, the novelty of the work is in its ability to study the evolution of the interaction and interference between the unimanual and bimanual representation of the task emerging throughout practice. Furthermore, as target movements in the paradigm used by Albert and Ivry are directly cued, an ability to transfer to unvisited configurations should imply the conceptualization of the stimuli as defining a common goal which operates at an abstract level of representation.

Albert and Ivry (2009) show that prolonged practice on incongruent patterns (e.g., one hand moving forward, one sideways) resulted in reduced bimanual interference which was manifested by shorter RTs and increased number of correct patterns by both hands. As the effect of congruency on movement reaction times was larger than the effect on movement time it may be that the main outcome of training was the evolution of a bimanual representation of the task which allowed for shorter planning times as was shown to

* *Corresponding author*. The Gonda Brain Research Center, Bar Ilan University, Ramat-Gan 52900, Israel.
E-mail address: ronens@mail.biu.ac.il

0010-9452/$ – see front matter
doi:10.1016/j.cortex.2009.02.008

occur for musicians who are proficient in generating bimanual tasks versus non-musicians (Hughes and Franz, 2007). As Albert and Ivry have not tested unimanual performance throughout training it is not possible to assess whether a global representation of the task evolved for each hand separately (i.e., the three line segments in each pattern were globally planned as a single segment). However, the finding that no significant improvement in the spatial accuracy was found over the six days of practice both for the incongruent and congruent trials further suggests that the outcome of the prolonged training was not two unimanual, effector specific representations of the task but a single bimanual representation.

Another finding presented in Albert and Ivry's (2009) paper is a less-than-perfect transfer of the performance gains to unpracticed patterns or configurations. Several studies aiming at exploring the nature of the representation underlying bimanual movements as well its accessibility to within-limb effector systems were conducted recently yielding inconsistent results and suggested that interhemispheric transfer depends on the specific characteristics of the bimanual task. Whereas some studies have shown that bimanual training substantially reduced spatial (Wenderoth et al., 2003; Vangheluwe et al., 2004) or temporal (Klapp et al., 1998; Kurtz and Lee, 2003) interference while unimanual training did not, others have shown that unimanual training can be partially transferred to bimanual movements (Nozaki et al., 2006). Furthermore, in different unimanual paradigms, researchers have uncovered skills that transfer from the dominant to the nondominant arm (Halsband, 1992; Gordon et al., 1994; Teixeira, 2000) and from the nondominant to the dominant arm (Taylor and Heilman, 1980; Parlow and Kinsbourne, 1990) as well as skills that transfer in both directions (Morton et al., 2001) and skills that do not transfer in either direction (Kitazawa et al., 1997; Rand et al., 1998; Baizer et al., 1999). Overall, these findings imply that patterns of generalization strongly depend on the task. Thus, the less-than-perfect transfer found in the work of Albert and Ivry may simply result from the fact that the training sets were devised such that one of the four shapes constituting the unpracticed configuration was never produced by the left hand, which was the nondominant hand for all the subjects. It may be that testing on unvisited configurations in which the right dominant hand generates a shape that was previously practiced only by the left nondominant hand would result in high performance gains suggesting that extensive training does/can abolish bimanual interference.

Another possible explanation for the imperfect transfer found in the work of Albert and Ivry (2009) may be the extensive amount of practice the subjects went through and the subsequent evolution of a bimanual primitive. A recent work of Vangheluwe et al. (2004) in which subjects were asked to generate cyclical lines with a single vertical orientation (line task) in one hand and lines with shifting orientations in the other limb (star task) has shown that instructing subjects to shift tasks between hands resulted in a perfect transfer suggesting that the ability to overcome directional interference and to dissociate limb movements following learning is transferable to untrained motor conditions and that learning to overcome mutual interference is generalisable and not specific to the trained condition and/or effector. The inconsistency between the results obtained in the study of Albert and Ivry and the 'star-line' task (Vangheluwe et al., 2004), apart from the difference in the paradigms used, may result from the extensive amount of practice that the subjects went through in the former work. Whereas the subjects who practiced the 'star-line' paradigm (Vangheluwe et al., 2004) trained for a total of 75 trials (three days, 25 trials per day), the subjects who participated in the study of Albert and Ivry practiced each target configuration for six days, 48 trials on each day, for a total of 228 reproductions per pattern. Given that several studies show that extensive motor training results first in an abstract, effector independent stage in which transfer to the untrained hand is almost perfect and is later followed by an effector dependent stage in which no performance gains are transferred to the untrained hand (Karni et al., 1998; Bapi et al., 2000), it may be that the bimanual movements generated in the 'star-line' study (Vangheluwe et al., 2004) could still be decoupled into two unimanual movements (as this option is handy only at the preliminary, effector unspecific stages of the motor skill acquisition), whereas the extensive training period in the study of Albert and Ivry resulted in the emergence of an effector dependent bimanual motion primitive. This notion is supported by the finding that the reaction times in Albert and Ivry's study have nearly asymptoted by the end of the last training session both for the congruent and incongruent patterns (Fig. 1) suggesting that learning has entered the effector specific stage. Testing the transfer performance throughout the training period could shed light on the evolution of a bimanual primitive and its characteristics.

A speculative explanation for the results obtained by Albert and Ivry (2009) may be that with the extended practice, a change in the internal representation of the task has occurred – from the generation of three discrete straight movements in each pattern with each hand to the evolvement of a unimanual globally planned movement (a open sided square facing up, down, left or right). The emergence of

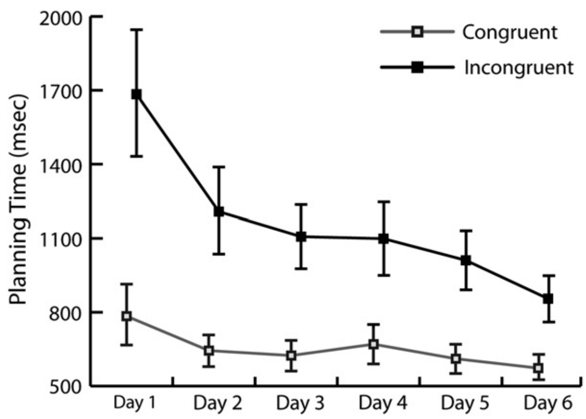

Fig. 1 – Planning times during the training phase. Planning time is defined as the sum of reaction time and the pauses that occurred prior to the start of the 2nd and 3rd segments. Participants became faster with practice, although there remained a substantial difference between incongruent patterns (black) compared to congruent patterns (grey). Error bars indicate ± the standard error of the mean.

a globally planned pattern may have resulted in a reduced number of competing responses – four possible patterns for each hand rather than twelve possible combinations of line orientations (three line orientations in each of the four patterns) and consequently in reduced translation-related interference leading to improved performance. This hypothesis is supported by the reduced pauses found both before the second and third segment. It may be that the prolonged training in Albert and Ivry's study first resulted in the generation of discrete motion primitives for each hand and later in the evolution of a bimanual motion primitive. As the RTs for incongruent trials were still significantly higher than the RTs for congruent trials it may be that the process of bimanual motion primitive generation was not completed. It may be that given more practice in the training sessions, a bimanual motion primitive would have emerged. Transfer to untrained patterns would have then resulted in a minimal, or lack of transfer (as the performance gains are specific to the over trained bimanual configuration and not to the two unimanual patterns) whereas the performance on the trained incongruent and congruent patterns would have been similar (as both patterns are represented as primitives). Testing this hypothesis calls for conducting the experiment for longer durations, way after performance asymptotes, and performing the transfer experiments throughout the training sessions.

Overall, although both the notions that motor representations (or "units of motor control") are changed in the course of practice and that intermanual interference depends on the kind of representation are not new, the study of Albert and Ivry (2009) is novel as it involves an experimental paradigm which calls for the evolution of both unimanual and bimanual primitives throughout learning and allows testing the interference and interplay between their representation. The results obtained in Albert and Ivry work suggest that a bimanual effector unspecific representation of the task is evolving throughout learning. Additional experiments should be conducted in order to test whether the evolution of the bimanual representation is accompanied by a fade away of the unimanual representation or whether they co-exist after a long training session.

REFERENCES

Albert NB and Ivry RB. The persistence of spatial interference after extended training in a bimanual drawing task. *Cortex*, 45: 377–385, 2009.

Baizer JS, Kralj-Hans I, and Glickstein M. Cerebellar lesions and prism adaptation in macaque monkeys. *Journal of Neurophysiology*, 81: 1960–1965, 1999.

Bapi RS, Doya K, and Harner AM. Evidence for effector independent and dependent representations and their differential time course of acquisition during motor sequence learning. *Experimental Brain Research*, 132: 149–162, 2000.

Diedrichsen J, Hazeltine E, Kennerley S, and Ivry RB. Moving to directly cued locations abolishes spatial interference during bimanual actions. *Psychological Science*, 12: 493–498, 2001.

Eliassen JC, Baynes K, and Gazzaniga MS. Direction information coordinated via the posterior third of the corpus callosum during bimanual movements. *Experimental Brain Research*, 128: 573–577, 1999.

Franz EA, Eliassen JC, Ivry RB, and Gazzaniga MS. Dissociation of spatial and temporal coupling in bimanual movements of callosotomy patients. *Psychological Science*, 7: 306–310, 1996.

Gordon AM, Forssberg H, and Iwasaki N. Formation and lateralization of internal representations underlying motor commands during precision grip. *Neuropsychologia*, 32: 555–568, 1994.

Halsband U. Left hemisphere preponderance in trajectorial learning. *Neuroreport*, 3: 397–400, 1992.

Hazeltine E, Diedrichsen J, Kennerley SW, and Ivry RB. Bimanual cross-talk during reaching movements is primarily related to response selection, not the specification of motor parameters. *Psychological Research*, 67: 56–70, 2003.

Heuer H. Coordination. In Heuer H, and Keele SW (Eds), *Handbook of Perception and Action, Motor Skills*, vol. 2. San Diego: Academic Press, 1996: 121–180.

Hughes CM and Franz EA. Experience-dependent effects in unimanual and bimanual reaction time tasks in musicians. *Journal of Motor Behavior*, 39: 3–8, 2007.

Kelso JAS, Putnam CA, and Goodman D. On the space–time structure of human interlimb co-ordination. *Quarterly Journal of Experimental Psychology*, 35A: 347–375, 1983.

Karni A, Meyer G, Rey-Hippolito C, Jezzard P, Adams MM, Turner R, et al. The acquisition of skilled motor performance: Fast and slow experience-driven changes in primary motor cortex. *Proceedings of the National Academy of Sciences, USA*, 95: 861–868, 1998.

Kennerley S, Diedrichsen J, Hazeltine E, Semjen A, and Ivry RB. Callosotomy patients exhibit temporal and spatial uncoupling during continuous bimanual movements. *Nature Neuroscience*, 5: 376–381, 2002.

Klapp ST, Nelson JM, and Jagacinski RJ. Can people tap concurrently bimanual rhythms independently? *Journal of Motor Behavior*, 30: 301–322, 1998.

Kitazawa S, Kimura T, and Uka T. Prism adaptation of reaching movements: Specificity for the velocity of reaching. *Journal of Neuroscience*, 17: 1481–1492, 1997.

Konzem PB. Extended practice and patterns of bimanual interference. Doctoral dissertation, University of Southern California, 1987.

Kurtz S and Lee TD. Part and whole perceptual-motor practice of a polyrhythm. *Neuroscience Letters*, 338: 205–208, 2003.

Morton SM, Lang CE, and Bastian AJ. Inter- and intra-limb generalization of adaptation during catching. *Experimental Brain Research*, 141: 438–445, 2001.

Nozaki D, Kurtzer I, and Scott SH. Limited transfer of learning between unimanual and bimanual skills within the same limb. *Nature Neuroscience*, 9: 1364–1366, 2006.

Parlow SE and Kinsbourne M. Asymmetrical transfer of Braille acquisition between hands. *Brain Language*, 39: 319–330, 1990.

Puttemans V, Vangheluwe S, Wenderoth N, and Swinnen SP. Bimanual directional interference: The effect of normal versus augmented visual feedback on learning and transfer. *Motor Control*, 8: 33–50, 2003.

Rand MK, Hikosaka O, Miyachi S, Lu X, and Miyashita K. Characteristics of a long-term procedural skill in the monkey. *Experimental Brain Research*, 118: 293–297, 1998.

Schumacher EH, Lauber EH, Glass JM, Zurbriggen EL, Gmeindl L, Kieras DE, et al. Concurrent response-selection processes in dual-task performance: Evidence for adaptive executive control of task scheduling. *Journal of Experimental Psychology: Human Perception and Performance*, 25: 791–814, 1999.

Swinnen SP, Young CB, Walter CB, and Serrien DJ. Control of asymmetrical bimanual movements. *Experimental Brain Research*, 85: 163–173, 1991.

Swinnen SP and Walter CB. Constraints in coordinating limb movements. In Colley AM, and Beech JR (Eds), *Cognition and Action in Skilled Behavior*. Amsterdam: North Holland, 1998: 127–143.

Taylor HG and Heilman KM. Left-hemisphere motor dominance in righthanders. *Cortex*, 16: 587–603, 1980.

Teixeira LA. Timing and force components in bilateral transfer of learning. *Brain Cognition*, 44: 455–469, 2000.

Vangheluwe S, Puttemans V, Wenderoth N, Van Baelen M, and Swinnen SP. Inter- and intralimb transfer of a bimanual task: Generalisability of limb dissociation. *Behavioral Brain Research*, 154: 535–547, 2004.

Walter CB and Swinnen SP. Asymmetric interlimb interference during the performance of a dynamic bimanual task. *Brain and Cognition*, 14: 185–200, 1990.

Wenderoth N, Puttemans V, Vangheluwe S, and Swinnen SP. Bimanual training reduces bimanual interference. *Journal of Motor Behavior*, 35: 296–308, 2003.