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Reduced asymmetry in motor skill learning in left-handed compared to right-handed individuals

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ABSTRACT

Hemispheric specialization for motor control influences how individuals perform and adapt to goal-directed movements. In contrast to adaptation, motor skill learning involves a process wherein one learns to synthesize novel movement capabilities in absence of perturbation such that they are performed with greater accuracy, consistency and efficiency. Here, we investigated manual asymmetry in acquisition and retention of a complex motor skill that requires speed and accuracy for optimal performance in right-handed and left-handed individuals. We further determined if degree of handedness influences motor skill learning. Ten right-handed (RH) and 10 left-handed (LH) adults practiced two distinct motor skills with their dominant or nondominant arms during separate sessions two–four weeks apart. Learning was quantified by changes in the speed–accuracy tradeoff function measured at baseline and one-day retention. Manual asymmetry was evident in the RH group but not the LH group. RH group demonstrated significantly greater skill improvement for their dominant-right hand than their nondominant-left hand. In contrast, for the LH group, both dominant and nondominant hands demonstrated comparable learning. Less strongly-LH individuals (lower EHI scores) exhibited more learning of their dominant hand. These results suggest that while hemispheric specialization influences motor skill learning, these effects may be influenced by handedness.

1. Introduction

Asymmetry of performance is evident in sensory, motor and perceptual domains of human behavior (Akpinar, Sainburg, Kirazci, & Przybyla, 2015; Amassian et al., 1993; Manoach et al., 2004; Steenbergen & van der Kamp, 2008; Velasques et al., 2011). Human handedness is one example of performance asymmetry and has been described as lateralization of proficiency in motor performance. The findings of interlimb asymmetry in performance of goal-directed actions have generated the dynamic-dominance hypothesis of motor lateralization. Sainburg and colleagues have elegantly demonstrated that dominant right dominant arm control in right-handed individuals is optimized for planning of intersegmental coordination (i.e., dynamics) while the non-dominant left arm control is optimized for positional accuracy and response to unexpected perturbation (Sainburg, 2005; Sainburg & Wang, 2002; Wang & Sainburg, 2007; Yadav & Sainburg, 2014). However, how the lateralization of behavioral proficiency in control of arm movements translates into motor skill learning is relatively unknown.

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Broadly speaking, motor learning is a process of improving the relatively permanent capability for movement with experience and/or practice. Recently it has been proposed that motor learning involves multiple distinct processes dependent on the task (Haith & Krakauer, 2013; Huang, Haith, Mazzoni, & Krakauer, 2011; Krakauer & Mazzoni, 2011). Motor adaptation has been used as one such form of motor learning to understand how each arm responds to systematic perturbations applied to goal-directed movements (Huberdeau, Krakauer, & Haith, 2015; Krakauer, Ghez, & Ghilardi, 2005). Upon initial perturbation, both right and left arms showed similar rates of adaptation and final degrees of adaptation to correct for perturbation-induced error. However, when assessed for transfer of adaptation between arms, there emerged a clear indication of asymmetry in the type of information transferred between arms. Nondominant arm training to perturbation improved initial movement direction, a measure of predictive control and planning of the dominant arm, but not vice versa. In contrast, dominant arm training improved endpoint accuracy of the nondominant arm, but the opposite was not true (Wang & Sainburg, 2006). This asymmetry in the transfer of information following adaptation aligns with the specialization of each hemisphere-arm system: dominant hemisphere-arm system is specialized for predictive control and the nondominant hemisphere arm system is specialized for impedance control to ensure accuracy (Mutha, Haaland, & Sainburg, 2013). Another form of learning that has been investigated for manual asymmetry is sequence learning and has yielded mixed results. While few studies demonstrated dominant arm advantage for performance improvement (Chase & Seidler, 2008), there were others who have indicated equal levels of performance improvements across both dominant and nondominant hands (Grafton, Hazeltine, & Ivry, 1998, 2002). Finally, many studies of sequence learning have examined improvements in short-term performance without any tests of how the sequence improvement was retained over time, which is a more robust measure of learning vs. performance.

Recent conceptualization of processes constituting motor learning has identified that learning a new skill, like that in a real-world (e.g., learning to swing a golf) engages cognitive and neural processes fundamentally different than that of adaptation and sequence learning (Haith & Krakauer, 2013). Skill learning requires syntheses of new movements/movement combinations to improve accuracy, speed, efficiency and consistency. Thus, two main behavioral features characterize motor skill learning: (a) improvement in the speed–accuracy trade-off as the skill is acquired and (2) reduction in variability of the skill with practice (Shmuelof, Krakauer, & Mazzoni, 2012). Motor skill learning often requires prolonged practice in the magnitude of days, months to years. This is in distinct contrast with adaptation where the learner is not required to acquire a new set of movements, but instead "recalibrate" a previously acquired skill to reduce perturbation-induced error. This adaptation occurs on a much shorter time-scale compared to motor skill learning. On the other hand in finger-tapping sequence learning paradigms, performance is quantified by separate measures of movement time and accuracy (Kantak, Mummidisetty, & Stinear, 2012). This may not be optimal because improvement in one measure (speed or accuracy) with little change or deterioration of the other may indicate skill learning or simply a shift in performance to a different part of an unchanged speed–accuracy tradeoff (Shmuelof et al., 2012).

Lastly, emerging evidence suggests that the key neural substrates and the time-course of their activation is distinct for different forms of learning. Motor skill learning relies on a neural network that predominantly engages the contralateral primary motor cortex and ipsilateral cerebellum (Shmuelof, Yang, Caffo, Mazzoni, & Krakauer, 2014). This is in contrast to the networks engaged in adaptation and sequence learning. For example, sequence learning relies heavily on the corticostriatal system (Debas et al., 2010; Lungu et al., 2014), while adaptation relies on the corticocerebellar system (Galea, Vazquez, Pasricha, de Xivry, & Celnik, 2011; Shmuelof et al., 2014; Van Mier, Tempel, Perlmutter, Raichle, & Petersen, 1998). Skill learning and adaptation also differ in the time course of neural engagement. During adaptation training, the cerebellum is predominantly engaged early during practice with motor cortex playing a critical role in post-practice consolidation (Galea et al., 2011). Alternatively, skill learning engages a cognitive-motor network including the motor cortex early during practice; and as skill develops, the cerebellum is more heavily engaged for planning of timing and agonist–antagonist coordination (Kantak, Jones-Lush, Narayanan, Judkins, & Wittenberg, 2013). With repetitive practice, muscular synergies and the resultant movement combinations required for task performance become efficiently represented in the motor cortex (Buetefisch et al., 2015; Classen, Liepert, Wise, Hallett, & Cohen, 1998; Kantak et al., 2013). Behaviorally, this motor skill learning is manifested as improved speed, accuracy and reduction in the number of submovements and variability (Hogan & Sternad, 2012; Pratt, Chasteen, & Abrams, 1994; Simo, Piovesan, Laczko, Ghez, & Scheidt, 2014; Thomas, Yan, & Stelmach, 2000). While motor control and adaptation studies have demonstrated asymmetry in transferred information between two arms, it is not known how lateralization of behavioral proficiency affects motor skill learning that is characterized by improvements in speed–accuracy tradeoff.

The majority of motor learning studies have predominantly investigated individuals with right-hand preference for activities as assessed by Edinburgh handedness inventory (EHI, Oldfield, 1971). Left-handed (LHD) individuals comprise approximately 10% of the total population and have been reported to be more heterogeneous compared to right-handed (RHD) individuals. Furthermore, studies investigating manual asymmetries in sensorimotor function have yielded mixed results in left-handed individuals (Borod, Caron, & Koff, 1984; Boulinguez, Velay, & Nougier, 2001b; Martin, Jacobs, & Frey, 2011). For example, a cohort of LHD individuals adapting to a visuomotor transformation demonstrated asymmetric intermanual transfer in a direction similar to RHD individuals (Wang & Sainburg, 2006). Dominant arm training improved predictive control of both arms while nondominant arm training improved position control of both arms. In contrast, Chase and Seidler (2008) observed little difference in intermanual transfer between the two arms in LHD individuals (Chase & Seidler, 2008). In accordance with the latter finding, Przybyla, Good, and Sainburg (2012) demonstrated that left-handed individuals may show lesser lateralization of motor control during goal-directed reaching compared to right-handed individuals