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The control of amplitude and direction in a bimanual coordination task

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ABSTRACT

Bimanual coordination requires task-specific control of the spatial and temporal characteristics of the movements of both hands. The present study focused on the spatial relationship between hand movements when their amplitude and direction were manipulated. In the experiment in question, participants were instructed to draw two lines simultaneously. These two lines were instructed to be drawn in mirror symmetric or perpendicular directions of each other while the length was instructed to be the same or different. The coordinative quality of amplitude control was compared when the task required symmetric and asymmetric bimanual spatial coordination patterns. Results showed that the amplitude accuracy decreased when different amplitudes and/or directions had to be generated simultaneously. The coordinative quality of direction was also compared when the task required symmetric and asymmetric bimanual spatial coordination patterns. Unlike amplitude, the direction accuracy was largely independent of coordination symmetry/asymmetry of direction or amplitude. The results suggest that the coordinative quality of amplitude control does not only interfere with amplitude asymmetry, but it also interferes with direction asymmetry. Moreover, in bimanual coordination amplitude control is more vulnerable to the influence of direction control demands than vice versa.

1. Introduction

Many voluntary actions involve bimanual coordination, that is, the simultaneous integration of movements of the two upper-limbs. When the two upper-limbs produce mirror or isomorphic actions, it is referred to as symmetric bimanual coordination, whereas it is called asymmetric bimanual coordination when different movements are required. Research has shown that tasks involving symmetrical movements of the two hands are relatively stable and precise, whereas the stability and accuracy of the performance usually declines when the action requires asymmetric bimanual coordination (Eliassen, Baynes, & Gazzaniga, 1999; Franz, Elliassen, Ivry, & Gazzaniga, 1996; Semjen, 2002; Spencer, Zelaznik, Diedrichsen, & Ivry, 2003). The difficulty of producing asymmetry bimanual movements has been denoted in the literature when discussing the "interferences" in bimanual coordination (Swinnen, Dounskaia, Levin, & Duysens, 2001). Traditionally, the tendency for symmetry (eg. In-phase movements) was defined as the co-activation of homologous muscles (Kelso, 1984). More recently, the emphasis has been shifting toward the role of perception and representation of action (Franz, Kerzel, Knoblich, & Prinz, 2001; Ivry, Diedrichsen, Spencer, Hazeline, & Semjen, 2004), and the possibly distinctive origins for different types of interferences (i.e. temporal vs. spatial interference; discrete vs. continuous movement interference) (Franz et al., 1996; Spencer et al., 2003).

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Temporal interference in bimanual coordination is the tendency to initiate and terminate movements of the two hands synchronously, and therefore it is difficult to produce complex movement phases (Haken, Kelso, & Bunz 1985; Kelso, Southard, & Goodman, 1979; Marteniuk, MacKenzie, & Baba, 1984; Semjen 2002; Semjen & Ivry, 2001). Spatial interference is the tendency of the two hands to produce movements with similar amplitude and/or in a mirror direction (Spijkers & Heuer, 1995; Wenderoth, Puttemans, Vangheluwe, & Swinnen, 2003). Ivry et al. (2004) reviewed interference reported in many bimanual coordination studies and identified an important discrepancy in temporal and spatial interference, suggesting distinct origins. There are two generally accepted hypotheses regarding the origins of temporal interference, depending on the type of motor task performed. Based on studies by Ivry and his colleagues (Franz et al., 1996; Semjen, 2002; Spencer, Semjer, Yang, & Ivry, 2006; Spencer et al., 2003), the temporal interference observed in discrete/discontinuous bimanual movements (i.e. simultaneously drawing one circle with each hand) is associated with an explicit representation of the temporal goal, which is constrained by the limited ability of the internal timing system in the cerebellum to represent complex temporal relationships. On the other hand these studies also showed that temporal interference in continuous tasks (i.e. simultaneously drawing repetitive circle with two hands) is not correlated with temporal interference observations in discontinuous tasks, and thus it is hypothesized that this pattern arises from interactions between time-varying spatial representations on the cortical level (Franz et al., 1996; Semjen, 2002; Spencer et al., 2003; Spencer et al., 2006). Spencer et al. (2003) found that patients with cerebellar damage exhibit deficits in discontinuous but not in continuous bimanual movements, providing evidence supporting a distinctive origin of temporal interference for discrete and continuous tasks. With respect to the spatial interference in bimanual coordination, which is the focus of the current study, a series of bimanual coordination studies imply that the spatial interference strongly relies on the cognitive representation of the task (Diedrichsen, Hazeltime, Kennerley, & Ivry, 2001; Diedrichsen, Ivry, Hazeltine, Kennerley, & Cohen, 2003; Mechsner, Kerzel, Knoblich, & Prinz, 2001). As summarized by Ivry et al. (2004), asymmetric bimanual coordination induces primarily lateral (left-dominant) cortical activation and it relies on the corpus callosum to share the goal representations with the other hemisphere. Moreover, the study of Eliassen et al. (1999) showed that the posterior region of the corpus callosum might be a major contributor to directional coupling in bimanual coordination tasks due to an observation that an epilepsy patient started to show spatial uncoupling in a directional asymmetric bimanual task after the resection of the posterior region of the corpus callosum. In other words, two spatial representations guiding spatial specifications of the bimanual task are produced in the left (dominant) hemisphere for movements on the right and left side of the working space respectively. The spatial interference arises from the overlap between these two spatial representations (Diedrichsen et al., 2001; Diedrichsen et al., 2003).

Spatial interference could occur when people draw two different amplitudes. The difference in amplitude between motions of the right and left hand normally results in an assimilation of movement lengths, i.e., the shorter amplitude tends to overshoot, whereas the longer amplitude tends to undershoot (Franz, 1997; Ryu & Buchanan, 2004; Spijkers & Heuer, 1995; Swinnen et al., 2001). Similar interference effects can also be observed in directional incongruent conditions where the directional trajectories become mutually coupled/mirrored (Eliassen et al., 1999; Franz et al., 1996; Wenderoth, Debaere, Sunaert, & Swinnen, 2005; Wenderoth et al., 2003). The majority of the studies focusing on spatial interference have investigated the constraining role of direction and amplitude separately and independently. Even so, interference findings in direction and amplitude were commonly discussed together without distinction between the two, which was based on an unverified assumption that direction and amplitude follow the same pattern of interference. In the domain of bimanual coordination, the relationship between amplitude and direction is largely unknown; even though it is of theoretical importance in comprehensively understanding the mechanisms of bimanual coordination. A few studies have tried to investigate whether direction and amplitude are controlled independently or interdependently in bimanual coordination. For instance, the studies of Swinnen et al. (2001) and Wenderoth et al. (2005) revealed some level of interdependence, as well as some degree of independence between amplitude and directional parameters in bimanual coordination, indicating that amplitude and direction are mediated by distinct but partially overlapping neural resources.

Swinnen et al. (2001) studied the spatial assimilation effect in a drawing task with different drawing directions and amplitudes for the right and the left hand. In their study, participants were asked to draw with the left hand (which in this study was synonymous for the non-dominant hand) vertical lines, while they drew with the right hand (i.e., in this study the dominant hand) lines in eight different directions. They also asked participants to draw the lines either 8 cm or 16 cm long. For each hand, participants' performance executed during the bimanual task was compared to performance of the same task executed unimanually. The results suggested that amplitude regulates the directional interference, whereas direction only partly affects amplitude interference. To further understand the relationship between amplitude and direction, Wenderoth et al. (2005) applied a functional magnetic resonance imaging (fMRI) protocol while participants performed a bimanual drawing task in which the movement direction and amplitude was manipulated per condition. Performance of each hand was analyzed. The behavioral results supported the interdependence of direction and amplitude in bimanual coordination tasks. It was shown that direction had an influence on the interference of amplitude. In addition, the brain imaging data showed that producing bimanual movements with different amplitude or different direction activated similar cortical areas (i.e. bilateral superior parietal-premotor areas). However, additional bilateral networks (i.e. bilateral dorsolateral prefrontal cortex, the anterior cingulate gyrus, and the supramarginal gyrus) are activated only when bimanual movements with different amplitudes are produced, while they are not activated when different directions are produced.

The studies of Swinnen and colleagues (Swinnen et al., 2001; Wenderoth et al. 2005) provided initial insights into the relationship between direction and amplitude in bimanual coordination tasks. The two studies analyzed the movement accuracy of each hand separately by comparing performance of each hand in a bimanual task to performance of the same hand when the task was performed unimanually. This analysis protocol only indirectly studied the quality of coordination between the two hands. The present study involves an analysis of the parameters representing the quality of coordination between the hands in different coordinative conditions directly, with the aim to more thoroughly understand the relationship between the direction and amplitude in bimanual coordination tasks.