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Research paper

Increased visual information gain improves bimanual force coordination

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HIGHLIGHTS

- Bimanual force variability decreased from 8 to 80 pixels/N.
- Significant improvements in bimanual coordination continued up to 256 pixels/N.
- Coordination is more sensitive to increased visual gains than force variability.

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ABSTRACT

Bimanual force control requiring asymmetrical forces between limbs is more challenging than bimanual force control when the limbs produce symmetrical forces. Previous studies investigated visual information gains between 8 and 80 pixels/N to facilitate asymmetrical force control. Given that previous studies limited visual information gain to 80 pixels/N, the current experiment expanded the range by increasing visual information gains (8, 80, 256, and 512 pixels/N). A second manipulation involved three task constraint coefficients imposed on bimanual force control: (a) left-biased, (b) right-biased, and (c) equal-biased. Analyses of 15 right-handed adult volunteers revealed a decrease in bimanual force variability and more negative correlation coefficient with increased visual information gain in the equal biased condition. Significant reductions in bimanual force variability were found between 8 and 80 pixels/N. In contrast, significant improvements in coordination patterns between hands continued up to 256 pixels/N. These novel findings demonstrate that bimanual force coordination was more sensitive to an increase in visual information gains (>80 pixels/N) than bimanual force variability.

1. Introduction

Bimanual coordination between two limbs is important for many daily tasks involving dissimilar or similar force production [10]. Loosening the cap on a water bottle is an example of dissimilar force production: one hand stabilizes the bottle while the other hand turns the cap counterclockwise. For these inherently complex tasks, higher centers appear to coordinate two different goals to accomplish the task. Moreover, visual information is critical for achieving optimal bimanual coordination because perceptual processes are highly associated with motor control processes [1,18]. Nonetheless, the contribution of visual information to bimanual hand coordination remains unclear.

Visual information is one of the most reliable sources of information related to force control tasks and movement performance [7,8,15]. Indeed, reducing the amount of visual information increases movement errors [9,13]. Hu et al. compared visual information performance to no visual information performance and focused that bimanual hand coordination was improved and movement variability was less with visual information compared with the no visual information condition [5]. In addition, Hu and Newell [8] compared a low-gain (8 pixels/N) visual information condition to a high-gain (80 pixels/N) visual information condition. The evidence indicated that bimanual hand coordination improved and

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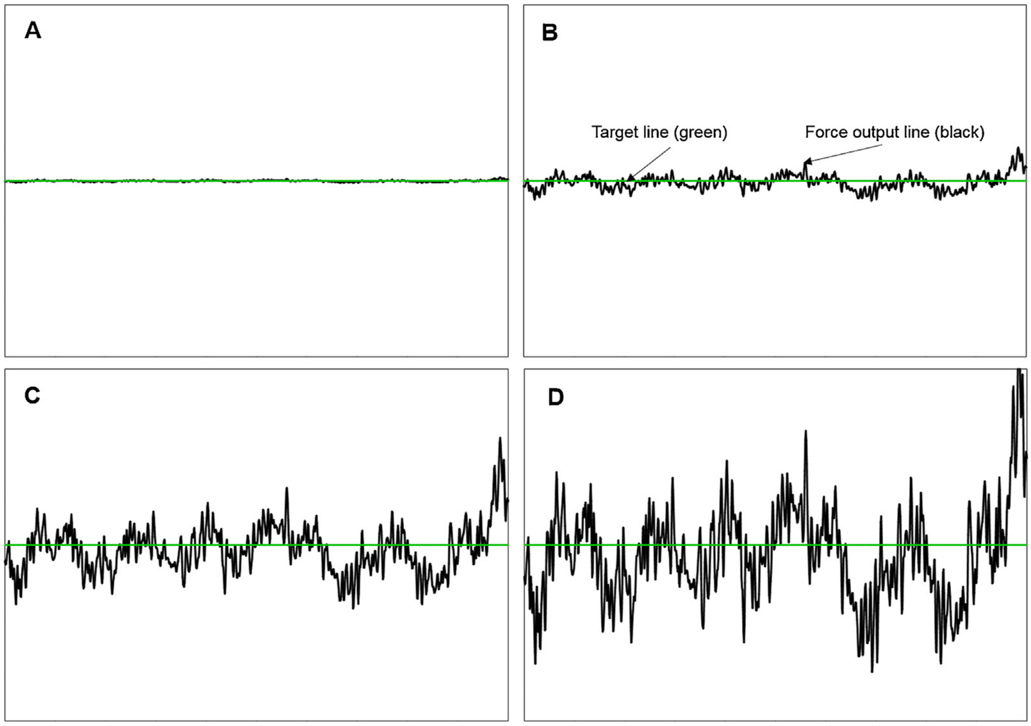

Fig. 1. Illustration of the visual information. The target was a green line on a white background. The force outcome from the subject was displayed as a black line. The four different visual information conditions were: (A) 8 pixels/N; (B) 80 pixels/N; (C) 256 pixels/N; (D) 512 pixels/N.

movement variability decreased during the high-gain visual information condition (80 pixels/N). However, whether bimanual task performances (e.g., variability and coordination) are altered above 80 pixels/N is still unknown.

In fact, during unimanual tasks performance improvements (e.g., task error and force variability) plateaued at visual information conditions above 80 pixels/N [2,14,16,17]. Moreover, Coombes et al. reported that a decrease in unimanual task error was minimized beyond a certain level of visual gain (e.g., visual angle >1°) because neurological responses in the visuomotor system were altered based on a specific level of visual gain [3]. Thus, one leading question of this study includes: Do higher-gain visual information conditions (>80 pixels/N) change bimanual force control performance?

Bimanual coordination tasks are inherently difficult to perform because of bimanual positive coupling, which refers to the tendency of the two limbs to produce symmetric actions that are spatially and temporally synchronized [8,11]. Thus, bimanual coordination tasks that require asymmetrical force production or different movements by the two limbs are difficult to accomplish compared to tasks that require similar force production. A second leading question is: Does task difficulty, imposed by three task constraint coefficients between hands influence bimanual force control performances?

Furthermore, evidence indicates that the amount of visual information about the task (i.e., 8 versus 80 pixels/N) interacts with the asymmetry of bimanual coordination tasks. At a visual gain less than 80 pixels/N, motor performance improvements by visual information were greater for the symmetric than the asymmetric bimanual coordination tasks [5–8]. However, sparse evidence exits on whether the interaction between visual information and bimanual force control symmetry persists for higher visual information gains (i.e., 256 and 512 pixels/N). Thus, we investigated the interaction between a wide range of visual information conditions (>8 and 80 pixels/N) and task constraint coefficients during bimanual coordination tasks of the upper extremities.

2. Methods

2.1. Participants

Fifteen right-handed volunteers (mean age = 25.6 years old; SD = 5.6 years) participated. All participants were healthy young adults with normal or corrected to normal vision. Before testing began, participants signed an informed consent approved by the University of Florida's Institutional Review Board (IRB02).

2.2. Experimental setup

The protocol involved performance of an experimental task in 12 different blocks of trials. The blocks were created by combining four visual gains and three hand biased conditions (i.e., two force asymmetry hand conditions and one equal symmetry hand condition). Four visual information conditions included: visual gains of 8, 80, 256, and 512 pixels/N (Fig. 1). To determine force asymmetry between the upper limbs, three coefficient setting ratios were imposed on the index fingers of the left and right hands: (a) 1.6:0.4; (b) 0.4:1.6; and (c) 1:1. Unequal task coefficients created a force asymmetry between constraint hands: the force output of one hand that had a higher coefficient by 1.6 and multiplying the force output of the hand that had a lower coefficient with 0.4. The condition with higher coefficient on left upper limb was termed left-biased and the condition with the higher coefficient on right upper limb was termed right-biased. A third condition with equal coefficients (i.e., ratio of 1:1) between limbs was called an equal-biased condition.

Before beginning each of the 12 blocks, participants received specific task coefficients (ratio setting). A block consisted of four practice trials and nine experimental trials. Across 12 blocks, participants performed 108 treatment trials. Each trial was 15 s long with a 10 s rest between trials. The testing order of the blocks was randomized and a 1 min rest was provided between the blocks.