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Perceptual influences of error size on voluntary force control during a compound sinusoidal force task

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ABSTRACT

Visual feedback that provides error information is critical to task quality and motor adjustments. This study investigated how the size of perceived errors via visual feedback affected rate control and force gradation strategy of a designate force task. Fourteen young adults coupled force exertions to a compound sinusoidal signal (0.2 Hz and 0.5 Hz) that fluctuated around a mean level of 30% of maximal voluntary contraction, when the size of execution errors were differently scaled with the error amplification factors. In the low (LAF) and high (HAF) amplification factor conditions, the execution errors in the visual display half and double of the real errors, respectively. The visualized error was the real errors in the medium amplification factor (MAF) condition. In addition to a phase-lead of force output, the LAF condition that virtually reduced the size of error feedback associated with a poorer task accuracy than the MAF and HAF conditions. Virtual increase in error size of visual feedback selectively suppressed the fast target force at 0.5 Hz. In addition, complexity and high-frequency components (> 0.75 Hz) of force outputs multiplied progressively with increasing error size. Error-enhancing feedback suppressed fast target force, accentuating the use of error information to tune force output, whereas error-reducing feedback enhanced fast target force in favor of predictive force control.

1. Introduction

Visual feedback serves an informational function of performance, with which a fraction of motor error is amended to advance motor skill. The brain predicts sensorimotor consequences with the visual feedback and previous experiences. Whenever error prediction is not accurate or motor outcome is unexpectedly distorted, additional neural excitation is needed to reconcile the deviance detection (Abdollahi et al., 2014). Intriguingly, virtual augmentation of the size of execution error via visual display (error-enhancing feedback) does not necessarily degrade task quality, but can expedite perceptual learning of a novel visuomotor task (Emken & Reinkensmeyer, 2005; Patton, Stoykov, Kovic, & Mussa-Ivaldi, 2006). With error-enhancing feedback, participants were able to execute a point-to-point movement more efficiently against the perturbation effects of force fields (Patton, Wei, Bajaj, & Scheidt, 2013). For potential rapid improvement in motor performance, error-enhancing feedback has been recently advocated in sport training (Milanese, Corte, Salvetti, Cavedon, & Agostini, 2016; Milanese, Cavedon, Corte, & Agostini, 2016) and

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motor recovery of neurological victims (Abdollahi et al., 2014; Israely & Carmeli, 2016). To date, the mechanism underlying performance modulation with the virtual size of error feedback is not fully clear, though the error-enhancing feedback is considered to enhance performance outcome with perceptual narrowing according to the cue utilization hypothesis (Easterbrook, 1959).

A visuomotor task is regulated by central planning (feedforward) and online control (feedback) processes (Huang, Su, & Hwang, 2014; Kuo, 2002). Online feedbacks from the visual and proprioceptive systems convey the most recent information about error status to correct movement deviations. The relative significance of the feedback and feedforward processes depends on the frequency demand of tracking, because feedback control with a considerable delay is less efficient to steer a fast visuomotor act (Huang et al., 2014). The brain favors a more predictive mechanism in pursuit of a fast target (> 0.4 Hz) to reduce computational load with real-time error feedback and coordination solutions in the oculo-manual system (Fukushima, Yamanobe, Shinmei, & Fukushima, 2002; Miall, Weir, & Stein, 1993). In addition to variations in cortical activity of parietal and fronto-central sites (Hill, 2014), structural changes in movement variability reflect the prevailing use of feedback or feedforward process (Miall, Weir, & Stein, 1986). If a visuomotor task is predominated by a feedforward process, movement variability is less complexity than those controlled by a feedback process (Baweja, Patel, Martinkewiz, Vu, & Christou, 2009; Kuznetsov & Riley, 2010). Alternatively, a feedback-based force task concurs with a greater force jerkiness (Huang et al., 2014) and lag time (Slifkin, Vaillancourt, & Newell, 2000) than a force task in favor of feedforward control. Under the framework of the sampled feedback hypothesis (Miall et al., 1986, 1993), numerous studies have emphasized the roles of force variability (or movement intermittency) as an additive control mechanism of task accuracy, because pulse-like elements of movement intermittency are scaled to remedy force-tracking errors (Pasalar, Roitman, & Ebner, 2005; Slifkin et al., 2000).

If variations in the size of perceived execution errors could cause a rebalance of the feedback and feedforward processes along the continuum, it was expected to alter task quality, rate control, and variability properties of a force behavior. To this aim, the present study was designed to investigate the behavior mechanisms for force-tracking a compound sinusoidal target with slow (0.2 Hz) and fast (0.5 Hz) components, which entailed feedback-based and predictive pursuits to code the slow and fast rhythmic movements, respectively (Barnes, 2008; Huang et al., 2014). It was hypothesized that 1) error-enhancing feedback will result in superior task performance, greater tracking lag-time and suppression of the fast target frequency (0.5 Hz) in force output than error-reducing feedback using a prevailing feedback control, and 2) error-enhancing feedback will lead to more complex force behaviors with a spectral shift toward higher spectral bands than error-reducing feedback, in support of more intensive corrective attempts during the compound sinusoidal force-tracking.

2. Methods

2.1. Participants

The participants were 14 right-handed healthy adults (8 males and 6 females; mean age: 24.1 ± 0.8 years). The University Institutional Ethics Committee (Institutional Review Board of the Chung Shan Medical University Hospital, Taiwan) granted research approval, and all of the participants signed an informed consent form before the experiment.

2.2. Procedures

Participants were seated 60 cm in front of the computer monitor with the right shoulder abducted by 45°, and the resting forearm was restrained on a platform. The right hand was held in a fixed position by a thermoplastic splint on the table. The index finger was held slightly abducted (5 degrees), and its abduction force was measured using a force transducer (Model: MB-100, Interface Inc., Scottsdale, USA). The maximal voluntary contraction (MVC) of the first dorsal interosseus (FDI) was predetermined as the peak force during three 3-s maximal contractions separated by 3 min pauses. The force-tracking task was a load-varying isometric contraction with index finger abduction, which required a participant to couple force output with a compound sinusoidal signal (0.2 Hz and 0.5 Hz) (Fig. 1(a)). The target signal fluctuated in a small range of 1.5% MVC with a mean level of 30% MVC. The target rate favored the use of combined feedback and feedforward processes in control of a force-tracking task.

There were three experimental conditions: low amplification factor (LAF), medium amplification factor (MAF), and high amplification factor (HAF). The amplification factor was used to scale the visualized error on the monitor. Before data collection, the participants completed three practice trials for each condition, wherein they did not know that the visualized error was manipulated. In these conditions, the size of the error feedback was displayed following mathematical transformations of the force output (Fig. 2) (Chen, Lin, Chang, & Hwang, 2017; Hwang et al., 2017). In the LAF condition, the visualized force (VF) displayed on the monitor was equivalent to the sum of half the real force (RF) and half the target signal (T) ($VF = 0.5 * RF + 0.5 * T$). Hence, the size of the visualized tracking error (VE) was half that of the real error (RE) ($VE = 0.5 * RE$). In the MAF condition, the visualized force was identical to the real force output, and the visualized error was equal to the real error ($VE = RE$). In the HAF condition, the VF was transformed with $VF = 2 * RF\text{-}T$. The size of the VE was twice that of the real error ($VE = 2 * RE$). The spatial resolution (1024 × 768 pixels) was identical in all three experimental conditions. The range of a compound sinusoidal force task of the target signal in the computer monitor was 2 cm, so that visual angle was consistently set at 1.91 degrees for all the three feedback condition (visual angle $= 2 \times \arctan(1/60) = 1.91$ degree). The relationship between veridical perception of the visual information differed with those previous studies using operational control of visual gain (or ratio of force to the pixels on the computer screen) (Lee Hong & Newell, 2008; Vaillancourt, Haibach, & Newell, 2006), because we manipulated the error size at a fixed visual gain. Each experimental condition consisted of 3 contraction trials separated by 3-min pauses, and the order of the trials was randomized for