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Speed, resistance, and unexpected accelerations modulate feed forward and feedback control during a novel weight bearing task

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ABSTRACT

We developed a method to investigate feed-forward and feedback movement control during a weight bearing visuomotor knee tracking task. We hypothesized that a systematic increase in speed and resistance would show a linear decrease in movement accuracy, while unexpected perturbations would induce a velocity-dependent decrease in movement accuracy. We determined the effects of manipulating the speed, resistance, and unexpected events on error during a functional weight bearing task. Our long term objective is to benchmark neuromuscular control performance across various groups based on age, injury, disease, rehabilitation status, and/or training. Twenty-six healthy adults between the ages of 19–45 participated in this study. The study involved a single session using a custom designed apparatus to perform a single limb weight bearing task under nine testing conditions: three movement speeds (0.2, 0.4, and 0.6 Hz) in combination with three levels of brake resistance (5%, 10%, and 15% of individual's body weight). Individuals were to perform the task according to a target with a fixed trajectory across all speeds, corresponding to a ~0 (extension) to 30° (flexion) of knee motion. An increase in error occurred with speed ($p < 0.0001$, effect size (eta^2): $\eta^2 = 0.50$) and resistance ($p < 0.0001$, $\eta^2 = 0.01$). Likewise, during unexpected perturbations, the ratio of perturbed/non-perturbed error increased with each increment in velocity ($p < 0.0014$, $\eta^2 = 0.08$), and resistance ($p < 0.0001$, $\eta^2 = 0.11$). The hierarchical framework of these measurements offers a standardized functional weight bearing strategy to assess impaired neuro-muscular control and/or test the efficacy of therapeutic rehabilitation interventions designed to influence neuromuscular control of the knee.

1. Introduction

Feed-forward and feedback movement strategies are fundamental to optimal neuromuscular control in humans [1,2]. Altered neuromuscular control is associated with poor human performance across the spectrum of function: from elite athletes falling short of a record to the person with Parkinson's disease unable to ambulate a short distance to be independent. Typically, injury occurs when the central nervous system is fooled with an event that was not expected, relying entirely on a feedback response. The integration of the anticipatory commands and the feedback commands is well documented; however, our understanding of feed-forward and feedback control during functional weight bearing movements remains elusive. In this study we assess the effects of manipulating the speed, resistance, and unexpected events on error during a novel functional weight bearing task.

While there is limited information on how speed and resistance cause the CNS to scale neuromuscular responses during weight bearing tasks, there are rich resources guiding us from the upper extremity literature. Feed-forward control of the upper extremity reflects the open-loop plan of movement, and has been shown to decrease in accuracy with increase in speed [1,3,4], and resistance [5,6]. Feedback control, however, is the closed-loop, error driven change in movement. Reaching experiments have provided evidence that unexpected acceleration/deceleration induced by mid-movement changes in speed [7,8] and resistance [9,10], also diminish movement accuracy. Because whole body unexpected events involve the vestibular, visual, and somatosensory systems, the findings may vary from reports for upper extremity perturbations.

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Our initial investigation of a single limb squat as a visuomotor task revealed that a fixed level of difficulty modulates the feed-forward and feedback control strategies as supported by changes in muscle activity about the knee. Improvements in performance can be achieved even under conditions where a person is denied visual feedback [11,12], is fatigued [13], older [14], or post-surgical [15,16]. A limitation of our previous reports is that only a single level of resistance and speed was assessed during the weight bearing task, suggesting that the assessment would show ceiling or floor effects in other populations.

During routine clinical assessment we typically measure impairments with a vast range of techniques (e.g. muscle testing, gross motor function exams, range of motion testing, sensory testing, timed standing balance, coordination, reflexes, and quality and endurance of gait). Testing how healthy people scale lower extremity movement and perturbation responses during a range of difficulty will provide insights into control of weight bearing functional movement. We believe that this is important in order to assess the integration of movement systems and strategies, and may provide a rapid method to characterize impairment, and, presumably, disability.

The purpose of this study was to determine if changes in speed, resistance, and unexpected acceleration either independently or in combination leads to reduced movement accuracy in a hierarchical pattern (greater error with greater resistance and/or greater speed). We hypothesize that an increase in speed and resistance would yield a linear decrease in movement accuracy, while unexpected perturbations would lead to a velocity-dependent and resistance dependent decrease in movement accuracy.

2. Methods

2.1. Subjects

A total of 26 healthy adults aged 19–45 years (mean(SD), 27.7 (6.7) years; nine females and seventeen males) participated in the study. All subjects enrolled in the study had no acute or ongoing orthopedic, neuromuscular, or neurological deficits or disorders. Each individual gave informed consent before participation and our institution's Human Subjects Institutional Review Board approved the study.

2.2. Paradigm

The study involved a single session using a previously developed therapeutic exercise system [17] to deliver nine testing conditions: three movement speeds (0.2, 0.4, and 0.6 Hz) in combination with three levels of brake resistance (5%, 10%, and 15% of individual's body weight). Only the dominant leg was tested, as was defined as the side with which one would kick a ball. Each testing condition was separated by a one-minute rest period. The order of testing condition is fixed across all subjects: medium, light, then heavy resistance for the medium speed, followed by the same resistance order at the slow speed, and lastly the fast speed (Top panel, Fig. 1A). Each subject was asked to track a computer

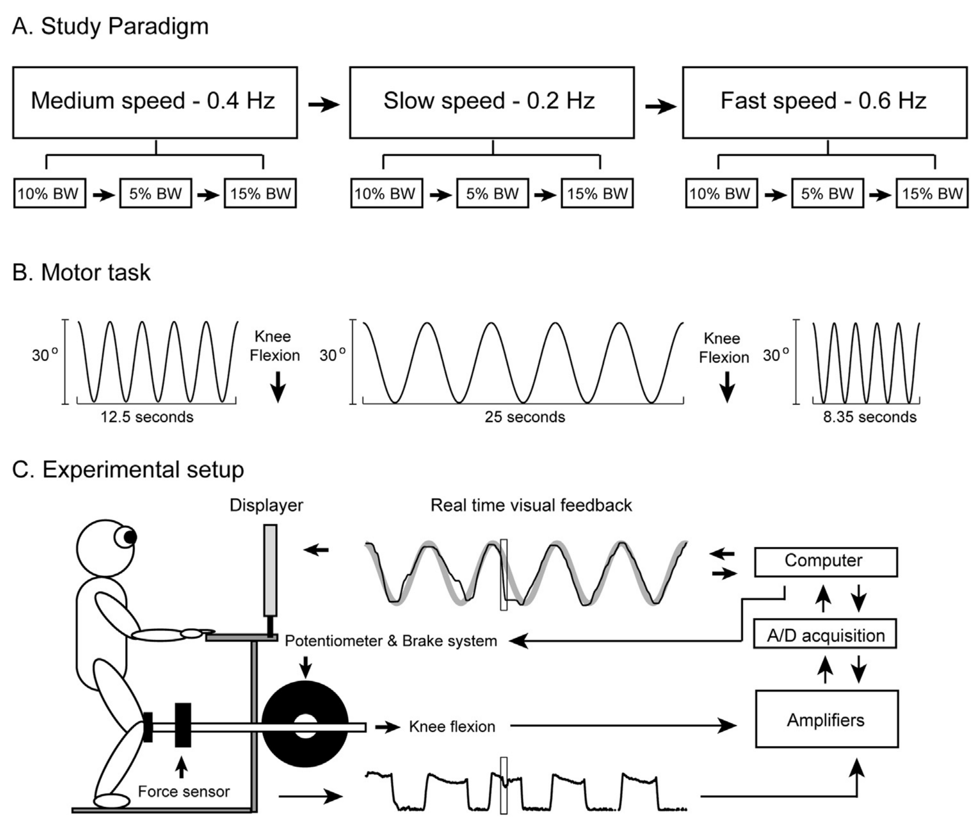

Fig. 1. Illustrations of study paradigms (A), motor tasks (B), and experimental setup (C). Nine testing conditions (3 speeds × 3 resistance levels) were assigned to each subject in order: the medium speed in combination with three levels of resistance, the slow speed in combination with three levels of resistance, and the fast speed in combination with three levels of resistance (A). The motor task consists of five cycles of the sinusoidal waveforms (i.e. target signal) set at three pre-determined frequencies: 0.2, 0.4, and 0.6 Hz, corresponding to slow, medium, and fast movement speeds (B). The target signal corresponded to ~30° of knee flexion and knee extension. Subjects were instructed to track computer generated sinusoidal targets as they performed a single limb squat exercise (C). Instantaneous visual feedback of actual knee position (the black trace) was provided to subjects on the same monitor as the target trace (the gray trace) (C). The brake system was turned off for a pre-determined period of time within a cycle to produce a perturbation. The rectangle overlaid on sinusoidal signals indicated the time period when the resistance was released. The bottom traces depicted force readings over time (C). BW: body weight.