IDENTIFYING SENSORIMOTOR CONTROL PHASES FOR PREDICTIVE SIMULATIONS USING VESTIBULAR CONTRIBUTIONS TO BALANCE

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Introduction

Predictive neuromuscular simulation is a powerful tool that can be used to examine how age-related decline in the neuromuscular system affects complex movement behaviours. These models rely on neuromuscular controllers that modulate sensory feedback – including vestibular information – to transition between different motor control phases. These phase transitions are commonly defined in gait simulations based on thresholds on the kinetics and kinematics of movement. The transitions between control phases in more complex movement, like rising from a chair, however, are not yet clear. Therefore, control phases of recently published predictive simulations on sit-to-walk (STW) have not yet been verified [1]. The aim of this study was to experimentally determine the contribution of vestibular feedback during a sit-to-walk task using electric vestibular stimulation (EVS) [2].

Methods

Three separate tasks were performed in the experiment: STW (sit-to-walk), STS (sit-to-stand), and GI (gait initiation). Each task was repeated 80 times per participant. All participants performed the STW task (N = 16). Half of the participants additionally performed the STS task (N = 8) while the other half performed the GI task (N = 8). Whole-body kinematics and ground reaction forces were recorded. During the trials, participants were subjected to a stochastic EVS (bandpass filtered 2.5-10.5 Hz) applied to the mastoid processes on each side delivered in a binaural bipolar configuration, leading to compensatory muscle and whole-body responses in the mediolateral direction [3]. The relationship between the input EVS signal and the output summed GRF of all five force plates was estimated using time-frequency coherence based on continuous Morlet wavelet decomposition. To objectively identify points at which the coherence level significantly changed during each task, a change point analysis was performed on the group average coherence level of each task. To assess whether the STW task could be described as a combination of STS and GI tasks, a weighted model combining the detected phases in STS and GI was used and compared to the STW results. The weighting functions represent how much of STW behaviour can be attributed to STS or GI.

Results

In all three conditions, a suppression of the vestibular responses was observed at the initiation of movement from a quite seated or standing position (Fig. 1). These transitions from posture to movement are thought to rely on the disengagement of one control policy before implementing another [2]. These results demonstrate that STW behaviour undergoes three transitions in the vestibular control of balance between four distinct sensorimotor control phases. During the first two phases, the coherence decreases for an extended period (> 1 s), similar to that observed in STS, where an initially seated participant flexes forward to initiate standing. The latter two phases closely match the transition to walking during GI, where the coherence rises for ~1 s and then falls into a rhythm synchronized with the gait cycle. Our weighted model indicates that STW can be represented as a combination of STS and GI behaviours with a sharp transition that occurs approximately around the time of seat-off (~1 s). The timings of the control phases identified differed from kinematic phases (Fig 1).

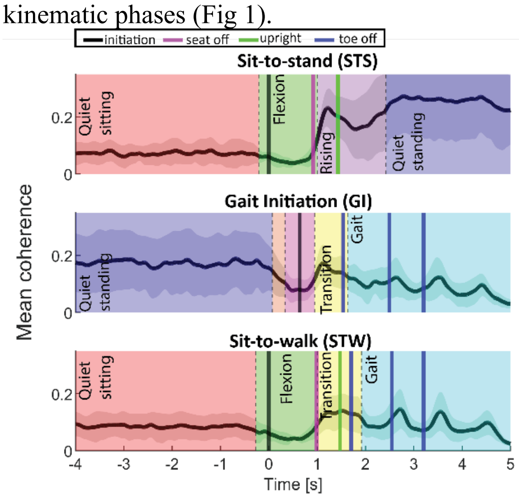

Fig 1. Motor control phases based on EVS coherence

Discussion

Our study used change point analysis of vestibular-evoked balance responses to characterize discrete shifts from one control policy to another, aligning with the discreet change in control policies employed by predictive simulations. The experimental results show, however, that the measured changes in vestibular evoked responses are never abrupt, and instead adapt gradually between phases. Future simulations can test whether these gradual changes may be due to factors such as muscle activation dynamics and neural delays. Also the use of kinematic thresholds to regulate neuromuscular controllers in predictive simulation should be reconsidered.

References

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