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Research article

Anticipatory postural adjustments as a function of response complexity in simple reaction time tasks

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ABSTRACT

The central nervous system preplans postural responses to successfully perform complex multi-joint movements. These responses have been termed anticipatory postural adjustments (APAs), and they constitute a general type of response to stabilize posture prior to movement initiation. APA sequences are elicited with shorter latency when a startling acoustic stimulus is applied, demonstrating their preplanned nature. Increasing task complexity using a simple reaction time (RT) paradigm has been shown to delay limb movement RT as a result of additional planning or sequencing requirements; however, the effect of task complexity on APA dynamics is unclear. The purpose of the present study was to investigate if task complexity modulates APA onset in a manner analogous to that observed in the primary effector. 13 participants completed 150 trials of simple (1-target) and complex (2- or 3-target) arm movements while standing on a force plate. Results indicated participants had significantly faster arm movement RTs in the simple versus the most complex condition. Similar to the primary effector, APA RTs were longer in the most complex (3-target) movement compared to both the 1-target and 2-target movements. Furthermore, APA excursion velocities were scaled to the complexity of the upcoming movement: the rate of APAs increased from simplest to most complex movements. These findings clearly demonstrate APAs are sensitive to task complexity, further elucidating their preplanned role in stabilizing posture which enables the successful completion of intended movements.

1. Introduction

The first groundbreaking study on postural adjustments was undertaken by Belen'kii and colleagues [3], in which they proposed that muscles in the lower limb are activated during the preparation for voluntary movement in order to maintain balance prior to new movement situations. In his seminal review, Massion [16] described how *internal constraints* – inertial characteristics of the body segments and the internal forces associated with muscular contractions – and *external constraints* (gravitational forces) contribute to skillful motor performance. The central organization of motor performance takes into account these constraints to perform complex multi-joint movements, with multiple parallel commands coordinated and integrated towards generating one fluid motion [1]. To facilitate this process, the central nervous system (CNS) preplans postural responses to accommodate internal and external constraints. Massion defined this response as an anticipatory postural adjustment (APA), which constitutes a general type of response for stabilizing posture prior to movement initiation [16].

Reaching and grasping can disturb balance unless a compensatory movement is initiated prior to an arm extension. Friedli and colleagues [8] examined how rapid, bilaterally symmetric elbow flexion or extension movements influenced ground reaction forces (reflective of APAs). Not surprisingly, ground reaction forces were directionally opposite in elbow flexion and extension movements, suggesting postural adjustments are specified by the dynamics of the upcoming focal movement [8]. In addition, Horak and colleagues [10] have demonstrated that APA characteristics differ if the same perturbation is expectedly or unexpectedly presented. The authors observed a systematic over- or undershoot in APA magnitude when perturbations were changed unexpectedly. Furthermore, a gradual reduction in APA magnitude was observed when the perturbation condition became predictable. Collectively these findings indicate APAs are shaped by characteristics of the perturbation as well as prior experience.

If an APA is a general type of modifiable adjustment that stabilizes posture prior to the initiation of a movement, different movements

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should elicit different stabilization strategies. Indeed, APAs have been shown to be adaptable to the spatial and temporal requirements of an upper limb task [2]. As such, a simple movement requiring a single component should elicit a different postural strategy than a complex movement requiring multiple components and multiple movement reversals, even if the initial component is the same as that generated in the simple movement. Originally designed to probe the effect of movement complexity on reaction time (RT), Henry and Rogers' [9] seminal experiment could also be used to investigate APA behaviour across progressively more complex movements. Their experiment consisted of three simple RT tasks, each with a varying number of movement components. As the complexity of the movement was increased, RT lengthened, suggesting differing preparation strategies for each of the movements. Importantly, using this simple RT paradigm participants were informed of the required movement prior to the imperative stimulus (IS) [18], allowing all responses to the impending movement to be prepared in advance.

The influence of task complexity on APA dynamics in a simple RT task is unknown. The primary purpose of this study was to characterize the extent to which task complexity modulates APA metrics in a manner analogous to those observed in the primary effector. Increased task complexity was hypothesized to prolong RT of the APAs and alter APA velocity profiles.

2. Methods

2.1. Participants

Thirteen (8 male, age range 21–37) healthy, self-declared right-handed participants with normal or corrected-to-normal vision, and no history of neurological, sensory, or motor disorders participated in this study. Testing of each participant took place in a single session and required approximately 1.5 h to complete. All participants provided written informed consent prior to beginning data collection. The study was approved by the University of British Columbia's Behavioural Research Ethics Board (H11-02368).

2.2. Experimental set-up and task

The participant stood without shoes with feet shoulder-width apart on a force platform (NDI True Impulse, Waterloo, Canada) in front of the KINARM End-Point Lab (BKIN Technologies Ltd., Kingston, Canada) and used their right hand to grasp the right manipulandum linked to the robotic motors. Arm movements were performed in the horizontal plane in response to targets presented on an augmented reality display (Fig. 1). Participants were informed that the upcoming task was a simple RT task consisting of a ballistic arm movement in one of three movement conditions. Participants were told to react as quickly as possible to the IS. While emphasizing the ballistic nature of this task, movement accuracy was not stressed. Prior to the IS, participants were informed which of the three movement conditions was to be performed. In the 1-target condition, movements were directed anteriorly (straight ahead) and terminated at the first target (A in Fig. 1). In the 2-target condition, the participant reached the first target and performed a reversal in the posterior direction and to the right before terminating their movement at the second target (B in Fig. 1). The 3-target condition involved a second reversal after reaching the second target, requiring an anterior (straight ahead) movement to reach the final target (C in Fig. 1). Importantly, regardless of the final target position, the initial movement (i.e., home position to target one) was identical across all movement conditions, in line with Henry and Rogers' original experiment [9]. Each trial required the participant to first reach the home position, represented by a red dot (visual radius of 1.0 cm). Following a randomized foreperiod (1000–3000 ms) an auditory IS was presented signaling the participant to initiate movement. All targets were the same size (visual radius of 0.5 cm) and switched from white to green

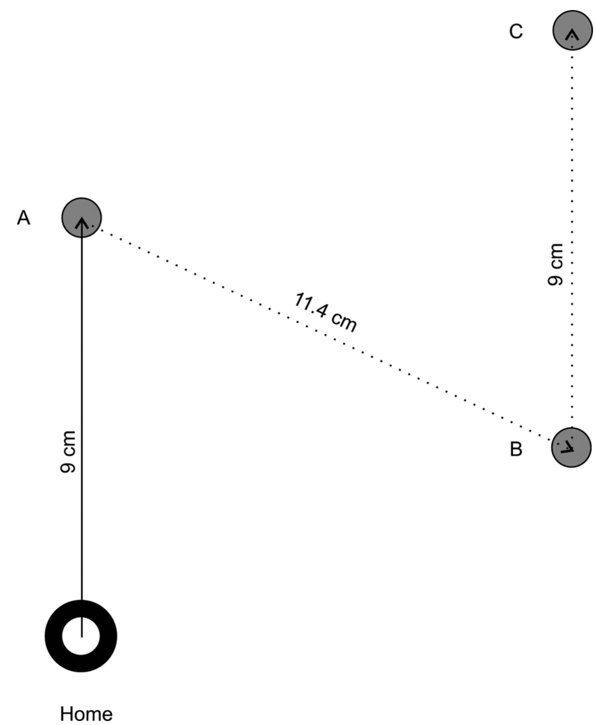

Fig. 1. Top view of the behavioural setup using the KINARM robot. Participants first reached the home position, and following a randomized foreperiod (1000–3000 ms) they initiated a movement in sequence to either the first target (A), the first and second targets (B), or the first, second and third targets (C) as quickly as possible.

when reached successfully. Onset was taken when the centre of the cursor left the home position. Following the completion of a practice block consisting of 10 trials for each condition, participants completed 150 trials (50 per complexity condition, presented randomly).

2.3. Recording equipment and data reduction

The KINARM recorded displacement and acceleration at each robotic joint angle. The robot used in this study was not equipped with the 6-degree of freedom force-torque sensor in the handle, thus limiting our analysis to kinematic variables. Reaction time of the arm was defined as the time interval between the presentation of the IS and the time at which the participant left the home position. Initial movement time (MT) was defined as the time interval between the time when the participant left the home position and the time at which the first target was reached (Fig. 1A), across all target tasks.

The force plate collected forces and moments in the X (leftward), Y (forward) and Z (vertical) directions in relation to the centre of the plate, which allowed for the calculation of centre-of-pressure (COP) displacements and velocities in both the anterior-posterior (AP) and medial-lateral (ML) directions using a custom written Matlab script (vR2013a, Mathworks Inc, Natick, MA). All COP signals were processed using a fourth-order, dual-pass digital Butterworth filter with a 5 Hz cutoff frequency. To best represent a steady-state window in which no APAs would be expected, displacements in COP were calculated with respect to the baseline value defined as the average position beginning 500 ms prior to movement onset [6,13,19–22] for 200 ms. The AP position of the COP (COP_{AP}) was calculated as M_x/F_z, and in the ML direction as $COP_{ML} = -M_y/F_z$. These measures took into account the distance between the surface of the force plate and its geometric center. Due to inter-trial, as well as inter-participant variability potentially caused by the availability of differing postural strategies [14], RT of the APA onset (APA_{onset}) was measured by taking the time point at which the COP displacement changed by 3 SD from the mean, calculated