Stance width influences frontal plane balance responses to centripetal accelerations

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ABSTRACT

Whenever the body is moving in a curvilinear path, inertial torques resulting from centripetal accelerations act on the body and must be counteracted to maintain stability. We tested the hypothesis that healthy subjects orient their center of mass in the position where gravitational torques offset the inertial torques due to centripetal accelerations. Ten healthy subjects stood on a platform that rotated in a circle at either a slow or fast speed, eyes open or closed, and in narrow or wide stance. Upper body, lower body, and center of mass (CoM) tilt with respect to vertical were measured and averaged across a 40 second time period of constant velocity. Body tilt was compared to the gravito-inertial acceleration (GIA) angle with respect to vertical. In all moving conditions, the upper body, lower body, and CoM tilted inward. However, this inward tilt did not reach the predicted GIA angle (CoM tilt was ~78° and 33° toward the predicted GIA angle in narrow and wide stance, respectively). Ratios of body tilt to GIA angle were minimally influenced by visual availability and magnitude of centripetal acceleration; but were largely influenced by stance width whereby narrow stance inward tilt was greater than wide stance. These results further highlight the important influence of the base of support on balance control strategies and enhance our understanding of how the balance control system compensates for inertial torques generated from centripetal accelerations.

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1. Introduction

To effectively maintain balance, humans must compensate for a variety of external and internal torques on the body. One category of torques present in all multi-segment movements are inertial torques which arise whenever one body segment accelerates relative to another [1]. For example, when turning during walking, centripetal accelerations of lower body (LB) segments produce inertial torques on the upper body (UB) which drive the body away from upright and toward the outside of the curved path. Previous studies indicated that inertial torques might be offset to some extent by subjects tilting their head and trunk inward when transitioning from straight-ahead walking to turning [2]; and inward body tilt was found to increase with greater centripetal acceleration [3,4]. To better understand the influence of centripetal accelerations and inertial torques on balance, the current study characterizes how standing balance responses are influenced by centripetal accelerations and how responses are modified by visual feedback and stance width.

Previous findings in healthy and vestibular deficient subjects showed that visual and vestibular sensory feedback and the biomechanical state of the body can influence the perception of horizontal in the presence of centripetal accelerations [5,6]. However, because these studies did not focus on freestanding balance responses, it is unknown if sensory feedback used to perceive horizontal is applied in the same way to maintain stability. It has been suggested that inertial torques could be sensed with force receptors in tendons and mechanoreceptors in feet [7–9]. Thus, to compensate for inertial torques, the nervous system could interpret and combine force receptors in conjunction with vestibular feedback to orient the body away from upright and toward the gravito-inertial acceleration (GIA) angle so that gravitational and inertial torques counteract each other and the center of pressure (CoP) remains mid-way between the feet (Fig. 1A, left). This strategy would be analogous to the inward tilt that bicycle riders make when turning. However, previous modeling studies indicate that passive muscle/tendon mechanics, proprioceptive feedback from muscle spindles and joint receptors, and visual feedback can orient the body upright in space when the