Gait & Posture 51 (2017) 52–57

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

A test of fixed and moving reference point control in posture

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ARTICLE INFO

Article history:
Received 16 May 2016
Received in revised form 19 August 2016
Accepted 26 September 2016

Keywords:
Reference point
Posture
COP distribution
Sample entropy

ABSTRACT

This study investigated two contrasting assumptions of the regulation of posture: namely, fixed and moving reference point control. These assumptions were tested in terms of time-dependent structure and data distribution properties when stability is manipulated. Fifteen male participants performed a tightrope simulated balance task that is, maintaining a tandem stance while holding a pole. Pole length (and mass) and the standing support surface (fixed surface/balance board) were manipulated so as to mechanically change the balance stability. The mean and standard deviation (SD) of COP length were reduced with pole length increment but only in the balance board surface condition. Also, the SampEn was lower with greater pole length for the balance board but not the fixed surface. More than one peak was present in the distribution of COP in the majority of trials. Collectively, the findings provide evidence for a moving reference point in the maintenance of postural stability for quiet standing.

1. Introduction

A prevailing viewpoint of postural control holds that through feedback mechanisms the system perceives deviations from a given reference point and generates corrective torques [1,2]. The reference point has been characterized as a location on the supporting surface that reflects an attractor or a set point [3]. In the general perspective of closed-loop control in posture, there are two working assumptions of the reference point control: fixed reference point (e.g., Refs. [4–6]) and moving reference point (e.g., Refs. [3,7]).

The fixed reference point holds that postural adjustments occur relative to a fixed location at the surface of support. The classic example of this form of postural control is the inverted-pendulum model [4], in which the fixed point would be the pivot of the pendulum (cf., [8,9]). The moving reference point assumption holds that the reference point may not be fixed to a spatial location but rather may move over time [10,11]. A particular example is the Rambling-Trembling model of Zatsiorsky and Duarte [12] in which posture is assumed to have two components: a slow moving reference point (i.e., rambling) that is accompanied by fast adjustments to the reference point (i.e., trembling).

The fixed and moving reference assumptions pose different constraints on models and theories of postural control but there have been few direct evaluations of them (e.g., Ref. [9]). The feedback loop based models tend to assume the fixed-point reference point so as to simplify the modeling approach to balance control. Nevertheless, the assumption of fixed-point control might directly mediate interpretation of the estimation of movement error and thus these two assumptions need to be directly assessed.

In the framework of a fixed reference point the stability of posture can be considered when the COM projection is maintained at the *particular* location of the fixed reference point. Given that the organism shows small and random fluctuations in its output (e.g., COP), we can expect that a highly stable posture will show random-like fluctuations with small amplitude (Fig. 2(A)). Nevertheless, when an unstable condition arises, the COM projection will deviate from the reference point by larger amplitudes requiring postural adjustments. These adjustments are assumed to be deterministic (i.e., given a deviation, a particular adjustment occurs) (e.g., Refs. [4,8]). Thus, in unstable conditions, adding large-amplitude deterministic components to a random-like structured signal increases its predictability (Fig. 2(B)) (see Ref. [13])

The predictions would be different for a moving reference point. The moving point has a deterministic nature that is assumed to have a relatively slow frequency [12]. Provided that no perturbations to the system occur and the individual is in a stable condition, the expected structure of the output will be relatively predictable (Fig. 2(C)). When unstable conditions are met, adjustments are necessary in the same way as the fixed-point reference assumption. Nevertheless, when a deterministic signal (of different frequency and amplitude) is imposed to another deterministic signal, the predictability is decreased provided that more

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http://dx.doi.org/10.1016/j.gaitpost.2016.09.028
0966-6362/

information is necessary to specify the structure of the signal. Thus, in unstable conditions, the predictability is expected to decrease (Fig. 2(D)).

Another aspect of the motor output that can provide evidence towards distinguishing the reference point assumptions is the distributional properties of the COP. Considering a fixed reference point with random-like structure[1] and given enough data points, the data would show a distribution with one peak or mode. On the contrary, if a moving reference point holds, the distribution may show more than one peak given that the random noise would vary around the different positions of the changing reference point. It should be emphasized that with a fixed reference point *all posture conditions* should show one peak in its distribution while the moving reference point assumption predicts that this is not necessary – but it may occur. Furthermore, notice that here the stability condition of postural support does not interact with this prediction.

In order to test the fixed and moving reference point assumptions, a systematic manipulation of stability is necessary. In this study, we used the tandem stance of one foot in front of the other to simulate the high-wire standing posture and systematically manipulate experimentally different levels of postural stability [14]. Two manipulations, standing surface of support (fixed and balance board surface) and pole length (no pole, 1.5, 3, 4.5 and 6 m) were used. Holding an increasing length pole (and increasing mass) allows the posture to become relatively more stable by making the height of COM lower to the surface of support and increasing the rotational moment of inertia of the body [14]. Accordingly, the individual's posture would be more resistant to perturbations, facilitating the maintenance of the COM within the base of support. Therefore, the longer the pole the participants' hold (within boundary conditions), the more stable they are and this adaptive influence would be strongest in the balance board condition.

2. Method

2.1. Participants

Fifteen male volunteers (age: 27.75 ± 4.41 yrs; weight: 78.08 ± 11.73 kg; height: 178.25 ± 6.36 cm) were recruited for this study. All subjects reported having no neuromuscular impairment or injury with normal or corrected to normal vision. Informed consent was obtained prior to the experiment, and the Institutional Review Board of The University of Georgia approved all experimental procedures.

2.2. Task

Participants were instructed to perform a tandem stance task (one foot in front of the other) while holding a pole with relaxed arms and bare feet (Fig. 1). The task goal was to be as steady as possible in maintaining their posture. The pole was held parallel to the medial-lateral axis and rested against the participants' right thigh. The right foot was positioned ahead of the left foot at a distance of 0.3 m. While standing, participants were asked to maintain visual contact with a point at eye level located 3 m away.

The posture testing consisted of two manipulations: length of pole (no pole, 1.5, 3, 4.5 and 6 m pole) and surface stability (stance on the plate/balance board). Thus, there were 10 conditions requiring approximately 1.5 h of data collection. In the no pole condition, the participants held a paper roll that was equivalent to the pole diameter. The pole conditions were randomized and the base of support conditions counterbalanced. Each posture condition consisted of three 30 s quiet stance trials.

Fig. 1. Schematic illustration of the task. Participant was instructed to hold a pole and stand still possible on the balance board/fixed surface with the tandem foot position.

2.3. Apparatus

The participant stood with each foot on one of the two adjacent force platforms (AMTI, Watertown, MA, USA). The COP time series was calculated based on the ground reaction force and moments in 3 orthogonal directions (along the direction of gravity, parallel to the ground in sagittal plane, and parallel to the ground in frontal plane). Data were recorded at a sampling rate of 100 Hz. The poles were of length of 1.5, 3, 4.5 and 6 m with a weight of 3.75, 7.5, 11.25, and 15 kg, respectively. In the no pole condition, the participants held a paper roll with the same diameter as pole instead (length: 0.9 m, weight: 170 g). All poles were constructed from steel with a uniform density and diameter of 6 cm. Two balance boards consisting of a wooden plank with a beam attached down the middle were used to make balance more challenging for the participants in the medial-lateral (ML) direction (beam: 4 (W) × 40 (L) × 4 (H) cm; wooden plank: 20 (W) × 40 (L) × 0.5 (H) cm).

2.4. Procedures

The foot position was marked by tape on the force plate to ensure consistent location of foot placement within and between each trial. After a task familiarization period of 30 s (in both surface conditions), the experiment started. An experimenter assisted the participants in gaining initial balance and pole position at the beginning of each trial. Data collection began as soon as the participant reported feeling balanced. To avoid the effects of fatigue, the participants were asked to sit on the chair 1 min between each trial during the rest period.

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[1] Here we are assuming a White Gaussian Noise.