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Sampling duration effects on centre of pressure descriptive measures

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ABSTRACT

The different measures used to characterize postural sway are sensitive to variations in sampling duration, yet there remains marked variability and a lack of consistency in this temporal parameter when compared between studies. We investigated the effect of sampling duration on 22 commonly used frequency and time domain measures and stabilogram diffusion coefficients. Participants stood quietly on a forceplate during two 600 s standing trials with eyes open and eyes closed. The results clearly show that the amplitudes of the descriptive measures are sensitive to sampling duration. Only measures related to the amount of sway were sensitive for eyes open versus eyes closed conditions. In addition to sample duration, the filter settings, sampling frequency and fitting windows should be standardized since they also affect the magnitude of the descriptive measures. Without such standards, the inability to accurately compare between studies will persist.

1. Introduction

Although force plate derived centre of pressure (COP) measures of postural sway have been useful in helping to screen for abnormal balance control, little success has been achieved in using static posturography as a tool for discriminating and/or diagnosing specific disease-related balance characteristics during quiet stance [1]. One potential limitation of posturography is the lack of standardization of testing protocol and measurement parameters for force plate derived COP measures during quiet stance. For example, there is little consistency among previous studies regarding the types of descriptive measures (DMs) used to quantify COP behaviour or the length of time used to sample COP, which likely contributes to the conflicting results reported for even the simple manipulation of vision on postural control (see Table 1). As a result there remains little, if any, common grounds from which comparisons between studies can be made in hopes to establish a concrete understanding of the characteristics of normal healthy postural control, let alone pathological implications.

The need for standards within the field of static posturography was recognized almost three decades ago in a report presented at the International Symposium of Posturography in Kyoto in 1981 [2]. The report featured a number of recommendations for standards in collection, measurement and presentation of posturographic data and called upon the need for future research to better understand the factors that may influence the results of posturographic measurement in hopes to validate the norms set out by the report (3). Sampling duration, one of the key factors highlighted in the Kyoto report, has been the focus of a number of recent investigations which have validated previous concerns. For example, studies have shown that the magnitudes of various COP summary measures in the time and frequency domains are significantly influenced by sampling duration [3,4].

Although these studies have provided important insight into the potentially confounding effect of sampling duration on COP measures, the investigations were limited to sample durations of less than 120 s, which may not be sufficient to capture the very low frequency, and unique characteristics of postural sway observed during more extended periods of quiet stance [5]. Furthermore, the effect of sample duration has only been examined on a few COP summary measures under normal sensory conditions, which may not be generalizable to other DMs or conditions used commonly within the field.

Studies have also demonstrated that the reliability of COP summary measures in both the time and frequency domains are susceptible to the effects of sample duration [3,6–10]. To ensure reliable DMs, averaging together a number of shorter trials whose net duration exceeds 300 s has been proposed as an effective alternative to collecting a single long standing trial. Although considered an effective approach to generate reliable COP summary measures, this process has not yet been validated to ensure the precision of a respective DM.

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Table 1
Overview of studies on the effect of visual condition on postural sway during unperturbed standing, which used the same descriptive measures we analyzed. Shown are the descriptive measures used to quantify the effect of vision, and the sampling duration of each study. See Table 2 and the supplemental material for the acronyms of each DM.

Citation	Descriptive measures	Sampling duration	Results of visual condition
Carpenter et al. [3]	RDIST, MPF	120 s	$RDIST_{A-P}$ > in EC MPF_{M-L} < in EC
Kim et al. [14]	MVEL MPF	75 s	MPF_{A-P} > in EC
Kunkel et al. [15]	RDIST, MVEL	62 and 30 s	$RDIST_{A-P, M-L}$ and $MVEL_{A-P, M-L}$ > in EC
Asakawa et al. [16]	RDIST	60 s	RDIST > in EC
Laufer et al. [17]	MPF, RDIST, MVEL	60 s	MPF_{A-P}, $RDIST_{A-P}$ and MVEL > in EC
Paulus et al.[18]	RDIST	60 s	RDIST > in EC
Prieto et al. [11]	MDIST, RDIST, MVEL, MFREQ, POWER, CFREQ, FREQD	30 s	$RDIST_{A-P}$ > in EC
Vuillerme et al. [19]	MVEL	10 s	no effect

Therefore, the first aim of the study was to examine the effects of sampling duration on a wide variety of COP measures recorded from quiet standing trials whose duration far exceeds those used in previous experiments. We hypothesized that increased sampling duration would significantly influence all descriptive measures in both the time and frequency domains. The second aim of the study was to determine whether the effects of vision on postural control are dependent upon sampling duration. We hypothesized that the effects of vision on postural control would be consistent across sampling durations. The third aim of the study was to determine whether the accuracy of DMs calculated from an entire 600 s trial would be different from the average of 10 continuous 60 s taken from the same 600 s standing trial. We hypothesized that DMs calculated from the average of 60 s trials would be significantly different those calculated from a single 600 s trial.

2. Methods

2.1. Participants

10 university students (5 males and 5 females, age 23–31 years) volunteered for the study. Participants were free from neurological or orthopedic disorders as verified by self-report. All participants provided informed consent as outlined by the University of British Columbia Ethics Committee.

2.2. Procedure

Each participant stood quietly on a forceplate with their feet positioned comfortably within a square defined by dimensions equal to their foot length. The feet were traced on the forceplate to ensure consistent foot positioning between standing trials. The participants were instructed to stand quietly with their arms hanging at their sides and head in a normal forward-facing position, with eyes closed (EC) or with eyes open (EO) and focused on a stationary target located at eye level, approximately 2 m away. Participants performed a 600 s standing trial for each visual condition, separated by a seated rest period (>4 min), to minimize any effects due to fatigue. The order of presentation for EO and EC trials was counter-balanced across subjects to minimize potential order effects.

2.3. Data analysis

Ground reaction forces and moments in three planes were sampled at 20 Hz and converted to a digital signal via a 16 bit A/D converter. Continuous displacement of COP was calculated offline for each individual 600 s record, and then divided into 10 intervals, starting from 60 s and increasing in length by increments of 60 s (i.e. 0–60, 0–120, 0–180..., 0–600 s). For each interval, DMs were calculated in the anterior–posterior (AP) direction (see Table 2 and Supplemental Material for specific details). The time domain and frequency domain measures were adopted from Prietto et al. [11]. The stabilogram diffusion measures were calculated following the methods of Collins and De Luca [12]. Note that the frequency domain measures were calculated for two frequency ranges: (1) from 0.15 Hz to 5 Hz as in reference [11] and (2) from $1/T$ to 5 Hz as in reference [3], where T is the sampling duration. With the latter method the lowest detectable frequency becomes smaller when the total sampling duration increases.

Table 2
ANOVA results for effects of sampling duration and vision on all COP dependent measures. Please note that "N" denotes non-significant ANOVA results.

Dependent measure	Acronym	Main effect (sample duration)	Interaction (sample duration × vision)	Time to stability (s)	Direction to stability
Frequency domain					
50% Power frequency[a]	P50	N	N	N/A	N/A
95% Power frequency[a]	P95	N	N	N/A	N/A
Centroid frequency[a]	CFREQ	$p = 0.002$	N	120	↓
Frequency dispersion[a]	FREQD	$p = 0.000$	N	N/A	↓
Mean power frequency[a]	MPF	N	N	N/A	N/A
Total power	POWER	N	N	N/A	N/A
50% Power frequency[b]	P50B	$p = 0.000$	N	180	↓
95% Power frequency[b]	P95B	$p = 0.000$	N	240	↓
Centroid frequency[b]	CFREQb	$p = 0.000$	N	420	↓
Frequency dispersion[b]	FREQDb	$p = 0.000$	N	240	↑
Mean power frequency[b]	MPFb	$p = 0.000$	N	240	↓
Time domain					
Diffusion coefficient short term region	DS	N	N	N/A	N/A
Diffusion coefficient long term region	DL	N	N	N/A	N/A
Scaling exponent short term region	HS	N	N	N/A	N/A
Scaling exponent long term region	HL	N	N	N/A	N/A
Critical point square displacement coordinate	CRITX	N	N	60	N/A
Critical point time interval coordinate	CRITDT	N	N	60	N/A
Mean velocity	MVEL	N	N	60	N/A
Mean frequency (rotational frequency)	MFREQ1	$p = 0.000$	N	180	↓
Mean frequency (sinusodal frequency)	MFREQ2	$p = 0.000$	N	180	↓
Mean distance	MDIST	$p = 0.000$	$p = 0.001$	N/A (EO); 300 (EC)	↑ EC
Standard deviation	RDIST	$p = 0.000$	$p = 0.001$	N/A (EO); 360 (EC)	↑ EC

[a] Denotes spectral measures that were calculated with a fixed low frequency bound of 0.15 Hz.
[b] Denotes spectral measures calculated with a lower bound that varies with sample duration (T) as $=1/T$.