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Citation	International journal of rehabilitation research, 39(1), 92-95 https://doi.org/10.1097/MRR.0000000000000143
Issue Date	2016-03
Doc URL	http://hdl.handle.net/2115/65001
Rights	This is a non-final version of an article published in final form in (provide complete journal citation)
Type	article (author version)
File Information	Int J Rehabil Res_39(1)_92-95.pdf

Title:

Adaptation of postural control while standing on a narrow unfixed base of support.

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Statement of conflicts of interest

None declared.

Statement of source of funding

This work was supported in part by a Japanese Grant-in-Aid for Scientific Research (25350747).

Abstract

The purpose of this study was to investigate the adaptation with practice of postural control while standing on a rocker board. Thirteen healthy young adults participated. Subjects were asked to stand in a sagittal plane on a rocker board with a semicircular base as steadily as possible for as long as they could. With practice, the duration of maintaining postural balance increased significantly and postural stability improved ($p < 0.05$). Furthermore, the distances between COP and the projection of COM decreased ($p < 0.05$), although joint motion of the lower extremities did not change ($p > 0.05$). This observation would be the consequence of highly redundant human locomotor system. With practice, the CNS was able to shift the COP position close to the accurate COM position.

Keywords: postural control; adaptation; rocker board; static balance

Introduction

Static balance relies on the ability of the central nervous system (CNS) to control the body’s center of mass (COM) within the limits of stability (LOS), defined as the maximum excursion area of the projection of COM (center of gravity: COG) within the base of support (BOS) (Riach and Starkes 1993). In rehabilitation, a foam mat or a balance board, such as a rocker board (seesaw), has often been used to improve static balance (Penzer et al. 2015; Hubbard 2010). It is important to understand how the CNS controls the COG to keep it within the LOS under this challenging condition and how this adapts with practice.

It is well established that “hip strategy” is enhanced when individuals stand in the forward–backward direction on a narrow movable surface with practice (Horak and Nashner 1986). In other words, hip movements increase to counter large perturbations by shifting the COG quickly back to a position well within the BOS. However, the hip strategy may be a result of the restricted condition of the BOS remaining constant relative to the movable surface. “Ankle strategy” may also be constrained by this condition of a narrow BOS fixed relative to the movable surface.

Therefore, the purpose of this study was to investigate the adaptation of postural control under the challenging condition of standing on a narrow unfixed base of support. The LOS narrows with age or in individuals with balance disorders (Blanchet et al. 2014). In these cases, the COG can shift easily to the boundary of the narrow LOS even when standing on a flat floor. The results of this study could have fundamental implications in the field of rehabilitation for postural control to improve static balance under challenging conditions.

Methods

Thirteen healthy young adults (seven male; mean age: 22.7 ± 1.3 years; height: 164.4 ± 9.7 cm; weight: 58.1 ± 11.6 kg), without any known neurological or motor disorders, participated in this study. Written informed consent was obtained from all subjects and the study was conducted in accordance with the Declaration of Helsinki.

Kinematic data in the sagittal plane were collected using a 3D motion analysis system (Motion Analysis Corporation, USA). Eight reflective markers were placed on the left side of the body (Fig. 1). These markers were used to calculate the COM and the angle joint movements of the hip, knee, and ankle (Winter 2009). A force plate (Kistler, Switzerland) was used to calculate the coordinates of the COP in the sagittal plane.

A rocker board (SAKAI Medical Corporation, Japan), 50 cm wide and 30 cm long, and with a semicircular base (6 cm radius) (Fig. 1). To start, subjects were instructed to stand barefoot on the rocker board with their feet parallel a width of right-and-left anterior superior iliac spine apart and their ankles in a neutral position. They held a handrail beside them and the surface of the board remained parallel to the floor. The feet position on the rocker board was standardized; 40% of the foot length from the heel was aligned with the semicircular base point of contact with the force plate in the sagittal plane (Okuni et al. 2006). After the initial positioning, subjects were asked to release the handrail and fold their arms across their chest, and then to stand as long and steady as possible with their eyes open. Each subject was required to repeat the task until he or she could remain standing on the board for more than 90 s.

Paired *t*-tests were used to evaluate the differences between the first and last trials for each subject. Statistical significance was set at $p < 0.05$.

Results

The mean value (±SD) of standing duration was 29.5 ± 33.6 s in the first trial and 129.9 ± 39.2 s in the last trial, a statistically significant increase ($p < 0.01$). The mean number of trials taken by subjects to achieve a duration of over 90 s was 11.3 ± 6.4 trials (range 6–26 trials). Figure 2A shows the RMS values of COG displacements, COP displacements, and margin of stability (MOS) (Hof et al. 2005) in the first and last trials. All were significantly reduced in the last trial compared to the first trial ($p < 0.05$). In contrast, the RMS values of the ROM of the hip, knee, and ankle joints showed no significant difference between the first and last trials (Fig. 2B). Figures 3A and 3B show the typical time course data of the COP and COG in the first and last trials, respectively. The RMS value of the COP–COG distance in the last trial was significantly smaller than that in the first trial ($p < 0.05$; Fig. 3C).

Discussion

The external variables improved with practice, while the internal variables did not. The external variables were position of COM and COP, while the internal variables were joint angles in this study. When we execute a motor task, we generally have many more degrees of freedom (DOF) than necessary to fulfill the requirements of the task. The coordination of redundant systems was first formulated by Bernstein (1967) as the DOF problem. Thus, this observation would be obviously the consequence of highly redundant human locomotor system, where the same task, described by external variables, can be performed by infinity of patterns of internal variables (various combinations of ankle and hip strategies). The quantitative effects of control of redundant system with practice would be addressed in future study.

The COP–COG distances decreased with practice, as did the magnitude of fluctuations in the position of the COP. COP–COG distances can be interpreted as information about error signals relative to the accurate COM positions (Winter 2009). In our previous study, the COP–COG distances during one leg standing increased with age, which indicated a reduced ability to adjust the COP position to the COM position (Mani et al. 2015). Therefore, we suggest that the ability to assess accurately the COM position in the internal representation (Bhatt et al. 2006) has improved with practice under the challenging conditions, allowing the CNS to shift the COP position closer to the COG position under real-time control (Hof 2008).

The large standard deviations were found in most of the measurements presented in the results section. In the first trial, the subjects showed large variability in duration of maintaining balance (range 5.0 - 63.9s). In addition, the subjects needed quite different numbers of trials to accomplish the task (range 6 - 26 trials). Therefore, the large standard deviations are caused by significantly different balancing abilities in the subjects.

Sehm B et al. (2014) demonstrated the structural brain plasticity in Parkinson’s disease induced by static balance training using a locker board. A balance board may be useful to improve postural coordination through synchronizing ankle and hip strategies to stabilize the COM in subjects with reduced balance abilities, such as patients with degenerative cerebellar disease (Ilg et al. 2009) as well as elderly individuals (Wang et al. 2015).

Acknowledgments

This work was supported in part by a Japanese Grant-in-Aid for Scientific Research (25350747).

Conflicts of interest

None.

References

Bernstein N (1967). *The coordination and regulation of movements.* Pergamon Press, London

Bhatt T, Wening JD, Pai YC (2006). Adaptive control of gait stability in reducing slip-related backward loss of balance. *Exp Brain Res* **170**, 61-73.

Blanchet M, Prince F, Chouinard S, Messier J (2014). Postural stability limits in manifest and premanifest Huntington's disease under different sensory conditions. *Neuroscience* **279**, 102-12.

Hof AL, Gazendam MG, Sinke WE (2005). The condition for daynamic stability. *Journal of Biomechanics* **38**, 1-8.

Hof AL (2008). The 'extrapolated center of mass' concept suggests a simple control of balance in walking. *Hum Mov Sci* **27**, 112-25.

Horak FB, Nashner LM (1986). Central programming of postural movements: adaptation to altered support-surface configurations. *J Neurophysiol* **55**, 1369-81.

Hubbard D (2010). Is unstable surface training advisable for Healthy Adults? *Strength and Conditioning Journal* **32**, ProQuest. pg. 64.

Ilg W, Synofzik M, Brötz D, Burkard S, Giese MA, Schöls L (2009). Intensive coordinative training improves motor performance in degenerative cerebellar disease. *Neurology* **73**, 1823-30.

Mani H, Hsiao SF, Takeda K, Hasegawa N, Tozuka M, Tsuda A, Ohashi T, Suwahara T, Ito K, Asaka T (2015). Age-related changes in distance from center of mass to center of pressure during one-leg standing. *J Mot Behav* **47**, 282-90.

Okuni I, Uchi M, Harada T (2006). Sagittal-Plane Spinal Curvature and Center of Foot Pressure in Healthy Young Adults. *J Med Soc Toho Univ* **53**, 254-260.

Penzer F, Duchateau J, Baudry S (2015). Effects of short-term training combining strength and balance exercises on maximal strength and upright standing steadiness in elderly adults. *Exp Gerontol* **61**, 38-46.

Riach CL, Starkes JL (1993). Stability limits of quiet standing postural control in children and adults. *Gait Posture* **1**, 105-111.

Sehm B, Taubert M, Conde V, Weise D, Classen J, Dukart J, Draganski B, Villringer A, Ragert P (2014). Structural brain plasticity in Parkinson's disease induced by balance training. *Neurobiol Aging* **35**, 232-9.

Wang Y, Watanabe K, Asaka T (2015). Age effects on multi-muscle modes during voluntary body sway. *Res Sports Med* **23,** 88-101.

Winter DA (2009). *Biomechanics and motor control of human movements* (4th ed.). Hoboken, NJ: Wiley.

Figure captions

Fig. 1 A subject standing on the rocker board onto the force plate with arms crossed. The small circles show the placements of reflective markers: the acoustic foramen, the acromion, the lateral epicondyle approximating the elbow joint axis, the wrist, the great trochanter, the lateral epicondyle of the knee, the lateral malleolus, and the second metatarsal head

Fig. 2 A) Root mean squared (RMS) values for the center of gravity (COG), center of pressure (COP), and margin of stability (MOS); B) RMS range of motion (ROM) values for the hip, knee, and ankle joints. The white bars represent the mean values ± SD in the first trial and the gray bars represent those in the last trial. All the mean values of the RMS COG, COP, and MOS in the last trial were smaller than those in the first trial. None of the RMS ROM values for any joint showed a significant difference between the first and last trials. * $p < 0.05$

Fig. 3 Time profiles for the center of gravity (COG) and center of pressure (COP) displacements, and the COP–COG distances. A) Typical time profiles of the COG and COP displacements in the first trial; B) typical time profiles of the COG and COP displacements in the last trial; and C) the mean values ± SD of the root mean squared (RMS) COP–COG distances in the first and last trials in the sagittal plane. Solid and dotted lines represent the COP and COG displacements, respectively. The mean RMS COP– COG distance in the last trial was significant reduced compared to the first trial. * $p < 0.05$

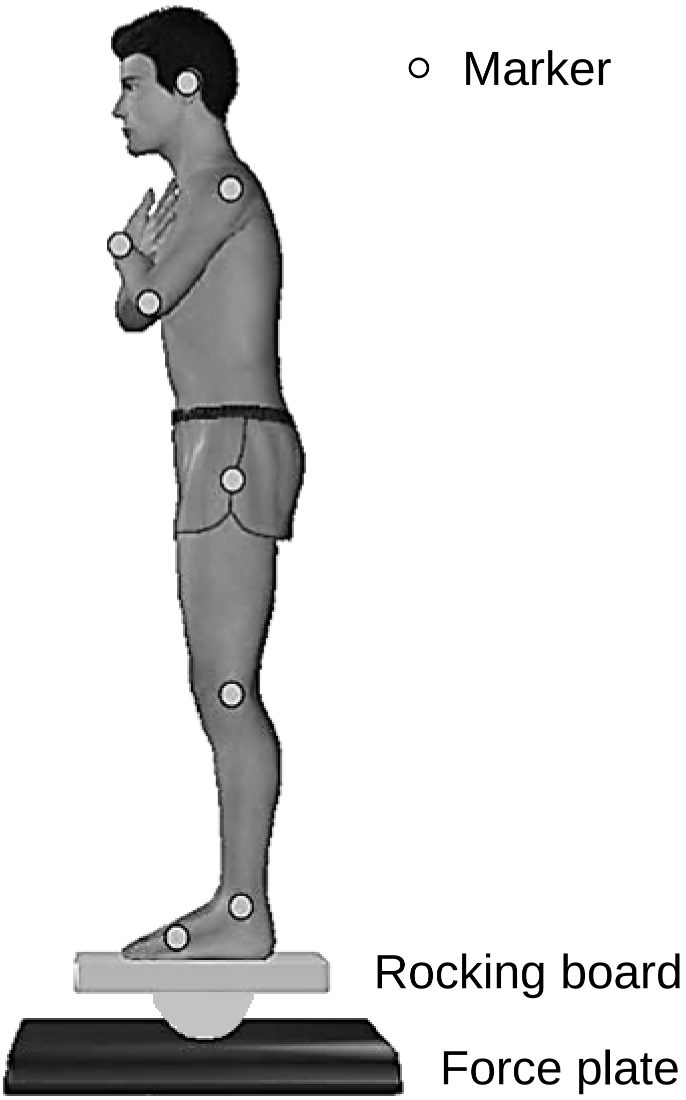

Fig.1

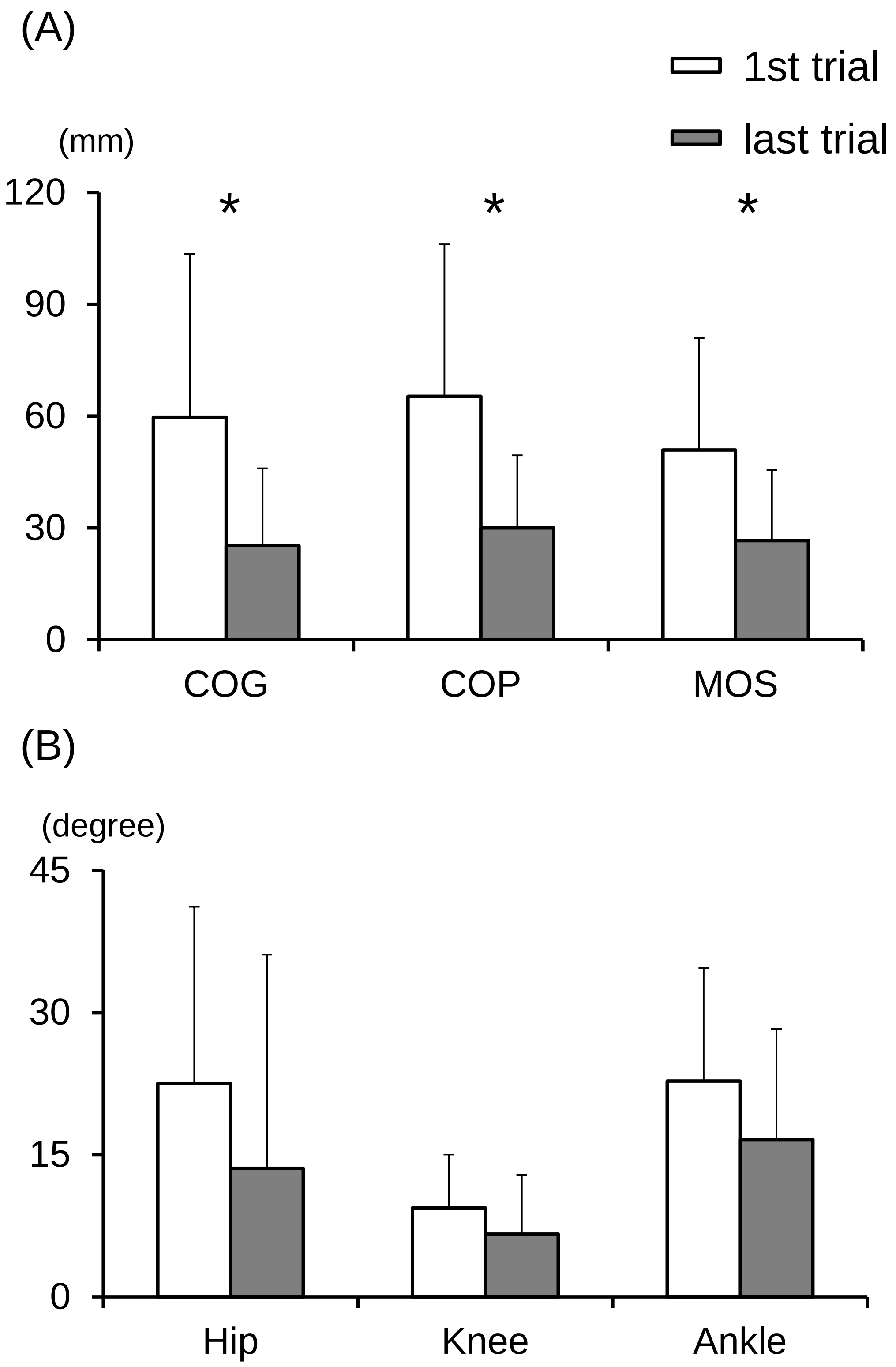
(A)
1st trial
last trial
(mm)
120
90
60
30
0
*
*
*
COG
COP
MOS
(B)
(degree)
45
30
15
0
Hip
Knee
Ankle

Fig.2

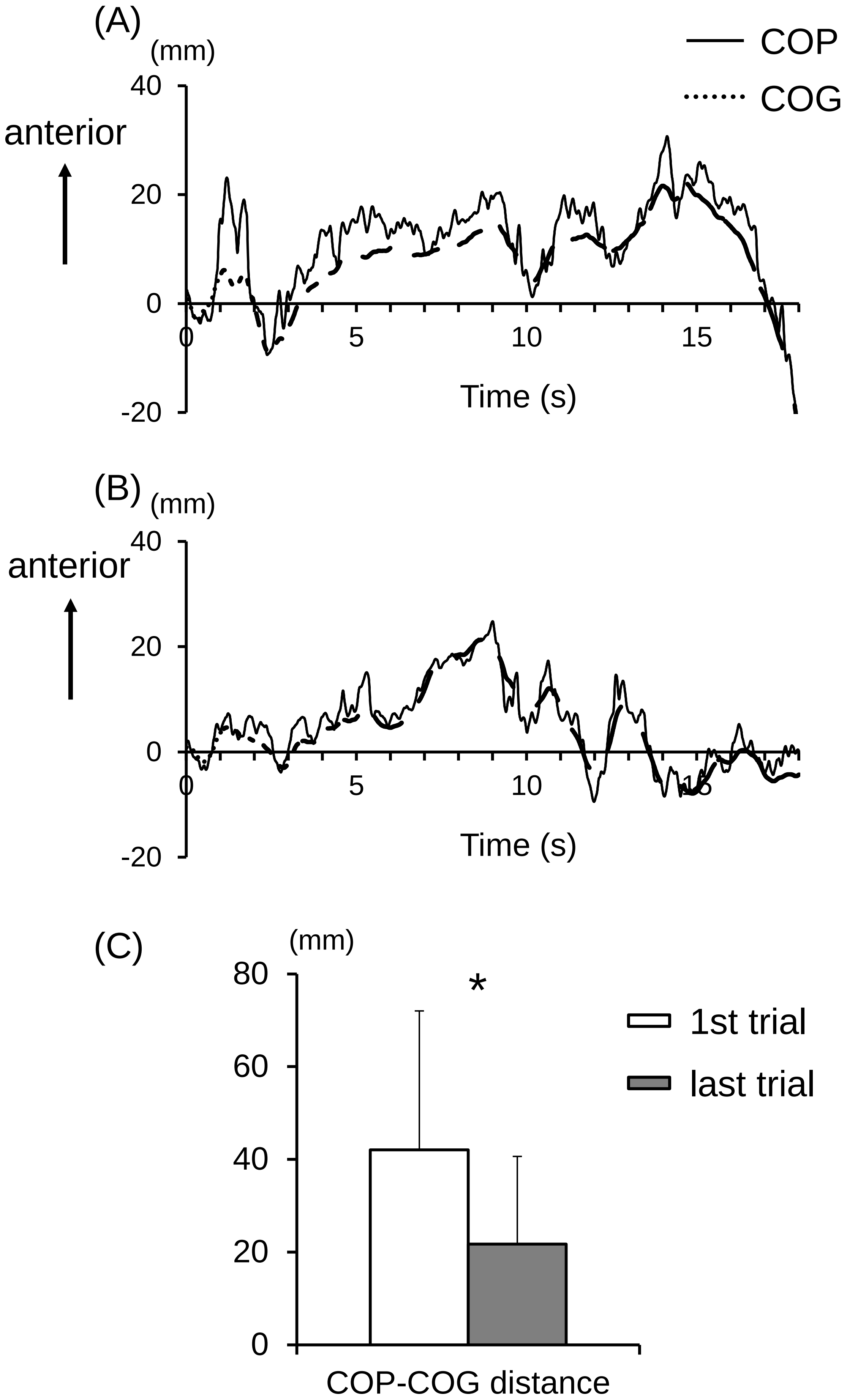
(A)
(mm)
COP
COG
40
anterior
20
0
-20
0
5
10
15
Time (s)
(B)
(mm)
40
anterior
20
0
-20
0
5
10
15
Time (s)
(C)
(mm)
80
60
40
20
0
*
1st trial
last trial
COP-COG distance

Fig.3