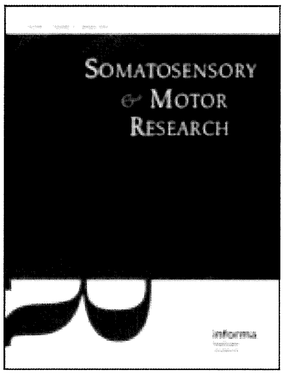

Immediate effects of plantar vibration stimuli during static upright posture following total hip arthroplasty in females

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Immediate effects of plantar vibration stimuli during static upright posture following total hip arthroplasty in females

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Abstract

Purpose: Proprioceptive function of the lower limbs deteriorates in patients following total hip arthroplasty. Patients show poor balance and rely more on visual information than proprioceptive information. Plantar vibration stimuli can mechanically enhance somatosensory input from the plantar cutaneous mechanoreceptors, thereby improving static balance. Plantar vibration stimuli may improve static balance in patients after total hip arthroplasty. This is the first study to investigate whether plantar vibration stimuli affects static balance during the early phase following total hip arthroplasty.

Materials and methods: In this cross-over design study, 16 female patients (aged 65.1 ± 11.0 years) received plantar vibration stimuli for 2 minutes or the sham interventions after total hip arthroplasty in a randomized order on different days. The foot centre of pressure was measured for the total path length, mediolateral path length, and anteroposterior path length directions before and immediately after the interventions in the static standing position both with eyes open and closed. Patients were instructed to minimize body sway when standing.

Results: A significant increase was observed in the centre of pressure parameters in the eyes closed condition than in the eyes open condition. The centre of pressure parameters for the eyes closed condition were significantly decreased after vibration interventions than that before intervention.

Conclusions: This study supports the view that plantar vibration stimuli can change static balance in patients in the early phase after total hip arthroplasty temporarily by up-weighting sensory information. These stimuli may serve as a treatment option for influencing balance following total hip arthroplasty.These stimuli may be useful as treatment for reweighing balance following total hip arthroplasty.

Keywords: Vibration stimuli; Total hip arthroplasty; Static balance; Plantar cutaneous; Plantar soles; Centre of pressure

Introduction

Total hip arthroplasty (THA) is a surgical procedure that is performed to restore hip joint function and decrease pain caused by hip osteoarthritis (Majewski et al. 2005). Whilst it decreases pain and improves balance, gait, and quality of life (Ethgen et al. 2004), recent studies have reported deficits in postural control, which can persist for 6-12 months following surgery (Trudelle-Jackson and Smith 2004; Majewski et al. 2005). This is significant, since impaired balance is a key risk factor that causes falls in THA patients. The study of posture control in THA patients is therefore a key area of research.

With eyes closed (EC), THA patients show significantly longer path lengths and increased foot centre of pressure (COP) parameters than asymptomatic controls (Pop et al. 2018; Wareńczak and Lisiński 2019). Maintenance of static balance requires interactions of orientation-related neural pathways from the somatosensory (proprioceptive, cutaneous), visual, and vestibular systems (Shumway-Cook and Horak 1986; Pasma J et al. 2014). When visual information is unavailable (as with EC), healthy subjects primarily rely on the vestibular system and somatosensory inputs from the lower limbs (Horak et al. 1990; Lord and Menz 2000). In contrast, THA patients rely more on visual information to maintain balance, suggesting that there are deficits in proprioceptive feedback from the lower limb (Domínguez-Navarro et al. 2018; Wareńczak and Lisiński 2019). The somatosensory deficits, along with the additional loss of visual input, are causes of the increased postural sway in THA patients than that in asymptomatic controls. Proprioceptive inaccuracy is one of the causes of low functionality during the follow-up period after joint arthroplasty (Trudelle-Jackson et al. 2002; van Dijk et al. 2006). Opinions about proprioception impairments after surgery vary (Karanjia and Ferguson 1983; Ishii et al. 1999). Recent studies report that THA patients develop hip joint proprioceptive deficits as a result of the surgical procedure, and that sense of hip joint position is better retained when soft tissue is preserved (Delanois et al. 2017; Onishi et al. 2017; de Lima et al. 2019). Increased postural sway when vision is unavailable could result from failure removal of the means to compensate for postural instability through increased reliance on visual information. In other words, THA patients rely less on proprioceptive information from the lower limbs, suggesting proprioceptive feedback deficits from the lower limb. Functional impairments of proprioceptive feedback and reliance on visual information have been identified as a risk factor contributing to balance dysfunction in THA patients for 2-3 years after surgery (Pop et al. 2018).

The sensorimotor system maintains postural control using afferent information from the somatosensory and visual systems, with the vestibular system contributing to balance and orientation control (Shumway-Cook and Horak 1986; Pasma et al. 2014). Ground resistance is detected by plantar cutaneous mechanoreceptors, which provide the somatosensory input used to correct posture (Vallbo et al. 1999; Viseux et al. 2019). Afferent information from the mechanoreceptors is, therefore, a critical source of information that is used to control static posture (Kavounoudias et al. 2001; Meyer et al. 2004).

Recent studies have demonstrated that somatosensory input from the plantar cutaneous mechanoreceptors of the foot has positive effects on postural control (Meyer et al. 2004; Viseux et al. 2019). This occurs when afferent activation enables corrective postural responses by providing spatial and temporal information (Wanderley et al. 2011) , and has no adverse consequences. This effect has been exploited as a promising intervention through plantar vibration stimuli (PVS), which has been recently shown to improve static balance with EC in elderly, neuropathic, and Parkinson's disease patients with sensory deficit (Jenkins et al. 2009; Wanderley et al. 2011; Stambolieva et al. 2017). Other studies on healthy adults without sensory deficits who underwent manual stimulation of the sole while standing on a rough surface have also reported sensory changes at a comparable magnitude (Preszner-Domjan et al. 2012).

An intervention designed to facilitate somatosensory input from plantar cutaneous mechanoreceptors may be beneficial for static balance control in patients during the early phase following THA. However, the immediate effects of PVS on static balance in this patient group are unknown (Pohl et al. 2015; Domínguez-Navarro et al. 2018; de Lima et al. 2019; Wareńczak and Lisiński 2019). We hypothesized that increased somatosensory input from plantar cutaneous mechanoreceptors will modulate postural control causing a temporary improvement in balance in individuals who have undergone THA. We hypothesized that increased somatosensory input from plantar cutaneous mechanoreceptors will modulate of the temporary effects of postural control in individuals who have undergone THA. In general, the prevalence of THA was higher among females than among males and increased with age (Kremers et al. 2015). The aim of this study was to investigate whether PVS affects static balance in patients during the early phase following THA in the females. Neurologically normal subjects are able to maintain balance during visual deprivation by integrating somatosensory information to guide postural adjustments. We therefore compared foot COP parameters between THA patients with eyes open (EO) and EC conditions.

Materials and methods

Subjects

The subjects were selected from those waiting for a THA at Hanna Central Hospital.

Inclusion criteria were: female, age 50-80 years, able to stand independently for 90 s, and able to walk 10 m. Exclusion criteria were: any cardiovascular, respiratory, abdominal, urinary, gynaecological, neurological, musculoskeletal, or other chronic disease. Sixteen female THA patients (mean age ± standard deviation: 65.1 ± 11.0 years, mean time since surgery: 6.06 ± 2.04 weeks), with a mean weight of 50.71 ± 5.9 kg, mean height of 153 ± 6.00 cm, and mean body mass index (BMI) of 21.4 ± 2.46 kg/m^2, participated in the study. All patients underwent primary unilateral THA (eight on the right side and eight on the left side) using the anterior (sixteen patients) or posterior (two patients) surgical approach on the affected limb. All participants provided written informed consent prior to enrolment. The protocol was approved by the ethics committee of the Nara Medical University (Permit Number: 1402-2), Nara, Japan, and all experiments were performed in accordance with the Declaration of Helsinki.

Procedure

All patients were familiarized with the PVS intervention and outcome measurements approximately 1 day before the actual study. In this cross-over design, a blinded researcher who was not involved in the study randomly allocated patients into two separate groups, namely, the A group and B group, using a randomized computer-generated sequence (Figure 1). The A group (n = 8) was allocated to the sham intervention after the PVS intervention, whereas the B group (n = 8) was allocated to the PVS intervention after the sham intervention. The PVS and sham interventions were conducted on two different days to avoid fatigue and provide adequate time to recover from the after-effects. In all subjects, the period between the PVS and sham interventions was 1 ± 2 days. Both interventions were performed in a standing position on the vibration platform with (PVS intervention) or without (sham intervention) PVS. Patients were barefoot during the intervention.

[Fig. 1 near here]

Posturography

Static balance function was measured using a force platform (Gravicorder G-5500; Anima Inc., Tokyo, Japan), which consisted of an equilateral triangle-shaped footplate with three inbuilt vertical force transducers to determine instantaneous fluctuations in the COP parameters. The force platform data were sampled at a frequency of 20 Hz. In the normal standing position, the feet were placed parallel to each other precisely 20 cm apart between the centre. To perform this test, participants were instructed to remain barefoot and static for 30 s while standing at ease and maintain the foot position on the force platform with EO while watching a circular chromatic target placed 200 cm in front of their eyes (Majewski et al. 2005; Wareńczak and Lisiński 2019). The subjects then rested in a seated position for 1 min, after which the measurement was repeated with EC to assess the effects of visual feedback on postural stability. The COP was measured from the ground reaction force recorded using the force plate. This static balance test was designed by Sziver et al. (2016) to decrease the effects of mental or physical fatigue on balance control, and a single measurement for each condition was performed (Sziver et al. 2016). A therapist who was not involved in randomization or delivering the interventions completed the pre- and post-intervention assessments. This therapist was blinded to group allocation and was not involved in the training sessions or other parts of the study.

Vibration intervention

Physical therapists performed the intervention using a plantar vibration platform (vibration platform; Takatori, Nara, Japan) (Figure 2). The vibration platform was provided free-of-cost by Takatori (Nara, Japan); however, Takatori did not play any role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript. This apparatus consists of a moveable rectangular platform built within a square ground surface, with a support bar mounted at the front. The platform comprised a surface of urethane foam material that produces rapid vibratory stimulation around a sagittal axis. The vibratory stimulation had a frequency of 40 Hz and sway amplitude of 1.8 mm. Patients were required to sit on the platform with their feet at an equal and standardized distance from the axis of rotation. Patients were supported in a seated position by a bench with their knees and hips in 90-degree flexion while holding onto the support bar at the front. Both interventions consisted of four sessions of 30 s stimulation separated by a break between each session.

Sham interventions

Sham interventions were performed using the same procedure with the exception that the vibration was not turned on. Before the onset of the study, all physical therapists received specific instructions on both interventions to ensure uniformity in treatment procedures. They were instructed not to communicate with the patients about the possible goals or rationale for either treatment. To ensure blinded assessment, there was no communication about group allocation between therapists. Participants were not blinded to the intervention (PVS or sham) since the presence of the vibrating stimuli would be apparent.

[Fig. 2 near here]

Sample size

The sample size was calculated using G*Power 3.1 software (Dusseldorf University, Dusseldorf, Germany). For this calculation, we considered COP as the primary outcome, as in a previous study (Wanderley et al. 2011). A priori power calculation was based on the F-test (two-way repeated measure analysis of variance [ANOVA]) for main effects at a 95% level of confidence. The alpha was set at two-tailed type I error of 0.05 with a power of 0.8. The effect size was set to 0.3. The data generated a desired sample size of at least 12 subjects per group. We decided to enrol more participants in each group to account for the possibility of dropout.

Analysis

The total length of the COP path (COP-L) was defined as the sum of the distances between all consecutive points on the COP path and used as an index of postural stability. The COP-L was processed through a space-time domain analysis including the calculation of the length of the COP displacements along the mediolateral (COP-ML) and anteroposterior (COP-AP) axes. These COP displacements reflect unsteady balance (Wanderley et al. 2011). Additional measures of postural sway included COP-L, COP-ML, and COP-AP with EO and EC. Statistical analysis was conducted using an Excel (Microsoft, USA) statistical software package (Ekuseru-Toukei 2016; Social Survey Research Information Co., Ltd., Tokyo, Japan). Assumptions of linearity, normality and equality of variances were examined using skewness of statistics and histograms. Skewness of <1 was considered satisfactory(Cohen et al. 1988) . Paired t-tests were used to draw comparisons between mean values pre and post-intervention with EO and EC. The partial effect size (r) was calculated as an estimate of effect size. The effect of group (sham, PVS) × time (pre, post) on measures of COP was evaluated using separate two-way repeated measures ANOVAs for EO and EC. The partial effect size (η2) was calculated as an estimate of effect size. The level of statistical significance was set at $P < 0.05$, and the magnitude of the difference was assessed by effect size, where the difference was graded as small (r: 0.1-0.3, η2: 0.01-0.5), moderate (r: 0.3-0.5, η2: 0.01-0.06), or large (r: >0.05, η2: >0.14) (Cohen et al. 1988).

Results

Figure 3 shows the COP for both visual conditions (EO and EC) and the pre-intervention COP measures. There were significant increases in the COP-L ($r = 0.7$, $P = 0.0019$), COP-ML ($r = 0.74$, $P < 0.0001$), and COP-AP ($r = 0.74$, $P < 0.0001$) in the EC condition compared to that in the EO condition pre-intervention.

[Fig. 3 near here]

There was no significant interaction between group and time in terms of COP parameters for either the EO (COP-L: $p = 0.95$, η2 = 0.000062; COP-ML: $p = 0.97$, η2 = 0.00003; COP-AP: $p = 0.93$, η2 = 0.00021) or EC (COP-L: $p = 0.81$, η2 = 0.0017; COP-ML: $p = 0.79$, η2 = 00.0023; COP-AP: $p = 0.83$, η2 = 0.0014) conditions. There were no significant changes with the sham intervention for the EO (COP-L: $p = 0.39$, $\eta 2 = 0.0036$; COP-ML: $p = 0.22$, $\eta 2 = 0.0018$; COP-AP: $p = 0.97$, $\eta 2 = 0.0000031$) or EC (COP-L: $p = 0.16$, $\eta 2 = 0.0036$; COP-ML: $p = 0.096$, $\eta 2 = 0.0065$; COP-AP: $p = 0.39$, $\eta 2 = 0.0013$) conditions (Figure 4 A and 4 B). There was no significant pre-/post-PVS intervention effect on the COP-L ($p = 0.33$, $\eta 2 = 0.0014$), COP-ML ($p = 0.45$, $\eta 2 = 0.0007$), or COP-AP ($p = 27$, $\eta 2 = 0.0028$) in the EO condition (Figure 3 C). However, there were significant decreases in the COP-L ($p = 0.019$, $\eta 2 = 0.01$), COP-ML ($p = 0.031$, $\eta 2 = 0.011$), and COP-AP ($p = 0.025$, $\eta 2 = 0.01$) values pre/post-PVS intervention in the EC condition (Figure 3 D).

[Fig. 4 near here]

Discussion

The most notable finding of this study was that PVS applied in the early phase following THA induced a significant decrease in the COP parameters, only in the EC condition. When visual information is unavailable, individuals must rely primarily on somatosensory (proprioceptive, cutaneous) information (Horak et al. 1990; Lord and Menz 2000). Our results reflect the effect of somatosensory information on postural stability. PVS resulted in decrease in postural sway in the EC condition, and somatosensory input from plantar mechanoreceptors immediately compensated for subjects' lack of vision.

We observed that THA patients in the sham group had increased COP parameters in the EC condition than in the EO condition, in concurrence with previous studies (Pop et al. 2018; Wareńczak and Lisiński 2019). These results indicate the failure of THA patients to compensate for postural instability using visual information rather than somatosensory information.

Our analysis of COP parameters showed a significant effect of the PVS intervention only in the EC condition. From the perspective of sensory re-weighting, individuals rely primarily on proprioceptive information when visual information is unavailable (Horak et al. 1990; Lord and Menz 2000). Thus, with EC, COP measurements reflect the dependence on proprioceptive information to achieve postural stability. Hence, these results suggest that the effectiveness of PVS also depends on proprioceptive or somatosensory information.

The increase in postural sway with EC suggest that THA patients relied mainly on visual inputs to regulate body sway. ~~Increases in postural sway with EC is indicates postural stability and an increased effort to rely on somatosensory information.~~ PVS, which increases somatosensory inflow, decreased body sway in the EC condition. The ability of postural control systems to re-weigh the available sensory information is a widely accepted concept (Pasma JH et al. 2015). Recent studies hypothesize that the decrease of sway paths in the EC condition after PVS result from an adaptive mechanism of the central nervous system (CNS), whereby information from the plantar mechanoreceptors is required for alternative sensory information (Bernard-Demanze et al. 2006; Vaillant et al. 2008; Preszner-Domjan et al. 2012). Thus, PVS resulted in improvements in postural sway in the EC condition, and activation of plantar mechanoreceptors partially compensated for subjects' lack of vision. This finding suggests that PVS may be used to increase the reliance temporary on somatosensory information and decrease the reliance on visual information temporary for basic postural control when visual information is unavailable. Another mechanism that has been proposed is improved sensory feedback to spinal and cortical areas (Priplata et al. 2003; Lipsitz et al. 2015). Plantar stimulation is deemed beneficial because it increases the sensitivity of plantar cutaneous afferent information sent to the CNS (Dhruv et al. 2002). Thus, the effect of different mechanical stimulation is likely to be caused by the increased sensitivity of mechanoreceptors of the plantar sole. Future research is needed to measure tactile thresholds before and after plantar mechanical stimulation.

Under the EO condition, there were no significant differences in COP excursion in PVS intervention, however, the COP decreased significantly in the EC. ~~Under the EO condition, there were no significant differences in COP in PVS intervention, but the COP decreased~~

significantly in the EC. The absence of the effect in open eye condition may be due to the redundancy of senses as, the CNS primarily uses visual and vestibular inputs, and the stimulated somatosensory input was used only secondarily (Preszner-Domjan et al. 2012). A recent study indicated that PVS remodulate sensory reweighing to induce the repeated plastic change of proprioceptive activity (Levin et al. 2017; Sienko et al. 2018). PVS can remodulate postural control in THA patients by facilitating somatosensory input from plantar mechanoreceptors. We believe that the decrease of sway paths in the EC condition after the mechanical stimulation showed the adaptive mechanism of the CNS. However, the effects of PVS on static and dynamic balance remain unclear in this study.

The present study has several limitations. First, whilst a number of theories have been proposed as to why PVS is effective, more research is required to better understand the neurophysiologic mechanisms of PVS in THA patients. These could include motor unit activation, modulation of excitability of the motor pool, and increase in the sensitivity of the stretch reflex (Bove et al. 2003; Pollock et al. 2010; Kipp et al. 2011). Second, we only assessed static balance, and did not assess patients' dynamic balance. Future studies should address whether PVS improves different types of balance. Third, since there was no follow-up, it was not possible to assess the long-term effects of the intervention. Therefore, further studies, including long-term follow-up, which assess function, are warranted to evaluate the long-term benefits of plantar vibration stimulation.

Conclusions

PVS decreased postural sway with EC, suggesting that PVS enhances somatosensory information and reduces reliance on visual information. This could support the hypothesis that PVS induces remodulation of somatosensory or proprioceptive afference and supports the use of stimulation of plantar mechanoreceptors to reduce reliance on visual information for static postural control. Further comparative studies are required to determine the clinical validity and outcome of balance rehabilitation therapy.

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Declaration statement

The plantar vibration stimuli platform was provided free of cost by Takatori (Nara, Japan). However, Takatori did not play any role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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Figure Legends

Figure 1 The study procedure and analysis

Sixteen participants were randomly allocated to either group A or group B.

A group (n=8) was allocated to the sham intervention after PVS intervention.

B group (n)=8 was allocated to the PVS intervention after the sham intervention.

Figure 2. Vibration platform

Sitting posture of the patients with total hip arthroplasty (THA) on the vibration platform. The bench was height-adjustable.

Figure 3. Pre-intervention centre of pressure

The centre of pressure for the eyes open (EO) and eyes closed (EC) conditions pre-intervention, showing individual variability. Centre of pressure (COP) of total trajectory length (COP-L), mediolateral trajectory length (COP-ML), and anteroposterior trajectory length (COP-AP) during the upright standing position with eyes open (EO) or eyes closed (EC) pre-intervention. Lines represent the range between the minimum and maximum. Boxes represent the lower, median, and upper quartiles. *$P < 0.05$.

Figure 4. Post-intervention centre of pressure

Differences in centre of pressure (COP) post-intervention for the eyes open (EO) and eyes closed (EC) conditions showing individual variability. A: Sham intervention and EO. B:

Sham intervention and EC. C: Plantar vibration stimuli (PVS) intervention and EO. D: PVS intervention and EC. Centre of pressure (COP) of total trajectory length (COP-L), mediolateral trajectory length (COP-ML), and anteroposterior trajectory length (COP-AP) during the upright standing position with EO or EC post-intervention. Lines represent the range between the minimum and maximum. Boxes represent the lower, median, and upper quartiles. * $P < 0.05$.

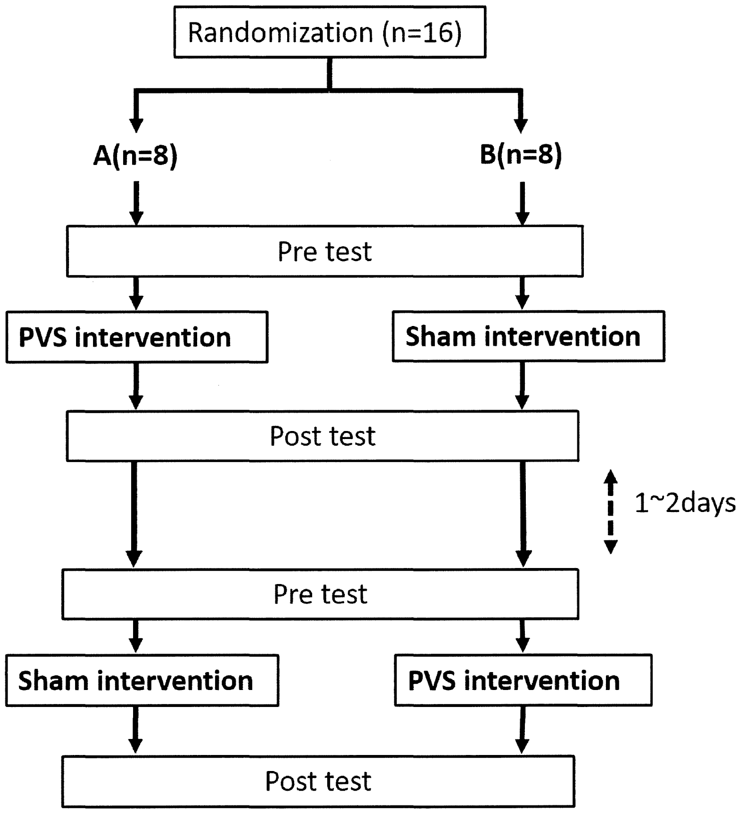

FIg1

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Fig.2

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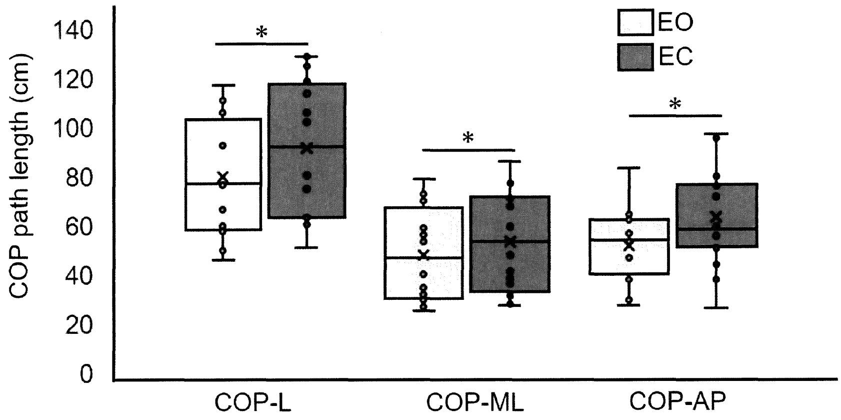

Fig3

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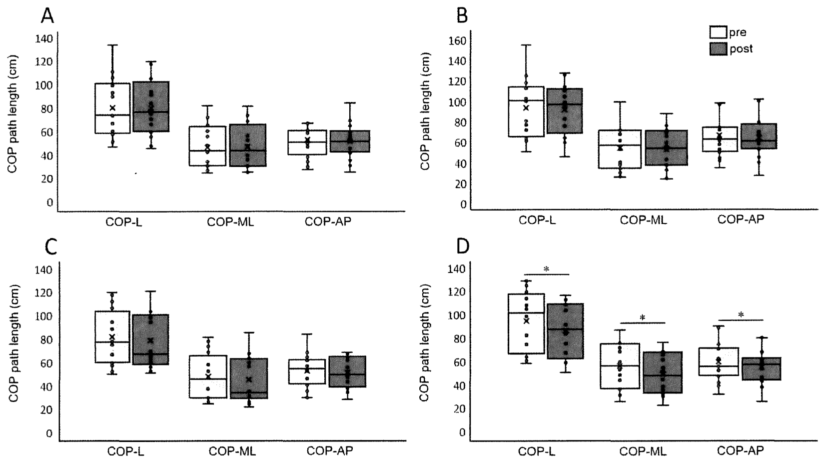

Fig4

92x53mm (600 x 600 DPI)