

Sit-to-Stand and Stand-to-Sit evaluation in a 62 year old woman eleven years after her unilateral total hip arthroplasty

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Abstract

Problem Statement. Total hip arthroplasty (THA) reduces pain and improves function; however, when reaching the end of its lifetime (about 10-15 years) the person may experience dysfunctionality. A 62 years old woman experiencing pain and dysfunctionality in daily activities eleven years after her left THA addressed our Lab for evaluation. **Approach.** The evaluation aimed at the Sit-to-Stand (SitTS) and the Stand-to-Sit (StandTS) tasks as those are related to functional performance as well as to lower limb strength. The feet placement (Parallel, Healthy Front, Affected Front) was tested considering that THA persons tend to shift their weight on their healthy limb to maintain their balance. The Model Statistic Single-Subject Analysis as described by Stergiou (2004) was applied to test the significance of the feet placement effect ($\alpha=0.05$). **Purpose.** The purpose of this study was to evaluate the feet placement effect on the ground reaction forces (GRFs), postural stability, and trunk and thigh kinematics during a movement sequence consisting of the SitTS task, the upright stance maintenance, and the StandTS task, in a 62 years old woman who addressed our Lab for evaluation due to pain and dysfunctionality eleven years after her left THA. **Results.** The SitTS and StandTS duration was not altered due to feet placement. The Affected Front feet placement indicated the main significant differences compared to the Parallel or the Healthy Front ones. In specific, the vertical GRF was decreased in the SitTS, whereas, in the StandTS, the anterior-posterior (AP) and the medial-lateral (ML) GRFs were increased and decreased, respectively. Neither the forward nor the lateral trunk tilt was altered due to feet placement, whereas its rotation was significantly reduced. The same thigh kinematics were observed in all three feet placements. The most critical finding was the decrease of postural stability in the semi-tandem feet placements (particularly the Affected Front), evidenced in the elongation of the center of the pressure path as well as of the time to stabilize the upright stance after standing up. **Discussion-Conclusion.** The evaluation indicates that the participant should avoid the semi-tandem feet placements, particularly the Affected Front one, as these could induce a falling risk due to the decreased postural stability after rising from the seated position. Furthermore, it should be pointed out that although the SitTS rather than the StandTS is more influenced by feet placement, the Parallel feet placement should be preferred for both tasks.

Keywords: Postural Stability, Upright Stance, Single Subject Analysis, Feet Placement, Center of Pressure, Inertial Sensors

Introduction

Total hip arthroplasty (THA) may effectively reduce pain and improve function (De Groot et al., 2008; Judd et al., 2003) compared to pre-operative levels. Although THA resolves the pain and improves the motor ability (Bourne et al., 2010), the movement patterns may not return to normal during dynamic tasks such as standing up from a chair (Boonstra et al., 2011; Caplan et al., 2014; Lamontagne et al., 2012; Talis et al., 2008). Standing up from a sitting position (Sit-to-Stand) is a fundamental daily task performed approximately 60 to 65 times per day (Dall & Kerr, 2010; Egerton & Brauer, 2009). Furthermore, the Sit-to-Stand (SitTS) is a sensitive measure for evaluating movement functionality in individuals with unilateral lower extremity pathology (Esbjörnsson & Naili, 2020). Besides the SitTS, also the Stand-to-Sit (StandTS) task is a common and essential activity in daily living (Kerr et al., 1997; Kim et al., 2019; Kralj et al., 1990; Lin & Lee, 2022) and may also be problematic for patients with hip pathologies, as those that have sustained a THA (Kim et al., 2019; Stefl et al., 2017).

THA persons appear to unload their operated hip and shift their weight to the non-operated side (Boonstra 2011; Caplan et al., 2014; Talis et al., 2008). When rising from a chair, the post-operative motion of the affected hip is smaller in the sagittal plane, and the internal extension hip moment is also smaller (Lamontagne et al., 2012). Furthermore, the post-operative hip mechanics in the frontal and transverse planes differ from both the non-operated side as well as from healthy subjects (Lamontagne et al., 2012). Therefore, compensatory movement strategies that favor the healthy limb may be preferentially used to accomplish the SitTS. Also, a forward foot positioning (that is, placing one foot in front of the other) has been reported to affect

weight loading between limbs, in both the SitTS and StandTS tasks (Roy et al. 2006; Shepherd & Koh, 1996). The trunk movement plays an important role in completing the SitTS and the StandTS tasks (Doorenbosch et al., 1994; Goulart & Valls-Solé, 1999). In specific, a decreased trunk angular displacement may be a sign of diminished functional ability (Dubost et al., 2005).

Although THA results in pain resolution and a high level of patient satisfaction it has a lifetime of about 10-15 years (Nugent et al., 2021) after which the patient may start to feel pain or discomfort as well as dysfunctionality in daily activities. This was the case of a woman at 62 years old woman with a left THA who addressed our lab for assessment due to pain and dysfunctionality in her daily activities. Thus, the purpose of this study was to evaluate the effect of feet placement on the ground reaction force profile, postural stability, as well as on trunk and thigh kinematics during a movement sequence consisting of the SitTS task, the upright stance maintenance, and the StandTS task, in a 62 years old woman eleven years after her left THA, who experienced pain and dysfunctionality in daily movements.

Methods

Subjects

A 62-year-old woman, who had undergone a left THA eleven years ago and was experiencing pain and dysfunctionality in daily movements, addressed our Lab for kinetic and kinematic evaluation. The participant was able to stand up from a chair and sit down independently without using her hands for support. Her body height was 160 cm and her body mass was 72Kg. She did not follow any rehabilitation program after the THA and, after the recovery period, she just returned to her everyday life activities, with a rather sedentary lifestyle and no regular exercise or regular physical activity. She was fully informed about the evaluation procedures followed by our Lab and she signed written informed consent.

Materials

A seat without hand support was used. The seat was adjusted to the participant's lower leg height so that her initial seated position was with the trunk vertical to the ground, the hip and the knee joint angles at 90° degrees, and the foot at full contact with the ground. The participant performed all trials with her own comfortable shoes. A force plate (Kistler Type-9286AA, Switzerland) sampling at 1000 Hz (Bioware Software Version: 5.4.3.0) was used to collect the ground reaction force (GRF) data in the vertical, anterior-posterior (AP), and medial-lateral direction (ML). In synchronization with the GRF data recordings, three wireless inertial sensors (Xsens Technologies, B.V., Enschede, The Netherlands, MTw Awinda IMU) sampling at 100Hz (Xsens MTw Awinda) were used to record the 3D angular displacement kinematics of the trunk and the two thighs. The trunk sensor was securely positioned one at the lower back (L5 level) and each thigh sensor was securely positioned on its lateral surface at its estimated center of mass.

Procedure

The participant adopted the seated position with both her feet on the force plate. The seat was positioned so that the longest dimension of the force plate (60cm) indicated the ML direction and its shorter dimension (40cm) indicated the AP direction. In all trials, the upper extremities were maintained crossed at the chest. During a single trial, the participant performed a movement sequence consisting of the SitTS task, the Upright Stance stabilization and resting, and the StandTS task. In specific, when she was instructed to initiate her trial, the participant stood up from the seat, and after she felt she was stabilized in the upright stance she rested in the upright stance for 5 sec and, in continuance, she sat down to the seat. She performed the SitTS - Upright Stance - StandTS sequence in the parallel feet placement (one foot next to the other at the preferred width distance between the two feet) and two semi-tandem feet placements, that is, the healthy foot positioned in front (Healthy Front) and the affected foot positioned in front (Affected Front), both at the preferred width distance between the two feet, as well as, at the preferred forward distance between the front the back foot. The participant performed four trials in each feet placement condition (1 min rest between trials of the same condition, 2 min rest between conditions).

The GRF time profiles and the inertially sensed profiles of the trunk inclination in the three feet placement conditions are illustrated in Figure 1. The parameters determined from the GRFs were the duration of the SitTS and the StandTS motion, as well as of the upright stance. Also, the maximum vertical GRF, anterior-posterior (AP), and medial-lateral (ML) GRFs were determined, respectively for the SitTS and the StandTS. The SitTS initiation was defined at the time point where the baseline of the vertical GRF baseline (feet resting period) was decreased at 2 SDs. The StandTS initiation was defined as the time point that the vertical GRF of the upright stance resting phase fell off at 2SD of the upright stance resting baseline, as this is explained in continuance). The upright stance total duration was defined from the termination time point of the SitTS until the StandTS initiation. The upright stance duration was discerned in the stabilization phase and the resting phase to estimate the feet placement effect on postural stabilization after SitTS. To define the upright stance stabilization phase, the mean and the SD of upright stance resting baseline was estimated during 500 ms at the part of the vertical GRF where the signal was visually estimated as indicative of a quiet upright stance (near the visually estimated StandTS initiation). Thus, the upright stabilization phase was defined from the end of SitTS until the time point that the vertical GRF fell off at 2SD of the upright stance resting baseline. Thereby, the part from the end of the stabilization phase until the StandTS initiation defined the resting upright stance. All upright stance

phases were visually verified, as the visual determination of steady standing after a SitTS task also appears valid (Etnyre & Thomas, 2007).

The trunk inertial sensor provided the data concerning the maximum forward and lateral trunk tilt, as well as the trunk rotation around the vertical axis, during the SitTS and the StandTS motions (all expressed in degrees). The initiation of the trunk tilt was defined as the time point that its angular displacement was increased over 2SD of the mean baseline value during the resting periods before the SitTS and the StandTS motions, respectively (Figure 1-Right). The thigh inertial sensors provided the data concerning their forward and backward angular displacement (in degrees) during the SitTS and the StandTS, respectively (Figure 1-Right).

Statistical Analysis

The statistical approach was the Model Statistic Single-Subject Analysis (SSA) for the Human Movement Responses as described by Stergiou (2004). The Model Statistic SSA analysis aims to calculate a critical value concerning the difference between the means of two conditions (critical mean difference). In continuance, for the selected level of significance, the critical mean difference is compared to the critical value provided by Table 1.4 in Stergiou (2004), pp 20-22 for the performed number of movement repetitions and the selected level of significance. If the mean critical difference is greater than the critical value the difference between the two means is considered significant. Thus, the statistical analysis aimed to the comparison of the estimated GRF, CoP, and trunk kinematics parameters between the two tandem feet placements, as well as the comparison of each tandem placement to the parallel one. The level of significance was set at $\alpha = .05$ and the critical value for the 4 trials (4 repetitions) performed in the present study was indicated at 1.5058.

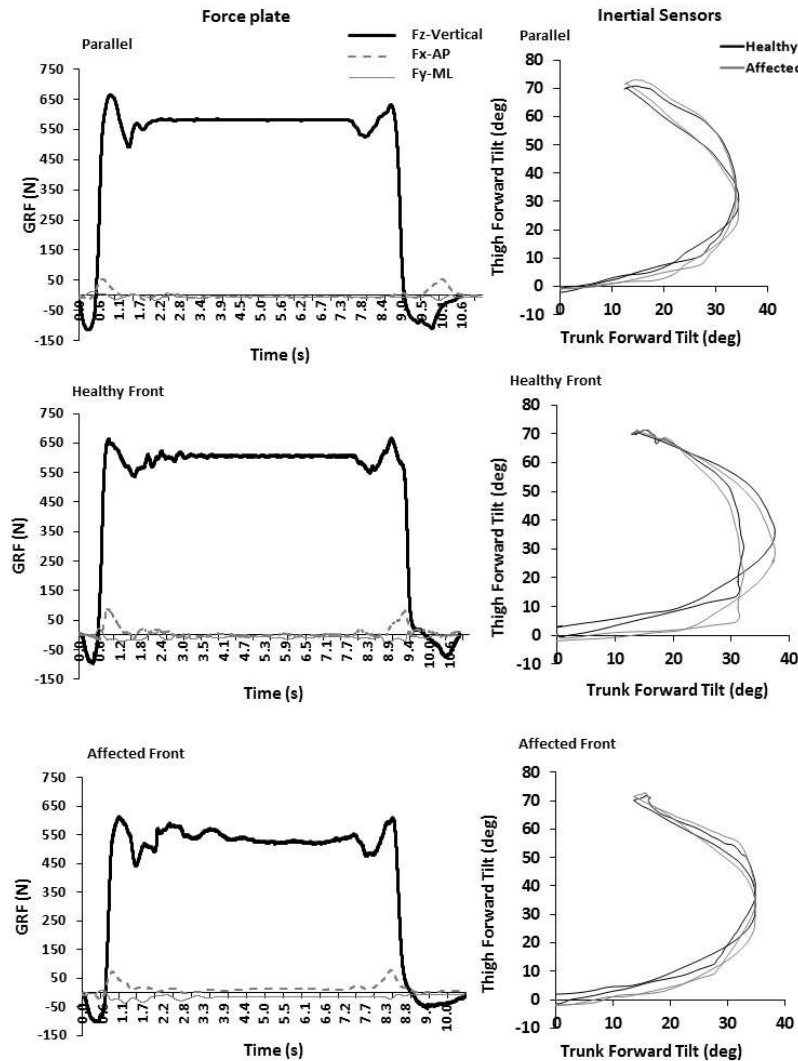


Figure 1. Left: Vertical, Anterior-Posterior (AP) and Medial-Lateral (ML) ground reaction forces (GRFs) in the Parallel (Top), Healthy Front (Bottom-Left) and in the Affected Front (Bottom-Right) feet placement. **Right:** Trunk - Thigh Forward Tilt measured with the inertial sensors, in the Parallel (Top), Healthy Front (Bottom-Left) and in the Affected Front (Bottom-Right) feet placement.

Results

SitTS and StandTS

The duration of the SitTS, the StandTS motions, and of the UP stance stabilization phase in the Parallel (black bars), Healthy Front (light grey bars), and the Affected Front (dark grey bars) semi-tandem feet placement are presented in Figure 2. No significant difference was found due to feet placement for the SitTS and the StandTS durations (Figure 2, Table 1). The mean (SD) of the peak GRFs in the vertical, AP, and ML directions are presented in Figure 3 for both the SitTS and the StandTS tasks. The maximum vertical GRF differed significantly due to feet placement only in the SitTS task. In specific, in Affected Front feet placement, the maximum vertical GRF was significantly lower compared to the Healthy Front and the Parallel feet placements ($\alpha=0.05$) (Figure 3, Table 1). Concerning the horizontal GRFs, the maximum AP GRF was significantly higher during the Affected Front compared to the Parallel feet placement, in both the SitTS and the StandTS motions ($\alpha=0.05$) (Figure 3, Table 1). The maximum ML GRF differed significantly only in the StandTS task ($\alpha=0.05$) (Figure 3, Table 1). In specific, in the Affected Front feet placement, the ML GRF was significantly lower than both the Healthy Front and the Parallel feet placements ($\alpha=0.05$), with the ML GRF during the Healthy Front being significantly lower than the Parallel feet placement (Figure 3, Table 1).

Upright Stance

No significant difference was found for the total upright stance time (Figure 2) with the critical mean difference between conditions at 1.12 (absolute difference of condition means: 0.10, 0.88, and 0.78, for the Parallel one minus the Healthy Front, the Parallel minus the Affected Front and the Healthy Front minus the Affected Front, respectively). Concerning the upright stance stabilization phase, a significant duration difference was noted between all feet placement conditions ($\alpha = 0.05$), with the two semi-tandem conditions significantly longer than the Parallel one, and the Affected Front significantly longer ($\alpha=0.05$) than the Healthy Front feet placement (Figure 2, Table 1). During the upright stance stabilization phase, in both the AP and the ML directions, the CoP path was significantly longer in the Affected Front than in both the Healthy Front and the Parallel feet placement ($\alpha = 0.05$) (Figure 4, Table 1).

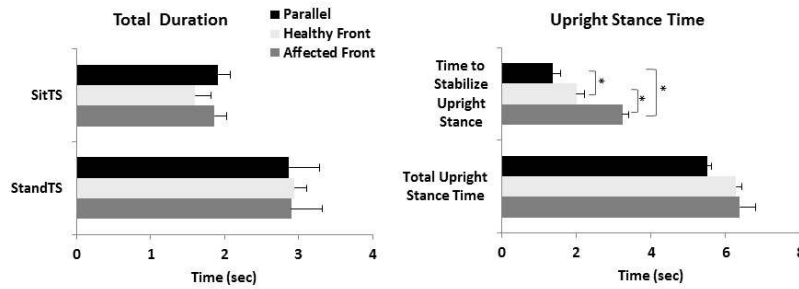


Figure 2. Mean (SD) for the duration of the SitTS task, the StandTS task and the Upright Stance stabilization phase in the Parallel (black bars), Healthy Front (light grey bars) and the Affected Front (dark grey bars) feet placements. *Significant differences between feet placement conditions at $\alpha=0.05$.

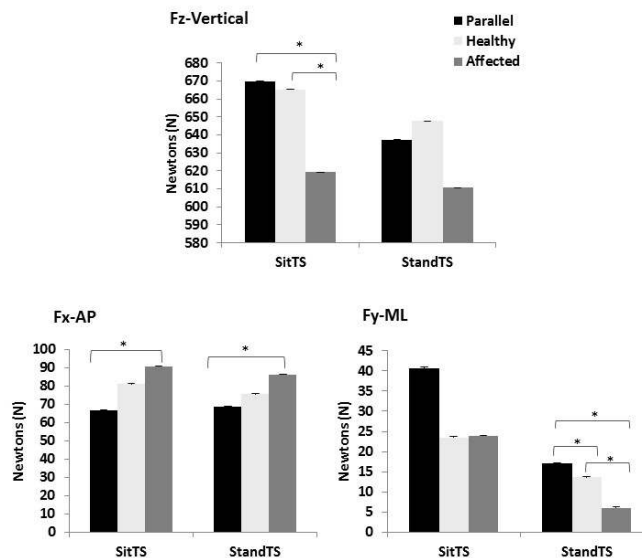


Figure 3. Center of pressure (CoP) path during the upright stance stabilization phase, for the SitTS and the StandTS tasks, in the Parallel (black bars), Healthy Front (light grey bars), and in the Affected Front (dark grey bars) feet placements. *Significant differences between feet placement conditions at $\alpha=0.05$.

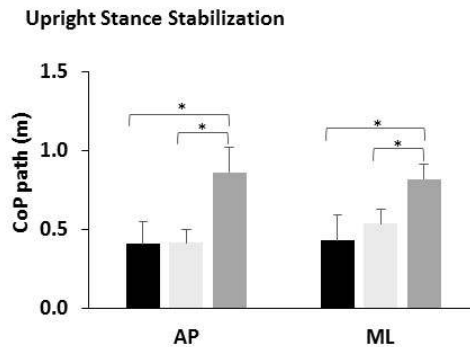


Figure 4. Mean (SD) for the maximum of the vertical (Fz), the anterior-posterior (Fx-AP), and the medial-lateral (Fy-ML) GRFs during the SitTS and the StandTS tasks, in the Parallel (black bars), the Healthy Front (light grey bars) and the Affected Front (dark grey bars) foot placements. *Significant differences between feet placement conditions at $\alpha=0.05$.

Trunk and Thigh Kinematics

The feet placement did not alter significantly neither the forward nor the lateral trunk tilt ($\alpha = 0.05$) (Figure 5). However, trunk rotation differed due to feet placement, with the Parallel one significantly higher than the semi-tandem feet placements, in both the SitTS and the StandTS ($\alpha = 0.05$, Figure 5). The thigh AP angular displacement was similar in both the SitTS and the StandTS and is presented in Figure 5. In specific, no significant difference was found for the thigh AP displacement nor between limbs in the same feet placement (critical mean difference for the comparison between limbs: 1.552, 0.704, and 1.263 for the Parallel, the Healthy Front, and the Affected Front foot placements, respectively) nor between feet placements (critical difference: 2.19 for the comparison between the Parallel and the Healthy Front, 1.65 for the comparison between the Parallel and the Affected Front, and 2.18 for the comparison between the Healthy Front and Affected Front).

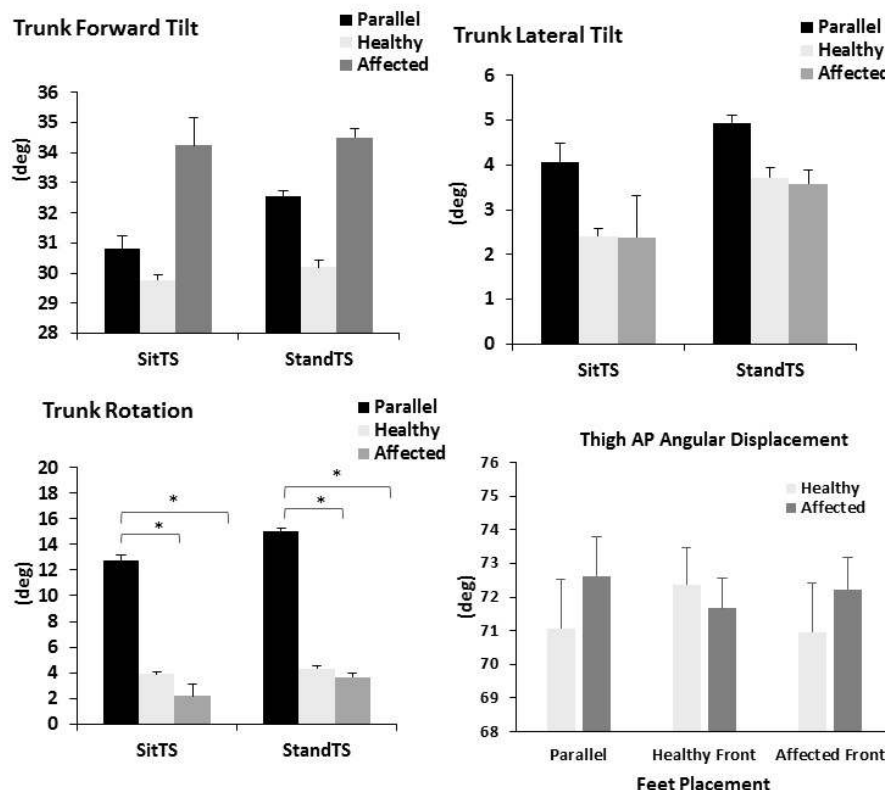


Figure 5. Trunk forward tilt, trunk lateral tilt, and trunk rotation were measured, during the SitTS and the StandTS motions, in the Parallel (black bars), the Healthy Front (light grey bars), and the Affected Front (dark grey bars) foot placements. The AP angular displacement of the thighs was similar in SitTS and StandTS; thus only the values of the SitTS in each feet placement are presented in the relevant panel. *Significant difference between conditions of feet placement at $\alpha=0.05$.

Table 1. Single-Subject Analysis statistics: If the absolute value of the conditions' critical difference concerning the compared feet placements is greater than the critical value of 1.5058 (as indicated for four repetitions by Table 1.4 in Stergiou 2004, pp 20-22) then the feet placement difference is statistically significant at $\alpha=0.05$).

		Absolute difference between the means of feet placement conditions			Conditions' Critical Difference	Percentage (%) difference between feet placement conditions		
		Parallel minus Healthy Front	Parallel minus Affected Front	Healthy Front minus Affected Front		Healthy Front vs Parallel	Affected Front vs Parallel	Affected Front vs Healthy Front
SitTS								
Task Duration		0.31	0.05	0.26	0.35	16%	3%	16%
Fz-Vertical		4.53	50.5*	45.97*	43.25	1%	8%*	7%*
Fx-AP		14.44	24.17*	9.74	15.42	22%	36%*	12%
Fy-ML		17.03	16.64	-0.38	19.20	42%	41%	2%
Trunk Tilt Forward		0.24	1.34	-1.57	8.28	1%	4%	5%
Trunk Tilt Lateral		1.66	1.68	0.03	5.65	41%	41%	1%
Trunk Rotation		7.00*	8.73*	1.73	6.007	55%*	68%*	44%
StandTS								
Task Duration		0.08	0.03	0.04	0.66	3%	1%	1%
Fz-Vertical		10.19	26.88	37.07	51.94	2%	4%	6%
Fx-AP		6.7	17.33*	10.62	13.04	10%	25%*	14%
Fy-ML		3.51*	11.08*	7.08*	0.35	21%*	65%*	56%*
Trunk Tilt Forward		1.26	1.93	3.19	9.14	4%	6%	10%
Trunk Tilt Lateral		1.22	1.35	0.13	9.18	25%	27%	3%
Trunk Rotation		8.21*	8.88*	0.66	6.348	55%*	59%*	15%
Upright Stance								
Total	Duration	0.10	0.88	0.78	1.12	2%	14%	12%
	COP AP path	0.07	0.29*	0.36*	0.25	5%	20%*	26%*
	COP ML path	0.17	0.43*	0.25	0.34	13%	33%*	17%
Stabilization	Duration	1.23*	1.87*	0.64*	0.30	38%*	58%*	32%*
	COP AP path	0.01	0.45*	0.45*	0.21	2%	112%*	107%*
	COP ML path	0.11	0.39*	0.28*	0.24	25%	91%*	53%*

*Significant difference between feet placement conditions at $\alpha=0.05$.

Discussion

The purpose of this single-subject analysis was to evaluate the effect of feet placement in GRFs, postural stabilization, and the trunk and thigh kinematics during a movement sequence consisting of the SitTS task, the upright stance maintenance, and the StandTS task, in a 62 years old woman who had undergone a left THA eleven years ago and addressed to our Lab for evaluation due to pain and dysfunctionality in her daily movements.

Total hip arthroplasty may effectively reduce pain and improve function (De Groot et al., 2008; Judd et al., 2003) compared to pre-operative levels. However, despite the pain resolution and a high level of patient satisfaction (Bourne et al., 2010) movement patterns may not return to normal during dynamic tasks such as standing up from a chair (Boonstra et al., 2011; Caplan et al., 2014; Lamontagne et al., 2012; Talis et al., 2008) which is a fundamental daily task performed about 60 to 65 times per day (Dall & Kerr, 2010; Egerton & Brauer, 2009). Sitting down is also a common and essential daily activity (Kim et al., 2019; Kerr et al., 1997; Kralj et al., 1990; Lin & Lee, 2022) and may be difficult in presence of hip pathologies, as in the case of THA (Kim et al., 2019; Stefl et al. 2017).

Due to their importance in daily living and their sensitivity to evaluating movement functionality in individuals with unilateral lower extremity pathology (Esbjörnsson & Naili, 2020) the SitTS and the StandTS tasks were selected for the evaluation of the 62 years old woman who addressed our Lab. The two tasks were embedded in a movement sequence initiated by the SitTS, followed by the upright stance stabilization after standing up, the resting in the upright stance for about 5 sec, after which the StandTS was initiated and completed. The main parameter of this evaluation was the total duration of the SitTS and StandTS tasks, as the time to complete the task is among the indicators of functional ability (Abujaber et al., 2015; Carmagos et al., 2009; Ganea et al., 2011). For example, elderly persons (Ganea et al., 2011) or persons with disorders (i.e. hemiparesis or stroke) (Roy et al., 2006) need more time to perform these tasks compared with healthy subjects.

The participant of this evaluation completed the SitTS and StandTS tasks at times similar to those reported in previous studies involving the effect of feet placement (Roy et al. 2006). In specific, Roy and coworkers (2006), during the Affected Foot placement reported 2.64s for the SitTS task and 3.33s for the StandTS task (hemiparetic participants), with our participant performing the SitTS at 2.15s and the StandTS at 2.67s in the Affected Front feet placement, with no significant difference between feet placements.

The feet placement affects the distance that the center of mass must be shifted forward, the upright stance stabilization after standing up, as well as the force timing and development (Brunt et al., 2002). As the operated hip has restricted or altered motion (Lamontagne et al., 2012), a forward rather than a parallel feet positioning during the SitTS and the StandTS tasks may affect the loading between limbs (Roy et al. 2006; Shepherd & Koh, 1996). In specific, when rising from a seated position, THA persons tend to use compensatory movement strategies that favor the healthy limb (affected hip unloading through weight shifting to the non-operated side) (Boonstra 2011; Caplan et al., 2014; Talis et al., 2008).

The evaluation of our 62 years old woman concerning the GRFs indicated that the Affected Front feet placement altered the vertical only GRF in the SitTS, whereas, in the StandTS task, only the two horizontal GRFs were altered. In specific, the significant decrease in the vertical GRF during the Affected Front SitTS task (-8% and -7% compared to the Parallel and the Healthy Front, respectively) was accompanied by a significant increase in the AP GRF, although this was significant only compared to the Healthy Front (+36%). The lower vertical GRFs in the Affected Front feet placement during the SitTS task are in accordance with the results of Brunt and coworkers (2002) who pointed out lower forces and increased muscle activity for hemiplegic patients compared with healthy subjects. A slower reactive strategy (Piano et al., 2020) may relate to the trade-off between the vertical and the AP GRFs appearing in the SitTS during the Affected Front semi-tandem feet placement most possibly due to the elongation of the base of support. Nevertheless, the increase of the AP GRF may associate with greater motor control demands to stabilize the upright posture after standing up as indicated by the increased time taken to stabilize the upright posture as well as the increased CoP path in both semi-tandem feet placements and particularly the Affected Front one. In the StandTS task, the AP GRF was also increased in the Affected Front feet placement but the vertical GRF decrease was not significant.

Piano and coworkers (2020) have pointed out the importance of the stabilization phase after rising from the seated position and the muscle weakness that remains after a THA (Lamontagne et al., 2012) may hinder the stabilization of the upright posture. After a THA, the lower limb biomechanics may not return to normal and persons may perform with different hip mechanics in the frontal and the transverse plane than persons without a THA (Beaulieu & Lamontagne, 2010).

The trunk movement plays an important role in completing the SitTS and the StandTS tasks (Duclos et al., 2008; Doorenbosch et al., 1994; Ganea et al., 2011; Goulart & Valls-Solé, 1999). For example, a decreased trunk angular displacement may be a sign of diminished functional ability (Dubost et al., 2005). When our 62 years old women performed the semi-tandem feet placements there was an increase in the forward trunk tilt accompanied by a decrease in the lateral tilt and a decrease in the trunk rotation. Nevertheless, compared to the Parallel feet placement, the differences yielded significance only for the trunk rotation.

In conclusion, based on the evaluation results, the participant could be advised to avoid the semi-tandem feet placements during the SitTS task, and particularly the Affected Front feet placement, as these could induce a falling risk due to the decreased postural stability after rising from the seated position. Furthermore, it should be pointed out that although the SitTS task rather than the StandTS is more influenced by feet placement, the Parallel feet placement should be preferred for both tasks.

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