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Fast Motion Speed Alters the Sit-to-Walk Spatial and Temporal Pattern in Healthy Young Men

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ABSTRACT

Sit-to-Walk (STW) is a critical task for daily independence, yet its two inherent destabilizing events (seat-off, walking initiation) may diminish postural stability under fast motion speed (FS). This study aimed at the FS effect on the STW spatial and temporal patterns, with a specific interest in the relative STW temporal pattern. The STW kinetics and kinematics were recorded ($n = 18$ men, 20.7 ± 2.0 years) at preferred and FS. Statistics included One-Way repeated measures ANOVA (SPSS 25.0, $p \le 0.05$). The FS spatial pattern reveals a discontinuous mode of the forward ground reaction force, indicating a balance rather than a propulsive strategy during the Rising phase. The FS relative temporal pattern reveals the prolongation of the Leaning phase (most possibly due to the feet repositioning), the shortening of the Rising and the Walking phases, and a relative delay in the spatial variables ($p \le 0.05$). Overall, the results do not allow the STW consideration at FS as a “magnified” with respect to force, or a “shrinked-in” with respect to time, copy of the preferred motion speed. As more generic and versatile than the absolute one, the relative temporal pattern may be used as a reference for a variety of populations.

Introduction

Sit-to-Walk (STW) is critical for daily living independence with research showing that a person rises from the seated position about 60 times per day [1]. It is a fluid transition from sitting to standing followed by walking initiation [2], with sit-to-stand and walking initiation being merged around the point of seat-off [2, 3]. Rising out of the seated position necessitates a considerable control of the body’s anterior-posterior stability for the safe body weight transfer from the buttocks to the feet. In continuance, walking initiation challenges the medial-lateral postural stability due to the transition from a double- to a single-legged stance [4] while the body is rising [2]. At fast motion speed, the amplification of the accelerations acting on the body [5, 6] may diminish postural stability, and thus enhance the falling risk. Lateral rather than anterior-posterior stability is often more challenging at fast motion speed [7], with the capacity to increase walking speed partly affected by the ability for lateral weight transfer [8]. For successful lateral stability, the modulations of the ground reaction forces (GRFs) and those of the center of pressure (CoP) are important [4, 9], and may reflect the effect of motion speed on the walking initiation strategy [2, 10, 11].

To the best of our knowledge, there appear three studies specifically aiming to examine the motion speed effect on the STW movement [12–14]. These studies report about various spatial and temporal, kinetic or kinematic, STW characteristics; however, except for the data provided by Kondilopoulos et al. [14], little is known about the motion speed effect on the STW spatial and relative temporal pattern. The relative STW temporal pattern may allow a more comprehensive insight regarding the way forces and velocities are generated under a temporal constraint such as the fast motion speed. In specific, previous studies document the dissociation between the absolute and relative timing when learning a motor skill [15, 16]. Furthermore, the relative over the absolute patterns are more generic and versatile and can be used as a normative reference for a variety of populations rather than only for populations of similar features as the ones from which the patterns were mined [17].

For the vast majority of the population, STW is an easy task that doesn't pose any challenge, regardless of the execution speed. It becomes a challenge for special populations, such as older individuals or patients prone to falling. However, even for young healthy populations, there is a lack of detailed information about the motion speed effect on its spatial and temporal patterns, particularly the relative temporal pattern. Thus, the purpose of the study was to examine the effect of fast motion speed on the STW spatial and temporal patterns, with a specific interest in the relative STW temporal pattern. Such information provides insight on the generalized motor pattern, such as if faster execution may be thought as a "magnified" with respect to force, or a "shrinked-in" with respect to time, copy of the preferred motion speed [16].

Materials and Methods

Participants

Eighteen young healthy men (20.7 ± 2.0 years, 71.1 ± 8.9 kg, 176.7 ± 4.8 cm) participated in the study. Details about the recruiting procedure and the inclusion criteria are provided in the Supplementary File. The study meets the ethical standards required [18] and was approved by the Institutional Review Board. Written consent forms were signed by all subjects.

Data collection procedure

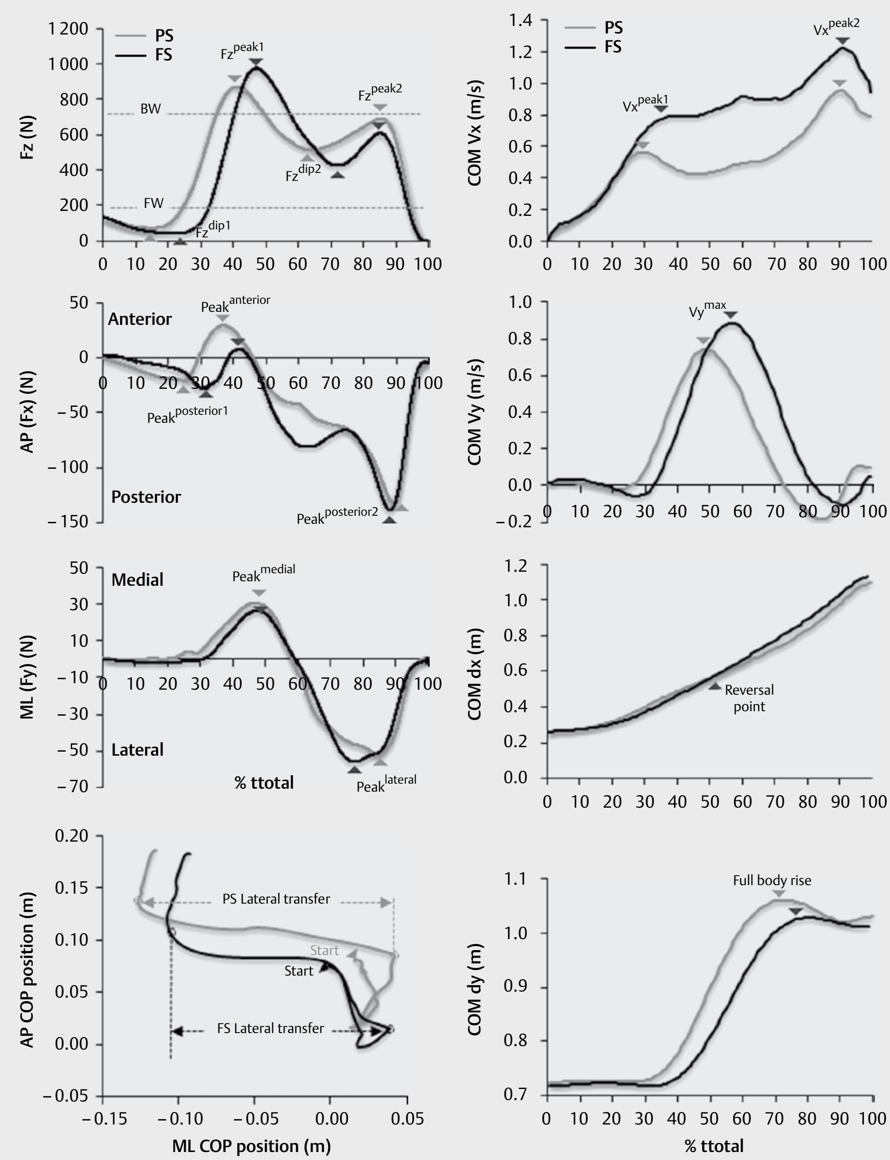
The participants sat at a backless and armless platform allowing the seat height standardization to 100 % of lower leg length (from the ground to knee joint center), the hip and knee joint angles at 90 °, the two-thirds of the thighs length in contact with the seat, the feet flat on the floor, and their arms folded in front of them during the entire task [2, 12–14, 19]. They were instructed to look straight ahead, to distribute their body weight evenly on both feet and, upon the vocal command "GO", to stand up and walk towards a target placed 2m in front of the seat (not required to cover the full distance). Two STW motion speeds were used, the preferred (PS: self-selected speed) and the fast one (FS: as if they were hurried to answer the phone or to stop an activated alarm). The right limb was the preferred one for walking initiation.

A single Kistler forceplate under both feet was used to collect the kinetic data (sampling at 1000 Hz, 60 × 40 cm, Type 9286AA, Bioware Software version 3.2.6.104, Winterthur, Switzerland) and a low pass 10 Hz filter was applied to all GRF data. In synchronization with the kinetic data, a camera sampling at 125 Hz was used for the kinematic data collection (RedlakeMotionScope®, type PCI 1000S, Player 2.3 Software, DEL Imaging Systems, LLC., Woodsville, USA). The camera was at a 1.16m height from the ground, and an 8m distance from the anterior-posterior axis of the movement so that, through the entire STW task, all body segments were visible at the right sagittal plane. The 2D rather than 3D data collection was based on previous STW [3] and sit-to-stand [20] studies. A four-segment model (head-arm-trunk (HAT), thigh, shank, and foot) was used to calculate the total body center of mass (CoM) with reference markers on the segmental CoM [21] (CoM calculation details are provided in the Supplementary File). A 4rth order Butterworth filter with a cut-off frequency at 10 Hz was applied to displacement and velocity raw data (Peak Performance Inc. software, Version 8.2, Colorado Springs, USA).

Data analysis

For all spatial variables extracted from the kinetic (▶ **Fig. 1 - Left**) and the kinematic (▶ **Fig. 1 - Right**) data curves, their absolute (s) and relative (% STW ttotal) occurrence time was estimated. The CoP-MLpath was used for the CoP lateral transfer (▶ **Fig. 1 - Left**) initiation and termination (maximum displacement or slowest velocity towards the swing and the stance limb, respectively) [10]. All variables are described in detail at the legend of ▶ **Fig. 1** and the footnote of ▶ **Table 1**.

Three STW phases were defined [19]: the Leaning (STW onset to seat-off), the Rising (seat-off to walking initiation), and the Walking (swing-off to stance-off). The terms Leaning, Rising, and Walking were used instead of Flexion, Extension, and Stance [19], respectively, as a closer association to the STW kinesiology. The kinetic onset was defined by the time point that Fz deviated from the resting feet baseline by 4 standard deviations and the kinematic one by the first CoM forward displacement. The kinetic seat-off by the time point of the first Fz peak and the kinematic one by the first increase in the CoM vertical velocity. The kinetic foot swing-off by the time point of maximum mediolateral CoP velocity and the kinematic one when the toe marker of the leading foot displaced in the plane of progression. Finally, the kinetic stance-off when Fz dropped to zero and the kinematic one when the toe marker of the trailing foot displaced in the plane of progression. The duration of the STW phases was expressed in absolute (s) and relative (% ttotal) time units, where ttotal refers to total STW duration.



▶ **Fig. 1** Left: Ensemble averaged time curves of the GRFs and the CoP (AP: anterior-posterior, ML: medial-lateral. Right: Ensemble averaged time curves of the CoM velocity (CoM Vx: horizontal velocity, CoM Vy: vertical velocity) and the CoM displacement (CoM dx: horizontal displacement, CoM dy: vertical displacement). Time is expressed as percentage of total STW duration (% ttotal). Preferred Speed (PS): Grey lines, Fast Speed (FS): Black lines. Each kinetic and kinematic curve was resampled at 1200 and 120 data points, respectively. The resampling procedure allows a realistic temporal pattern, however, it leads to lowered curve magnitudes compared to the actual ones presented in ▶ **Table 1**. The resampling criteria was decided by the trial with the minimum data points across participants and speed conditions.

Statistical analysis

One way ANOVA for repeated measures was used to test the differences between PS and FS (SPSS version 25.0, IBM Corp., Armonk, NY, USA). The Cohen's d effect size, as well as the lower and the upper bound of the 95 % confidence interval for the PS and FS means, were also determined. The level of significance was at $p \leq 0.05$.

Results

▶ **Figure 1** shows the kinetic and kinematic ensemble-averaged time-curves. ▶ **Figure 2** shows a representative participant at the events defining the kinematic STW phases. All absolute kinetic and kinematic occurrence times are provided in the **Supplementary File**.

▶ **Table 1** Spatial kinetic and kinematic pattern. Mean (SD) values in the preferred (PS) and the fast (FS) motion speed, as well as their percentage difference (PS = 100 %). Cohen's d effect size (d EF) and the lower (LB) and upper (UB) bounds for the 95 % confidence interval (CI) of the mean are also presented.

Variables	PS	FS	diff % units	*P* value	d ES	95 % CI of the mean (LB / UB)	
	Mean (SD)	Mean (SD)				PS	FS
Kinetic pattern							
Fz^{dip1} (N)	−80.4 (39.7)	−119.2 (46.3)	+ 48.3	< 0.001 *	0.9	(−100.1/−60.6)	(−142.2/−96.1)
Fz^{peak1} (N)	880.3 (137)	1047.6 (143.2)	+ 19.0	< 0.001 *	1.2	(883.9/1016.5)	(1009.2/1142.6)
Fz^{dip2} (N)	381.1 (56.3)	336.2 (111.5)	−11.8	0.001 *	0.5	(422.4/479.6)	(305.6/423.5)
Fz^{peak2} (N)	645.6 (98.7)	612.5 (93.9)	−5.1	0.019 *	0.3	(670.2/760.8)	(589.4/692.1)
Fx^{post1}(N)	−41.6 (15.9)	−58.1 (25.8)	+ 39.7	0.011 *	0.7	(−50.4/−34.4)	(−70.9/−45.3)
Fx^{ant} (N)	54.2 (20.0)	40.0 (29.3)	−26.2	0.058^{ns}	0.6	(44.2/64.1)	(25.4/54.5)
Fx^{post2} (N)	−137.8 (32.3)	−151.5 (51.8)	+ 9.9	0.165^{ns}	0.3	(−153.9/−121.8)	(−177.3/−125.7)
Fy^{med} (N)	41.4 (15.5)	37.0 (17.0)	−10.6	0.153^{ns}	0.3	(33.7/49.1)	(28.5/45.5)
Fy^{lat} (N)	−57.9 (12.5)	−63.4 (18.2)	+ 9.5	0.095^{ns}	0.4	(−64.1/−51.7)	(−72.5/−54.4)
CoP-AP path (m)	0.44 (0.07)	0.45 (0.07)	+ 2.3	0.955^{ns}	0.0	(0.26/0.32)	(0.26/0.33)
CoP-ML path (m)	0.38 (0.09)	0.31 (0.09)	−18.4	0.705^{ns}	0.1	(0.26/0.36)	(0.28/0.37)
CoP-LT dF (m)	0.23 (0.03)	0.22 (0.04)	−4.3	0.914^{ns}	0.0	(0.21 / 0.24)	(0.2 / 0.24)
CoP-LT dL (m)	0.26 (0.05)	0.24 (0.10)	−7.7	0.994^{ns}	0.0	(0.21/0.26)	(0.19/0.28)
CoP-LT VF (m/s)	1.05 (0.34)	2.04 (1.08)	+ 94.3	< 0.001 *	1.2	(0.88/1.21)	(1.5/2.57)
CoP-LT VL (m/s)	1.68 (0.47)	2.55 (1.16)	+ 51.8	0.003 *	1.0	(−1.91/−1.44)	(−3.13/−1.97)
Kinematic pattern							
$CoM\text{-}Vx^1$ (m/s)	0.67 (0.08)	0.87 (0.16)	+ 29.9	< 0.001 *	1.6	(0.63/0.71)	(0.79/0.95)
$CoM\text{-}Vx^2$ (m/s)	1.03 (0.17)	1.30 (0.25)	+ 26.2	< 0.001 *	1.3	(0.95/1.11)	(1.18/1.42)
CoM-Vy max (m/s)	0.90 (0.11)	1.05 (0.15)	+ 16.7	< 0.001 *	1.2	(0.85/0.95)	(0.98/1.13)
CoM-Δx-seat-off (m)	0.18 (0.03)	0.19 (0.04)	+ 5.6	0.181^{ns}	0.3	(0.16/0.19)	(0.17/0.21)
CoM-Δy-seat-off (m)	0.01 (0.02)	0.01 (0.02)	+ 0.0	0.651^{ns}	0.1	(0.00/0.02)	(0.00/0.02)
CoM-Δx-max (m)	0.84 (0.09)	0.88 (0.10)	+ 4.8	0.005 *	0.4	(0.79/0.88)	(0.83/0.93)
CoM-Δy-max (m)	0.35 (0.02)	0.34 (0.03)	−2.9	0.041 *	0.5	(0.34/0.36)	(0.33/0.35)
Step length (m)	0.65 (0.09)	0.73 (0.13)	+ 12.3	< 0.001 *	0.7	(0.61/0.70)	(0.67/0.79)

* Significant difference between PS and FS at p ≤ 0.05. Cohen's d effect size (ES) interpretation: small (d = 0.2), medium (d = 0.5), and large (d = 0.8) according to Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates. Kinetic spatial variables extracted (▶ **Fig. 1**, left). Ground reaction force variables: Fz^{peak1} = 1st Fz peak; Fz^{peak2} = 2nd Fz peak; Fz^{dip1} = 1st Fz dip; Fz^{dip2} = 2nd Fz dip; Fx^{post1} = 1st posterior Fx peak; Fx^{ant} = maximum anterior Fx peak; Fx^{post2} = 2nd posterior Fx peak; Fy^{med} = maximum medial Fy peak; Fy^{lat} = maximum lateral Fy peak. Center of pressure (CoP) variables: CoP-AP path = total CoP path in the anterior-posterior direction; CoP-ML path = total CoP path in the mediolateral direction; COP-LT dF and COP-LT dL = forward and lateral CoP displacement during the lateral transfer (LT); COP-LT VF and COP-LT VL = maximum forward and maximu lateral CoP velocity during the lateral transfer (LT). Kinematic spatial variables (▶ **Fig. 1**, right). $CoM\text{-}Vx^1$ and $CoM\text{-}Vx^2$ = respectively, 1st and 2nd peak of the CoM horizontal velocity; CoM-Vymax = maximum vertical CoM velocity; CoM-Δy and CoM-Δx = vertical and horizontal CoM displacement, respectively; step length = rear heel difference between the stance and the swing limb at foot touch-down.

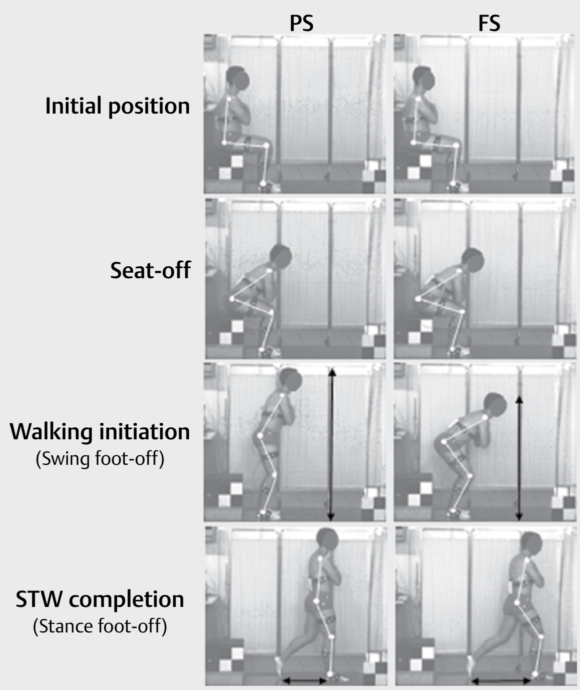
Kinetics

Spatial pattern

In FS, the vertical GRF variables were all significantly increased (p ≤ 0.05). Except for Fx^{post2} (p = 0.011), the horizontal GRFs were not altered (p > 0.05) (▶ **Table 1**). The CoP-dL was not altered in FS (p > 0.05); however, CoP-VF and CoP-VL were significantly increased (p ≤ 0.05) (▶ **Table 1**).

Temporal pattern

In FS, the kinetic STW duration (▶ **Fig. 3**) was significantly shorter (-28 % p < 0.001), and the absolute kinetic STW phases (▶ **Fig. 3**) were all significantly shorter in FS (p < 0.001 for all). In relative time units, the Leaning phase was prolonged (p ≤ 0.05) while the Rising and the Walking phases were shortened (p ≤ 0.05) (▶ **Fig. 2**). The relative duration of the feet unweighted part within the Leaning phase was significantly elongated in FS (PS: 17.2 ± 5.5 % ttotal, FS: 25.1 ± 6.6 % ttotal, p < 0.001) although its absolute duration was not altered (PS: 0.286 ± 0.078 s, FS: 0.321 ± 0.083 s, p = 0.062). In the FS Leaning phase, the peaks and dips of the vertical forces were significantly prolonged (tFz^{dip1} and tFz^{peak1}, p ≤ 0.05). In the FS Walking phase, the relative tFz^{dip1} was prolonged (p ≤ 0.05) whereas tFz^{peak2} was not altered (p > 0.05) (▶ **Table 2**). Concerning the horizontal forces, the FS relative time of the anterior-posterior ones was prolonged within the Leaning phase (p ≤ 0.05 tFx^{post2}, and tFx^{ant}) but shortened within the Walking phase (p ≤ 0.05, tFx^{post2}); the mediolateral forces changed significantly only during the Walking phase (earlier Fy^{lat}, p ≤ 0.05) (▶ **Table 2**). The relative initiation, termination, and Vmax of the CoP lateral transfer were all delayed in FS (p ≤ 0.05) (▶ **Table 2**), but its relative duration was not altered (PS & FS: about 22 % ttotal, p > 0.05).



▶ **Fig. 2** A representative participant at the events defining the kinematic STW phases. The similar body configuration at seat-off, the lower body rise at walking initiation, and the longer walking step in Fast Speed (FS - Right) compared to Preferred Speed (PS - Left) are illustrated.

Kinematics

Spatial pattern

The FS CoM-Vx was significantly increased ($p \leq 0.05$) (▶ **Table 1**). The seat-off and Walking initiation occurred at lower COM rise (−0.93 %, p = 0.008 and −10.37 %, p = 0.00, respectively, ▶ **Fig. 1** and ▶ **Fig. 4**). At STW completion, the final CoM rise was significantly lower in FS than PS (−1.84 %, p = 0.004) (▶ **Table 1**). Relative to the final CoM rise, the CoM rise at Walking initiation was significantly lower in FS (−17.0 ± 4.42 %) than PS (−9.12 ± 4.28 %) ($p < 0.001$).

Temporal pattern

Similarly to the kinetic one, the FS kinematic STW duration as well as the absolute phases were significantly shorter ($p < 0.001$ for all) (▶ **Fig. 3**). The significant changes in the relative phases ($p \leq 0.05$) were similar to the kinetic ones (Leaning was prolonged, Rising and Walking were shortened) (▶ **Fig. 2**). The relative occurrence time of CoM-Vx^{peak1}, CoM-Vy^{max}, and CoM-Δy^{max} were significantly prolonged ($p \leq 0.05$) but CoM-Vx^{peak2} was not significantly altered ($p > 0.05$) (▶ **Table 2**).

Discussion

This study aimed to examine the effect of fast motion speed on the STW spatial and temporal patterns, with a specific interest in the relative STW temporal pattern. For the young healthy participants of the study, and regardless of motion speed, STW may be an easy and not challenging task. However, the relative over the absolute patterns are more generic and versatile and can be used as a normative reference for a variety of populations rather than only for populations of similar features as the ones from which the patterns were mined [17]. Thus, the inclusion of young only participants in the present study does not void the value of the results as a normative reference for populations that STW sets a postural stability challenge.

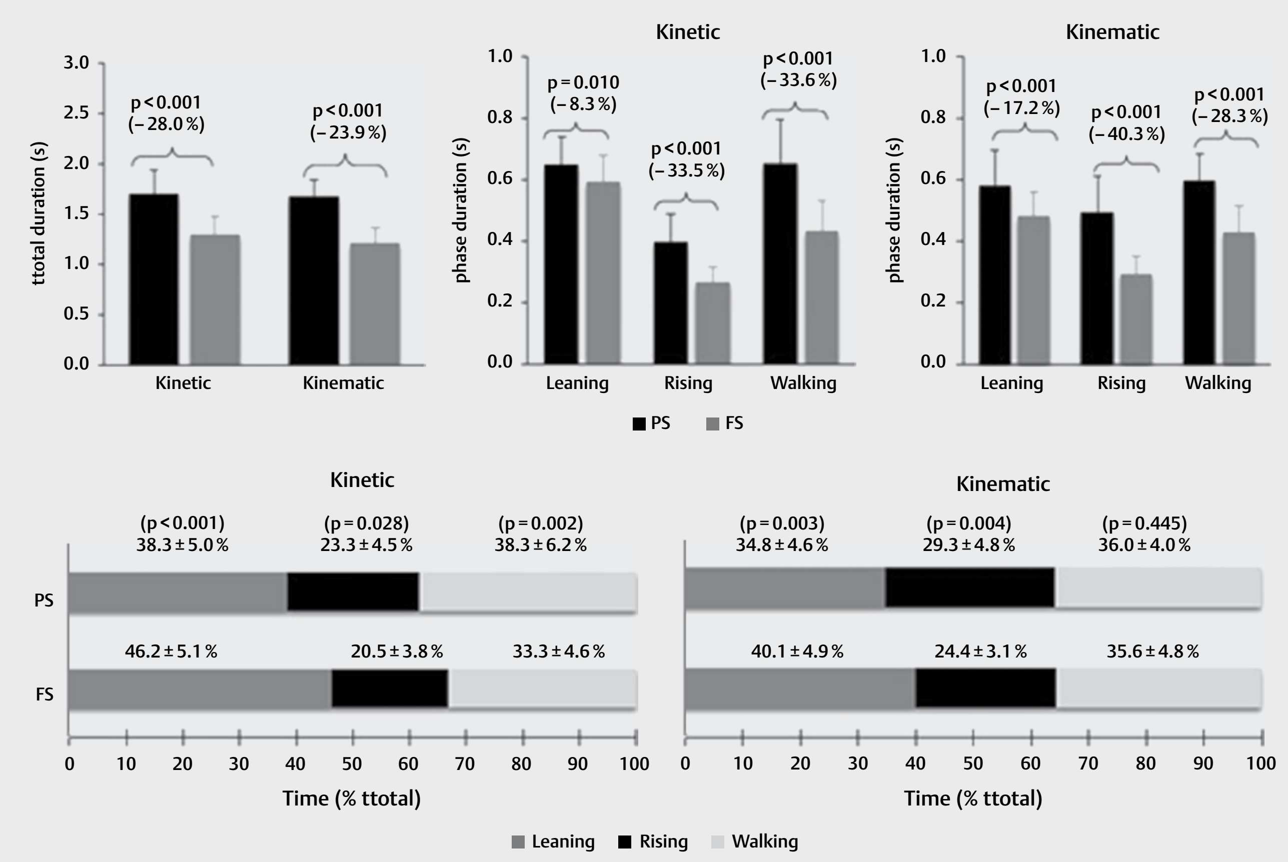
Spatial pattern

The evidence of a directional motion speed effect agrees with previous studies [22, 23] for the sit-to-stand task. Pai and Roger [22] suggest that different neuromuscular control strategies may be employed to accomplish the tasks of balance control in the horizontal direction and changing the gravitational potential energy in the vertical one. Thus, the motor control system may seek to reduce the number of separate independent movement dimensions by tightly regulating or constraining certain aspects of the movement [24]. During the FS Rising, a balance rather than a propulsive strategy may be reflected in the discontinuous mode of the propulsive force (evidenced by the additional posterior peak about mid-way of the CoP lateral transfer). In both PS and FS, walking initiation occurs while the body is still rising, however at a lower CoM position at FS than PS. Thus, the discontinuous mode of propulsive force most possibly targets to dampen the increased forward acceleration and regulate the lateral postural stability at walking initiation [25, 26]. The lower body rise at FS walking initiation corroborates with the more "flexed" body position under increased walking speed [13] which may potentially induce a lateral stability challenge [8]. Active control of lateral rather than anterior-posterior stability is normally required for transferring one's body weight between the two walking limbs [7], with better lateral stability favoring the walking speed increase [8].

The CoP traces of the present study were similar to those of previous studies [2, 10, 11]. The CoP traveled the same amount of distance in FS as in PS; however, during the first half of its lateral transfer, a forward rather than a lateral shift appears to dominate in FS (▶ **Fig. 1**). The trajectory and duration variations of the CoP lateral transfer are associated with the timing of walking initiation [2]. In FS, the characteristic rapid initial CoP shift towards the swing leg most possibly indicates that the unloading process of the stance leg begins prior to (or at) seat-off, with a significant loading of the swing leg at seat-off [2]. According to Magnan and coworkers [2], the CoP trajectory in our study indicates that, in both PS and FS, our participants did not prioritize the seat-off braking impulse to attain a certain level of postural stability before walking initiation; instead, they appear to emphasize the forward continuation of the body's movement for the walking maneuver. As discussed by Bestaven and coworkers [11], the rapid sideways shift of the CoP from the swing foot towards the anterior part of the stance foot (most often observed in young subjects and evidenced at FS CoP trace) indicates not only a rather early gait initiation as the body is still rising, but also an efficient forward postural control.

Temporal pattern

As expected, the FS STW duration was shorter and within the documented range of decrease (from −24 % up to −28 %) [12–14].



▶ **Fig. 3** **Top:** Mean (SD) absolute duration of the total STW (Left) as well as the kinetic (Center) and the kinematic (Right) STW phases. The percentage difference between preferred (PS – black bars) and fast (FS – grey bars) speed of motion with the negative sign indicating a decrease in the FS. **Bottom:** Relative duration pattern of the kinetic (Left) and the kinematic (Right) STW phases (Leaning, Rising, Walking). The base of percentage (100 %) is the absolute kinetic and kinematic STW duration, respectively. * Significant difference between PS and FS at p ≤ 0.05. Note: The kinematic onset took place later than the kinetic one resulting in a significantly shorter kinematic duration in FS (−6.5 %, p = 0.000) but not in PS (−1.6 %, p = 0.355).

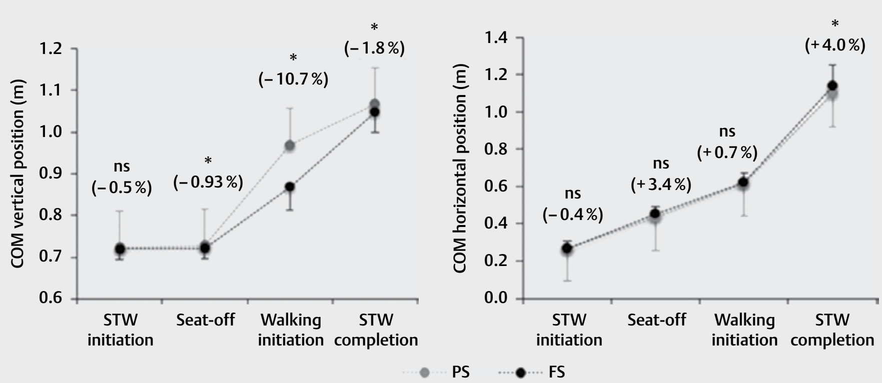
Overall, the significant alterations due to FS, highlight the critical role of the preparatory Leaning phase - during which the feet unloading and loading take place - for the STW motor control. The prolongation of the feet unweighted part within the Leaning phase may be associated with the generation of “optimal” braking joint moments, most possibly through controlling the horizontal inertial component of the trunk, as well as the efficient coupling of the horizontal and the vertical momentum [15]. To perform the STW, an horizontal momentum is generated by trunk forward-leaning and a rising vertical momentum is generated by the lower limb extension [15]. The rising momentum is affected by the feet position [27]. If the feet are positioned behind the knees, the movement of the center of gravity relative to the point where the GRF is applied will decrease. Thus, the resultant GRF and the ankle dorsiflexor activity will be reduced [27]. The particular role of the feet may be graphically evidenced in ▶ **Fig. 1** where the FS trace of CoM-Vx does not rise above the PS trace until after about 50 % of STW ttotal, that is after the feet braking impulse has been applied (PS: 35.7 %, FS: 41.0 % of STW ttotal). When the PS videos were visually inspected, only 5 persons appeared to displace their feet more posteriorly to the knees, while the other 13 ones performed slight ankle dorsiflexion. However, in FS, 12 participants clearly repositioned their feet more posteriorly, with pronounced ankle dorsiflexion and noticeable eversion in the 6 participants who did not alter their feet position. One could argue that the feet position relative to the knees (anterior or posterior to the knees) was not standardized; however, we aimed to examine the effect of motion speed without interfering in the preferred body configuration. Due to its effect on postural stability [5, 6], one could also argue the non-inclusion of head acceleration in the present study. The head acceleration should be considered in future STW protocols, particularly when participants sustain vestibular, proprioceptive, and ocular impairments (i. e. elderly, neurological patients, etc).

In conclusion, the FS spatial and temporal, kinetic and kinematic changes suggest that the fast STW execution is not a “magnified” with respect to force, or a “shrinked-in” with respect to time, copy of the preferred STW speed. In specific, a balance rather than a propulsive strategy is evidenced in the discontinuous mode of forward

▶ **Table 2** Temporal kinetic and kinematic pattern. Mean (SD) of the relative occurrence time (% ttotal) in the preferred (PS) and the fast (FS) motion speed, as well as their percentage difference (PS = 100 %). Cohen's d effect size (d ES) and the lower (LB) and upper (UB) bounds for the 95 % confidence interval (CI) of the mean are also presented. Variables are described in ▶ **Table 1**.

% STW ttotal	**PS**	**FS**	**diff % units**	***p* value**	**d ES**	**95 % CI of the mean (LB / UB)**	
	Mean (SD)	**Mean (SD)**				**PS**	**FS**
Kinetic pattern							
tFz^{dip1}	17.2 (5.5)	25.1 (6.6)	+ 7.9	< 0.001 *	1.3	(14.5/19.9)	(21.8/28.3)
tFz^{peak1}	38.3 (5.0)	46.2 (5.1)	+ 7.9	< 0.001 *	1.5	(35.8/40.8)	(43.6/48.7)
tFz^{dip2}	63.9 (6.9)	72.5 (4.8)	+ 8.6	< 0.001 *	1.4	(60.4/67.3)	(70.1/74.9)
tFz^{peak2}	85.4 (2.6)	84.8 (2.8)	−0.6	0.239^{ns}	0.3	(84.2/86.7)	(83.4/86.2)
$tFx^{posterior1}$	26.6 (5.2)	35.0 (5.1)	+ 8.4	< 0.001 *	1.6	(24.0/29.2)	(32.4/37.5)
$tFx^{anterior}$	35.7 (4.6)	41.0 (4.5)	+ 5.3	< 0.001 *	1.1	(33.4/38.0)	(38.7/43.2)
$tFx^{posterior2}$	89.7 (1.7)	88.3 (2.2)	−1.4	0.033 *	0.7	(88.9/90.6)	(87.3/89.4)
tFy^{medial}	46.5 (6.2)	48.5 (6.8)	+ 2.0	0.355^{ns}	0.3	(43.4/49.6)	(45.1/51.9)
$tFy^{lateral}$	83.0 (6.7)	79.5 (4.8)	−3.5	0.027 *	0.6	(79.6/86.3)	(77.1/81.8)
$tCoP\text{-}LT^{start}$	46.3 (7.4)	48.8 (7.7)	+ 2.5	< 0.001 *	0.3	(42.6/50.0)	(64.5/71.4)
$tCoP\text{-}LT^{end}$	68.0 (6.9)	70.8 (4.8)	+ 2.8	< 0.001 *	0.5	(44.9/52.6)	(68.4/73.1)
tCoP LT Vmax	61.0 (8.1)	66.7 (4.6)	+ 5.7	0.005 *	0.9	(57.0/65.0)	(64.4/69.0)
Kinematic pattern							
$tCoM\ Vx^{peak1}$	31.1 (4.5)	39.9 (6.3)	+ 8.8	< 0.001 *	1.6	(28.9/33.3)	(36.8/43.1)
$tCoM\ Vx^{peak2}$	91.1 (2.6)	91.8 (3.6)	+ 0.7	0.443^{ns}	0.2	(89.8/92.5)	(90.1/93.6)
tCoMVy-max	50.5 (5.0)	58.0 (7.4)	+ 14.9	0.001 *	1.2	(27.3/32.2)	(33.5/37.4)
tCoMdy-max	70.5 (7.0)	81.8 (7.9)	+ 16.0	< 0.001 *	1.5	(47.0/52.0)	(38.3/45.7)

Variables are described in ▶ **Fig. 1** and ▶ **Table 1**. * Significant difference between PS and FS at p ≤ 0.05. Cohen's d effect size (ES) interpretation: small (d = 0.2), medium (d = 0.5), and large (d = 0.8) according to Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.



▶ **Fig. 4** Vertical (left) and horizontal (right) CoM position at critical STW events during PS and (Grey markers) FS (Black markers). The percentage of increase (+ sign) or decrease (- sign) in the FS compared to the FS is noted. * Significant difference at p ≤ 0.05.

ground reaction force in the FS Rising phase. The FS significant changes of the relative temporal pattern indicate a change in the organization of movement sequence (prolonged Leaning phase and shortened Rising phase). The prolongation of the relative Leaning phase is associated with the initial feet unloading and loading, which highlights the role of the feet in the generation of fast horizontal velocity. Thus, a safe STW task should aim at the preparatory Leaning phase, so that body weight is effectively transferred forward as the person rises out of the seated position. In turn, a well-balanced seat-off will allow better postural stability for the subsequent simultaneous Rising and Walking initiation, particularly as the latter occurs at lower body rise in FS. Overall, the results concerning the relative temporal pattern may possibly contribute to rehabilitative training while learning the movement sequence rather than the constituent movement per se.

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Conflict of Interest

The authors declare that they have no conflict of interest

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