

# Tactile and proprioceptive sensory stimulation modifies estimation of walking distance but not upright gait stability: a pilot study

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**Abstract.** [Purpose] Recently, there has been growing interest in the somatosensory system, but little data exist on the interaction between dynamic postural control and the somatosensory system. The purpose of this study was to determine whether a training program, based on tactile and proprioceptive sensory stimulation of the trunk with the use of perceptual surfaces, improved the estimation of walking distance by healthy subjects, the ability to walk toward a memorized distance without vision, and whether it increases upright gait stability. [Subjects and Methods] Ten healthy subjects with a mean age of  $31.9 \pm 2.5$  years were enrolled and participated in 10 daily sessions of perceptual training using perceptual surfaces, for 45 minutes each session. An experimental indoor test measured the subjects' ability to perceive walking distances to a memorized target in an indoor environment. [Results] After treatment, the distances that were traversed were closer to the target than before treatment. Trunk acceleration did not differ significantly between pre- and post-training and did not increase significantly after training. [Conclusion] Treatment with perceptual surfaces stimulating the trunk midline improves the estimation of walking distance and modifies proprioceptive gait patterns, allowing various corrective strategies to be implemented during ambulation. **Key words:** Trunk midline, Perceptual surfaces, Gait patterns

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## INTRODUCTION

The trunk midline is the reference for orientation of the body in space and is the “point” of comparison for the synthesis of all tactile, kinesthetic, and pressure-related information from the two sides of the body<sup>1</sup>). Thus, the trunk midline can be considered the axis of symmetry around which the body organizes motor behavior<sup>2</sup>). The corpus callosum is the principal interhemispheric commissure, and its functions include the exchange of information between the two central hemispheres and integration of the inputs that reach one or both of them<sup>3</sup>).

All somatosensory callosal connections appear to provide a common anatomical substrate: this phenomenon is known as midline fusion. Callosal fibers ensure the unitary perception of visual and somatosensory space. The body regions that are represented in the callosally connected zones of the first somatosensory area (SI) were identified as the midline

of the somatosensory space<sup>4</sup>). The subjective vertical midline of the body is the result of multisensory integration of vestibular, proprioceptive, visual, and tactile afferences<sup>5, 6</sup>). Meilinger and colleagues hypothesized that every alteration of these afferences produces an abnormal representation of the body system, which receives incoherent information, and answers in a reflex and primitive manner<sup>7</sup>).

The integration of spatial information that is perceived<sup>8, 9</sup>) from different viewpoints is a common yet largely unexamined cognitive ability<sup>10, 11</sup>). Locomotion is supported by additional content, which is closely related to behaviors, such as modulation of the gait cycle, from vision control<sup>12–14</sup>). As Logan and colleagues have pointed out, “frequency response functions between visual scene motion (input) and trunk kinematics (output) change very little or not at all with gains in trunk orientation in the standing posture and under walking conditions”<sup>15, 16</sup>).

There is evidence of a correlation between heading and the rate at which strategic modifications in trunk yaw decrease, because adaptive recalibration of locomotor trajectory using optic flow stimuli depends on the rate at which the kinematic variability that is associated with strategic control is reduced<sup>15</sup>). However, Logan and colleagues consider that the increased gain reflects a decline in stability, due to a change in the control problem from standing to locomotion. Keeping the body upright with the use of vision during walk-

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ing is complicated by the additional locomotor processes that occur.

When vision is deprived, subjects operate not according to a pre-established pattern of action but in relation to its internal representation of the previously seen target. Moreover, this internal representation is based on "its relative location within the task environment"<sup>14</sup>. Visual feedback allows a subject to have the same gait patterns in various surroundings, whereas visual deprivation has environment-specific effects on gait dynamic stability<sup>16</sup>.

The significance of visual feedback underscores its importance in pathological conditions, such as patients with post stroke hemiplegia who might be unable to adapt to changing visual or surface conditions<sup>17</sup>.

Iosa and colleagues reported that the surrounding environment influences the performance of subjects who are asked to walk toward a memorized target. When fewer external cues were available, participants relied more on information on body mechanics and body feedback to complete the task accurately. Conversely, in a small indoor environment that was rich in environmental cues, subjects perceived the target as a finish line that was not to be overshoot<sup>18</sup>.

Mohapatra and colleagues indicated that under blindfolded conditions, anticipatory postural adjustments are not generated. They proposed that the increased EMG activity in leg and trunk muscles after a perturbation, indicating lower postural stability, reflects a lack of anticipatory postural adjustments (and relative compensatory postural adjustments) when vision is unavailable<sup>19</sup>. Other research suggests that the priority of whole-trunk control in the mediolateral direction is higher than in other directions and is linked to attention, whereas whole-trunk control in the vertical rotation and anteroposterior directions is passively regulated and requires minimal attentional control<sup>20</sup>.

As recently demonstrated in chronic pain conditions, alterations in somatosensory perception can change the body's sense of posture<sup>21</sup>. The possibility of training a subject to understand his position with respect to the gravitational axis through a specific cutaneous training program opens new avenues in body posture perception and action<sup>22</sup>. Also, the maintenance of chronic low back pain is linked to a disorder of altered perception of the trunk<sup>23</sup>. Perceptual Surfaces (PSs) reduce static and dynamic balance impairments, even in patients with Parkinson disease (PD)<sup>24</sup>. The function of the trunk is crucial in PD: other studies have shown how vibrotactile biofeedback of the trunk improves postural stability in PD<sup>25</sup>.

Thus, multiple sensory stimuli contribute to conscious awareness of the body, but the manner in which the central nervous system constructs and updates the body schema after injury or on visual deprivation is unknown. This issue remains controversial. For example, Pereira and colleagues demonstrated that local muscle vibration does not improve the sit-to-walk performance of healthy young adults<sup>26</sup>.

The purpose of this study was to determine the effects of tactile and proprioceptive sensory stimulation of the back on perception of the body midline and on the capacity to walk toward a memorized distance without vision or trunk stability in healthy subjects.

We hypothesized that training individuals' perceptive

capacity (pressure and somesthetic sensation) by providing dedicated instruction that is based on cognitive exercises that are performed using a specific rehabilitative tool would modify their estimation of walking distance and upright gait stability.

## SUBJECTS AND METHODS

Ten healthy subjects (mean age  $31.90 \pm 2.47$  years, mean weight  $64 \pm 11.4$  kg, and mean height  $170.4 \pm 7.56$  cm) were recruited and matched with 10 healthy control subjects (mean age  $30.5 \pm 2.8$  years, mean weight  $65 \pm 10.20$  kg, and mean height  $169.5 \pm 8.40$  cm). The subjects gave their informed consent to participation in the study, and approval was obtained from the local ethics committee of the S. Lucia Foundation (n° CE-PROG 266-09). The subjects were asked to perform an experimental indoor test wearing comfortable shoes that they usually wore, not specialty shoes, such as boots, ballet shoes, high heels, and flip-flops.

We examined the subjects' abilities to perceive and estimate the length that they were required to walk over a given distance in an indoor environment. The subjects had to walk toward a memorized target 3 m, 6 m, or 10 m from a reference position (0 m) in a 20 by 5 m<sup>2</sup> laboratory, without obstacles on a linear trajectory in the middle of the laboratory, with their eyes closed and prompted by an acoustic signal to begin walking.

Only the experimenter and one subject were present in the laboratory. The environment was quiet, with good natural lighting, and there were no other items or furniture that could serve as external references for the subject. Similar to the experiment that was conducted by Iosa and colleagues<sup>27</sup>, before starting the test, the investigator positioned the subject at 0 m and showed him the distances that were set at 3 m, 6 m, and 10 m to facilitate memorization of the trajectories that the subject had to cover blindfolded.

Subjects were asked to stand on a starting line. The target was a person who stood on 1 of 3 strips that were placed on the ground 3 m, 6 m, and 10 m from the starting line. The subjects were asked to memorize the position of the target, fixing it for several seconds; blindfold themselves; and, after an acoustic signal, walk to the target. Participants were asked to stop walking when they believed that they had reached the target. An experimenter measured their errors, in meters, after the walking task. No verbal aid was provided to the subjects during the trials. The experimenter promptly warned a subject if he was going to hit a wall. The sequence of the 3 tasks (1 for each distance) was randomized among the subjects.

At the end of each test when a subject stopped at one of the targets, a tape measure was used to determine the distance that was traveled and the distance that remained to complete the task. After each sequence, the subject, still blindfolded, was returned to the starting line by the investigator, preventing him from knowing whether an error had been committed to avoid learning opportunities.

No side effects were recorded during the test, and the investigator never had to stop a subject. The entire study group was tested before starting treatment with PSs (=T0) and after 10 treatment sessions with PSs (=Tend). Five randomly

chosen subjects repeated the test immediately after the first treatment session of sensory-motor evaluation with PSs (= T1) to exclude the possible influence of learning of the task.

To complete the test, an accelerometer was fixed at the level of the L2/L3 vertebrae with an elastic band (FreeSense®, Sensorize, sampling frequency 100 Hz, weight 94 g). Accelerometry is a technique that generates data on the dynamic stability of gait with regard to movements of the trunk during walking.

The accelerometer provided acceleration data of the trunk along the 3 body axes (anteroposterior, laterolateral, and craniocaudal) to assess upright gait stability.

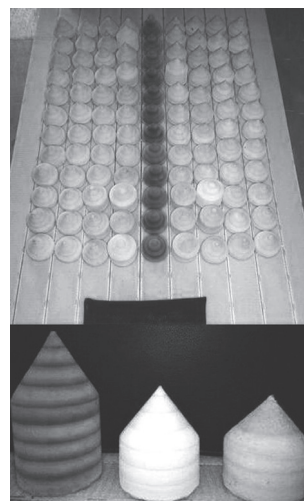
Upright gait stability has been defined as the capacity to minimize upper body accelerations<sup>18)</sup>. Upper body accelerations were analyzed after subtracting their mean values and low-pass filtering at 20 Hz, and summarized in terms of acceleration root mean square (aRMS), which is a measure of acceleration dispersion (coinciding with the standard deviation due to subtraction of the mean signal). We computed the aRMS for each body axis, to obtain information on upright gait instability<sup>18)</sup>. The aRMS was computed for each of the 3 acceleration measures along the 3 body axes and averaged over the 3 values of 3 consecutive steps in the central section of the walking pathway<sup>28)</sup>.

The number of steps that were performed was computed as the number of AP-acceleration negative peaks<sup>29)</sup>, and the average step length was calculated as the ratio between the distance that was walked and the number of steps (step length refers to the distance between 2 successive placements of the 2 feet, whereas stride length refers to the distance between 2 successive placements of the same foot, formed by 2 steps).

The perceptual surfaces protocol (PS) was developed as follows. Stimulation of awareness of the trunk midline is effected using a specific tool, called SUPER (perceptual surfaces, PS), patented in 1997 by Ennio Spadini (reference 01291920, Rome, Italy). SUPER is a therapeutic system that is based on the interaction between a subject's back and a support surface comprised of small latex cones of various dimensions (height: 3–8 cm; base diameter: 2–4 cm) and rigidity (20 to 60%). These cones are applied with their inferior bases on a rigid wood surface through elastic strips, and typically, over 100 cones are used for each session. Subjects were asked to lay supine on the surface that was formed by the smoothed apex of these cones, creating reaction forces to the patient's weight, generated by interaction with the cones.

The base conformation of the PSs comprises blue cones that represent the anteroposterior trunk midline (60% rigidity), yellow cones that represent the paravertebral, and the remaining areas that are symmetrically adjacent on either side of the midline (40% rigidity) (Fig.1). We chose this conformation on the basis of the following principles: to provide greater stimulation to the skin of the posterior midline of the trunk (blue cones with greater rigidity than the yellow ones), and to provide symmetrical stimulation to other areas of the body.

Subjects were asked to lie supine on these cones, with their knees and hips flexed, so that their weight was supported by many reaction force vectors, 1 for each cone. These forces generate high pressure in the small areas of contact, resulting in intensive perceptive stimuli. The base



**Fig. 1.** Surfaces for perceptive rehabilitation in the basic configuration and below an examples of cones with varying dimensions.

conformation allowed us to determine spatial alterations in the back (subjects with antalgic postures and scoliosis), based on the distribution of pressures on the subjects' backs and their perception of back pressures (i.e., sensory-motor evaluation in the first session).

Subjects were asked to relax and find the most comfortable position, breathing normally. Subjects had to recognize the areas of support, indicating the surface of the body that was in contact with a particular area, describing and counting the number of cones, checking the distribution of the load on the bed and correcting it, and paying attention to posture. The subjects reported how they perceived and felt the cones, particularly if the load was distributed uniformly and symmetrically with respect to the trunk midline.

After the evaluation session, each subject underwent 10 sessions in 2 weeks (5 days per week). Subjects performed 45 minutes of a cognitive-perceptive task (divided into perceptual-motor and active phases) to improve their perception of the trunk and, in particular, their midline.

The perceptual phase helps a subject become aware of the position of his body segments with respect to the various cones. The perceptual-motor phase is characterized by growing awareness of the trunk midline. Diaphragmatic breathing, associated with retroversion of the pelvis in the expiratory phase, allows the curves of the spine to flatten and the muscles to stretch to increase the support surface. The actual exercise comprises a perceptual task that increases in difficulty, asking the patient to perceive the elasticities and heights of the surfaces. The active phase involves movement of the arms and legs, displacement, and weight control of the trunk and pelvis. The base conformation can be modified during the session to improve contact between the trunk and the surfaces of the cones.

At the end of each session, the experimenter examined the interaction between the skin on the back and the surfaces that relieved the hyperemic area on the patient's back.

In subsequent sessions, cones with varying elasticities

were positioned by the therapist to improve the symmetry of contact between the surface and the patient's back, considering the hyperemia in the previous session. The experimenter measured perception through the symmetry, quality, and uniformity of the supports.

Empirically, in the static posture after sessions with the PSs, the perceptive capacity of the trunk was assessed using quality representation and symmetry, with respect to the line of the spinous processes, of the hyperemic areas that were created by the support with the PSs. "Quality" was defined as the magnitude of the hyperemic area that is left by the cones on the skin and signs of pressure from the cones that remain on the skin of the trunk.

The aim was to improve the subjects' abilities to recognize, perceive, and discriminate the trunk midline and enhance their sensory experience.

In the control group, subjects were asked to lay supine with the knees and hip flexed. Subjects were asked to relax and find the most comfortable position, breathing normally. Lumbar exercises were performed: lumbar bridging, lumbar pelvic tilt and hamstrings and piriformis supine stretching.

All measures were continuous and distributed normally (Lilliefors test); thus, parametric statistical methods were employed. The mean  $\pm$  standard deviation was computed for all parameters. To compare the results between pre- and post-treatment performances, repeated-measures analysis of variance was performed using time (pre- vs post-treatment or first vs second assessment) and distance (3 m, 6 m, or 10 m) as the main factors, and axis (AP, LL, or CC) as an added factor when acceleration was analyzed. SPSS 17.0 and a significance level of 0.05 were used for all statistical analyses.

## RESULTS

Before treatment, the subjects displayed the greatest errors in walking 10 m, followed by walking 6 m and 3 m. This error was always negative: subjects tended to walk less distance than required.

By analysis of variance, there was a significant effect of

time (pre- vs post- treatment,  $F=5.968$ ,  $p=0.037$ , observed power 59%) and distance ( $F=8.055$ ,  $p=0.012$ , observed power 91%) but not of their interaction ( $F=2.977$ ,  $p=0.108$ , observed power 36%). The reduced error was related to a longer distance being walked, which was founded on longer steps (in mean +5%) and more steps performed (in mean one more). Although step length and number of steps did not improve significantly over time (analysis of variance,  $p>0.05$  for both), their combination significantly improved the subjects' performances.

There were no significant changes in the error in walking distance estimates among the subjects who repeated the test immediately after the first treatment session (effect of trial:  $F=0.374$ ,  $p=0.574$ ); the absence of visual and verbal feedback did not allow the subjects to correct their mistakes. Non-significant differences in these errors were observed at  $T_{end}$  in those who undertook the test for the second time at  $T_1$  or at  $T_{end}$ .

Despite the general increase in speed and acceleration after treatment, their changes were not statistically significant (Table 1).

Time did not affect self-selected walking velocities pre- and post-treatment ( $F=2.924$ ,  $p=0.121$ ). Subjects walked slower over the 10-m distance than over the other 2 distances (factor distance:  $F=15.734$ ,  $p<0.001$ ), without any significant interaction with time ( $F=0.067$ ,  $p=0.935$ ) (Table 1). Similarly, by analysis of variance of aRMS values along the 3 body axes (Table 1), there were no significant effects of time, pre- versus post-treatment ( $F=2.091$ ,  $p=0.182$ ), or distance ( $F=2.454$ ,  $p=0.114$ ); only axis had a significant effect ( $F=11.689$ ,  $p=0.001$ ), with greater acceleration along the CC axis. The interactions of time and distance ( $F=1.963$ ,  $p=0.169$ ) and between time and axis ( $F=0.141$ ,  $p=0.869$ ) were not statistically significant.

## DISCUSSION

The purpose of this study was to determine whether a training program that is based on tactile and proprioceptive

**Table 1.** Mean and standard deviation of the gait parameters

Parameters	Time	3 m	6 m	10 m
Errors (m)	T0	-0.15 $\pm$ 0.11	-0.70 $\pm$ 0.29	-1.57 $\pm$ 0.45
	Tend	0.05 $\pm$ 0.11	-0.13 $\pm$ 0.18	-0.33 $\pm$ 0.29
WS (m/s)	T0	0.84 $\pm$ 0.20	0.82 $\pm$ 0.13	0.68 $\pm$ 0.18
	Tend	0.89 $\pm$ 0.20	0.88 $\pm$ 0.15	0.72 $\pm$ 0.15
Step length (m)	T0	0.43 $\pm$ 0.09	0.51 $\pm$ 0.09	0.52 $\pm$ 0.09
	Tend	0.46 $\pm$ 0.10	0.53 $\pm$ 0.09	0.55 $\pm$ 0.05
Number of steps	T0	7 $\pm$ 1	10 $\pm$ 2	16 $\pm$ 2
	Tend	7 $\pm$ 1	11 $\pm$ 2	17 $\pm$ 1
aRMS-AP (m/s <sup>2</sup> )	T0	1.16 $\pm$ 0.35	1.23 $\pm$ 0.32	1.18 $\pm$ 0.27
	Tend	1.20 $\pm$ 0.33	1.35 $\pm$ 0.42	1.33 $\pm$ 0.29
aRMS-LL (m/s <sup>2</sup> )	T0	1.15 $\pm$ 0.43	1.14 $\pm$ 0.30	1.09 $\pm$ 0.22
	Tend	1.17 $\pm$ 0.39	1.32 $\pm$ 0.50	1.26 $\pm$ 0.31
aRMS-CC (m/s <sup>2</sup> )	T0	1.40 $\pm$ 0.56	1.60 $\pm$ 0.51	1.47 $\pm$ 0.37
	Tend	1.40 $\pm$ 0.40	1.73 $\pm$ 0.52	1.75 $\pm$ 0.43

sensory stimulation of the trunk, performed using perceptive surfaces, modified the locomotor body schema and improved estimation of walking distance and upright gait stability.

After treatment with perceptive surfaces, the distances that were traversed were closer to the target than those before treatment, because the subjects increased their awareness regarding perception and estimation of the walking body. Furthermore, they increased their spatiotemporal gait parameters by taking longer steps. Trunk accelerations did not differ significantly between pre- and post-training sessions. There was a non-significant increase in trunk acceleration, which were likely related to the increase in gait speed<sup>30</sup>, after training<sup>31</sup>.

The concept of the trunk having a fundamental dynamic function during walking is a recent model. Until the 1990s, the trunk was considered to be a static passenger unit of a locomotor apparatus that was located primarily at the lower limb level<sup>34</sup>. Our study shows that tactile and proprioceptive stimulus of the trunk, with a new rehabilitation tool, can influence the behavioral pattern of locomotion.

In particular, the most important result of our study was that stimulation of the trunk improved the ability of the locomotor body schema to walk toward a memorized target without visual support. This result is in conflict with the older model, in which the lower limbs are a locomotor unit and the upper part of the body is merely a passive passenger<sup>5</sup>. Our findings are consistent with a recent suggestion that the upper body has an active function during walking<sup>32</sup>. Thus, our results suggest that the locomotor body schema includes the upper body not just the lower limbs. In this model, the CNS integrates many sensory inputs visual, vestibular, cutaneous, gravito-inertial, and proprioceptive inputs to compute spatial and body coordinates during a walking task, assigning a different weight to each input, depending on the environment and the constraints in which the movement is performed<sup>33-35</sup>. Shenton suggested that proprioceptive inflow is an important sensory input in the online representation of the body in space<sup>36</sup>, and that the processing of proprioceptive information is context-dependent<sup>37</sup>.

The presence of a body schema has been well described, as has the function of the location of tactile stimuli on body surfaces in promoting a body schema during the spatial representation of the body (position) and walking (locomotor body schema)<sup>38</sup>.

The perception of tactile stimuli and proprioception is critical for conveying information about the relative positions of body parts when assuming a posture or during walking. The decrease in perception, for example, during pain conditions could drastically change the body schema<sup>39, 40</sup>. Two studies of patients with chronic and non-specific low back pain reported that training with perceptual surfaces (PSs), targeting back midline perception, reduces pain<sup>41</sup> and improves postural control<sup>42</sup>.

How the body schema is generated in the CNS is unclear, but we know that the body schema and sensory information interact; thus, their conflict might generate pain, as shown in the experiment conducted by McCabe and colleagues using healthy volunteers<sup>43</sup>. Furthermore, the position of the body (sitting or standing) might alter the accuracy of the imagination of movements (i.e., mental simulation of an action

without its actual execution) such as walking<sup>44</sup>.

Trunk biomechanics and thus trunk movement perception and action are fundamental for establishing self-body representation (position), and during body movement, efficiency of the locomotor body schema<sup>37</sup>.

Our proposed exercise, the use of the trunk midline, and tactile and proprioceptive stimulation of the trunk enhance the locomotor body schema by generating more accurate information regarding trunk perception, the trunk-body midline, and gravity perception, and the interaction between trunk-body midline perception and space during a specific task. This enhancement in the locomotor body schema is a likely reason why the subjects displayed fewer errors in estimating walking distances after the intervention. That the subjects showed no improvement in estimating errors in a second evaluation (after the first session) indicates that the learning effect was negligible during repetition of the task.

Thus, the improvements are likely attributable to the increase in movement perception during walking (locomotor body schema) while blindfolded.

The blindfolded walking test is a complex task in which perception of the distance that has been walked should match the actual distance that is covered without visual correction. As reported by Schmidt, better trunk proprioception improves the efficiency of walking while blindfolded. Schmidt and colleagues applied vibratory stimuli if the trunk muscle spindle noted changes in the trajectory direction during walking, even in the presence of vision<sup>45-48</sup>.

Overstimulation of perceptual and proprioceptive trunk sensory information, as occurs during trunk muscle vibration, might disrupt the steering of locomotion<sup>49</sup>.

The subjects showed improvements in their estimation of distance errors while walking blindfolded. This was likely due to enhanced trunk proprioception, which was the target of our training program. Further studies should confirm these preliminary results and our hypothesis with more rigorous experiments and a larger sample.

Our study highlights the importance of trunk perception in computing egocentric space information during body locomotion. An example of the relative dependence of postural control on visual, vestibular, and somatosensory inputs was discussed by Horak and Nashner, who measured changes in postural sway in the standing position. They proposed that the apparent displacement of visual information and postural vertical input was the result of a recalculation of the central orientation of the gravity vector, based on a model in which the central nervous system extracts and interprets afferent information to construct a picture of reality (motor imagery)<sup>50</sup>.

Before treatment, subjects made errors that were proportional to the distance that was to be traveled. The same result was achieved in an experiment using a similar indoor pathway<sup>29</sup>. The mistakes were always negative: subjects tended to choose a shorter distance than the distance required. This pattern might be due to fear of hitting a wall or the ground, resulting from decreased body perception during walking (the locomotor body schema). This hypothesis is supported by the finding that before treatment, subjects walked with shorter steps, which is typical of people who are fearful of falling<sup>51</sup>, and of those with reduced somatosensory informa-

tion, as might occur during indoor blindfolded walking<sup>29</sup>).

Our results reinforce the hypothesis that working on the representation of the midline and motor imagery of the trunk creates a bridge between perception and movement, which can give rise to new functional strategies<sup>52</sup>. Blindfolded subjects evaluate movements better, because the motor patterns that are learned for ambulation, compared with specific tasks, can be affected by and depend on visual representations of the same image and are related to motor imagery, which is linked to somesthetic perception.

Our results also show that after training, upright gait stability was unchanged, likely because upright gait stability is modified in pathological walking pattern conditions to a greater extent than in healthy subjects<sup>30</sup>. Enrolling healthy and young subjects did not address this issue. But, this hypothesis should be confirmed with an ad hoc sample with pathological conditions and age-matched healthy subjects.

This study had several limitations, such as the absence of a control group; however, the repetition of the test immediately after the first treatment session should eliminate any suspicion of a bias linked to the learning effect. Furthermore, our small sample size did not allow us to examine the differences between genders<sup>29, 53</sup>, only within-subject comparisons were made pre- and post-treatment. We did not plan to measure lateral errors, but we noted lateral deviations during the tests. Also, we did not measure joint kinematics during walking, losing important information, especially with regard to the function of the hips. Finally, a potential bias of our test was the learning effect. Although we did not find statistically significant differences in the performance of subjects who were tested and immediately retested, the absence of significant differences could be due to the reduced sample size (5 subjects) with which this sub-analysis was performed. Nevertheless, the values of their performance during the retest were similar to those that were recorded in the first test, suggesting the absence of any effect. The potential bias of learning should be taken into account, and the interpretation of our results should be made with caution.

In light of our results, future studies in this field should be performed with larger sample sizes to determine whether perceptive rehabilitation, integrated into traditional rehabilitation programs, improves locomotor body awareness and enhances stability and walking performance in pathological conditions (e.g., stroke, ataxia, cerebral palsy, juvenile idiopathic scoliosis, and low back pain). In conclusion, this pilot study demonstrated that perceptive stimulation of the trunk midline improves the estimation of walking distance, implicating the upper body in the locomotor body schema.

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