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# optimal exploitation of sensory electrical stimulation for regulating postural balance depends on participants' intrinsic balance abilities

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## Highlights

- Improving postural balance using somatosensory stimulation is not systematic.
- Interindividual variability could explain the heterogeneous nature of the results.
- Individuals with the worst initial balance control benefit more from stimulation.

## Abstract

*Background:* The sensory electrical stimulation applied to the postural muscles provides additional sensory information that improves postural balance but this improvement seems to be highly subject-dependent. *Research question:* The first aim was to analyse the effects of sensory electrical stimulation on postural balance and the second aim was to analyse these effects depending on intrinsic postural balance abilities of subjects. *Methods:* Twenty healthy young male participants completed a monopodal postural task with sensory electrical stimulation (1ms; 10Hz;  $7\pm 2$ mA i.e., twice the intensity corresponding to the sensory threshold) and without sensory electrical stimulation. Pearson's product-moment correlations were performed on centre of pressure parameters to assess whether the participant's balance abilities at baseline were related to the beneficial effects of sensory electrical stimulation. *Results:* The results showed positive correlations for all the variables measured (i.e., with  $r^2$  from 0.32 to 0.35). Evidence suggests that subjects' abilities to take advantage from electrically induced additional afferents depended on participants' intrinsic balance abilities. In fact, subjects who exhibited the worst postural balance at baseline (i.e. without stimulation) benefited more from the effects of sensory electrical stimulation than subjects who displayed the best postural balance at baseline. *Significance:* In physically impaired subjects, as part of functional rehabilitation, sensory electrical stimulation would be particularly interesting in order to limit their risk of falling.

**Key words:** sensory electrical stimulation; somatosensory electrical stimulation; balance control; postural balance; sensory threshold; sensory information

## 1. Introduction

Proprioception can be assimilated to the sensitivity that provides information about the positions and movements of body segments and the whole body in space at all times [1]. This sensory information emanating from muscle, tendon and joint sensors as well as its central integration are fundamental in the regulation of postural balance [2]. Proprioception makes it possible to detect the slightest segmental movement that shifts the centre of mass and is likely to induce body imbalance which needs to be counteracted to prevent falling [3].

The disruption of proprioception due to pathology, injury or age advancement is likely to degrade postural balance and thus **could accentuate the risk of fall**. In contrast, the refinement of proprioception in any type of subject (i.e., pathological, healthy, young or older subject) is likely to improve postural balance and thus to enhance motor performance [1,4,5]. In all cases, whether it is question of rehabilitating or optimizing motor output, any means likely to improve proprioception deserves to be deployed durably and regularly [1]. However, workloads which aim at refining or reconditioning proprioception through challenging motor tasks (e.g., dynamic and strongly destabilizing) cannot always be safely implemented in physically diminished subjects (i.e., pathological, injured or older subjects) with functional limitations and at high risk of falling [6]. In turn, artificial stimulations of proprioceptive sensors turns out to be particularly relevant during the completion of easy motor tasks (e.g., static and weakly destabilizing) in order to limit the fall risk [6]. To this end, peripheral electrical stimulation **applied to the postural muscles** seems to be suitable provided that it only stimulates the sensory pathway (i.e. activates sensory neurons only, not motor

neurons) in order to facilitate the integration of afferents that it induces. The simultaneous stimulation of both sensory and motor neurons could indeed provoke collisions between the antidromic motor action potentials and the orthodromic sensory action potentials at the spinal level [7] which would create as a result interferences in the integration of induced afferents. The pure sensory electrical stimulation involves the implementation of current intensities below, at, or just above the sensory threshold -i.e., the minimal intensity of stimulation that can be perceived- but below the motor threshold. **Actually, the motor threshold corresponds to** the minimal intensity of stimulation that can generate a direct motor response which characterizes a force production likely to generate involuntary non-controlled segmental movements and thus disturb postural balance- [8].

On these **neurophysiological data**, the sensory electrical stimulation provides additional sensory information that indeed improves postural balance [9–11] but some studies showed that this is not always the case [12,13]. **Based on these results**, the hypothesis that this optimizing effect on postural balance is not systematic could stem from the fact that not all subjects react in the same way to the sensory stimulation. The effects of this stimulation on postural balance could be subject-dependent and related to subjects' abilities to take advantage or not from additional afferents. These abilities could depend on subjects' proprioceptive acuity and balance ability, which mainly results from motor experience but above all on individual predispositions [1,14]. Based on these considerations, knowing that there is a close link between the level of proprioceptive acuity and the level of postural balance [1,14], it would be logical that the optimizing effect of the sensory electrical stimulation on postural balance are related to postural balance at baseline (without sensory stimulation).

Therefore, the first aim was to analyse the effects of sensory electrical stimulation applied to the postural muscles on postural balance and the second aim was to analyse these effects depending on intrinsic postural balance abilities of subjects.

## **2. Material and methods**

### *2.1 Subjects*

Twenty healthy male subjects participated in this study (age  $19.8 \pm 0.9$  years; height  $176.6 \pm 6.3$  cm; body mass  $75 \pm 14.1$  kg). Exclusion criteria included balance disorders of pathological or drug-related origin, as well as musculoskeletal injuries in the past two years. Participants were asked to avoid any intense activity and not to consume any exciting substance 24 hours before the completion of the protocol. They voluntarily signed an informed consent form before starting the experiment, which was in accordance with the Helsinki Declaration. All procedures were approved by and performed in accordance with the relevant guidelines and regulations of the University of Pau and Adour Countries Ethics Committee.

### *2.2 Procedure*

Subjects were asked to stand on a stabilometric force platform which recorded the centre of foot pressure -COP- (Stabilotest, Technoconcept, Mane, France; 40 Hz sampling frequency) as motionless as possible in a monopodal stance on their dominant leg (i.e. the leg used to kick a ball) for 30 seconds while looking at a fixed target positioned 2 m in front of them. They had their arms crossed in front of the chest and the non-supporting leg was bent at a  $90^\circ$  knee joint flexion angle. After having completed two familiarization trials in order to avoid any learning effect [15],

the following trials were recorded for the statistical analysis. The participants had to perform this postural task in a control (CONT) condition and while being continuously submitted to a sensory electrical stimulation (SS condition) in a counterbalanced order (one test for each condition). Four rectangular electrodes (100x50 mm; Dual Leadwire, Compex, Vista, USA) were placed on the motor points of the vastus medialis, vastus lateralis and rectus femoris muscles, and on the proximal part of the quadriceps straddling the vastus lateralis and the rectus femoris. The sensory electrical stimulation (1 ms width continuous pulse at a 10 Hz frequency) was delivered using a Compex 2 stimulator (Compex, Ecublens, Switzerland) set at an intensity twice as high as the sensory threshold intensity (but always below the motor threshold). Any sub-sensory current was deliberately obscured because it is likely to facilitate postural balance in healthy and pathological subjects thanks to a phenomenon of stochastic resonance [16–19]. The mean intensity used for the sensory current was  $7\pm 2$  mA. To determine the sensory threshold, the intensity was increased until the subject perceived the current. The intensity was then decreased so that it could no longer be perceived. This was repeated 3 times and the lowest intensity perceived by the subject was defined as the sensory threshold.

### *2.3 Data analysis*

COP surface (COPs, 90% prediction ellipse area) and mean COP velocity on the mediolateral (COPx) and antero-posterior (COPy) axes were calculated to characterize postural balance. The lower these parameters, the more efficient the postural balance [20]. The absolute difference ( $\Delta$ ) between the control (CONT) and the sensory (SS) conditions was calculated for each COP parameter ( $\Delta$ COPs = COPs\_CONT – COPs\_SS;  $\Delta$ COPx = COPx\_CONT – COPx\_SS;  $\Delta$ COPy = COPy\_CONT – COPy\_SS) in order to differentiate subjects who benefit from sensory

electrical stimulation (positive value of absolute difference) and those who do not (negative value of absolute difference).

#### *2.4 Statistical analysis*

A 6-variable dataset (COPs\_CONT, COPx\_CONT, COPy\_CONT,  $\Delta$ COPs,  $\Delta$ COPx,  $\Delta$ COPy) was used for the statistical analysis. The normality of the data was checked using the Shapiro-Wilk test. Two variables did not meet the assumption of normal distribution ( $\Delta$ COPs and  $\Delta$ COPy) because of the presence of an outlier. The subject identified as an outlier was entered as an illustrative individual in the statistical analysis. Then, all the dataset followed a normal distribution. One-sample t- tests were employed for  $\Delta$ COPs,  $\Delta$ COPx and  $\Delta$ COPy to test the null hypothesis:  $\Delta$  equals zero (no benefit from sensory electrical stimulation). Pearson's product-moment correlation tests were also undertaken between COPs\_CONT, COPx\_CONT, COPy\_CONT and  $\Delta$ COPs,  $\Delta$ COPx,  $\Delta$ COPy respectively, to assess whether potential beneficial effects of sensory electrical stimulation could be related to the participant's balance abilities at baseline. The level of significance was set at  $p < 0.05$ .

### **3. Results**

One sample t-tests showed that the magnitude of the absolute difference between the CONT and SS conditions ( $\Delta$ COPs:  $-22.07 \pm 138.75$  mm<sup>2</sup>;  $\Delta$ COPx:  $0.17 \pm 5.48$  mm/s;  $\Delta$ COPy:  $0.76 \pm 3.39$  mm/s; mean $\pm$ SD) were not significantly different from zero ( $\Delta$ COPs:  $p = 0.497$ ;  $\Delta$ COPx:  $p = 0.8963$ ;  $\Delta$ COPy:  $p = 0.3426$ ). Scatterplots illustrating correlations between COP parameters in the CONT condition and the absolute difference between CONT and SS conditions ( $\Delta$ ) are shown in figure 1. For all COP parameters, the Pearson's product-moment correlation indicated a positive

correlation between values in the CONT condition and  $\Delta$  values (COPS:  $r^2 = 0.32$ ,  $p = 0.01196$ ; COPx:  $r^2 = 0.35$ ,  $p = 0.007664$ ; COPy:  $r^2 = 0.33$ ,  $p = 0.01051$ ).

#### 4. Discussion

The **first** aim was to analyse the effects of sensory electrical stimulation **applied to the postural muscles** on postural balance, and the **second aim was to analyse these effects** depending on intrinsic postural balance abilities **of subjects**. **First, results from one-sample t- tests performed on absolute differences between the CONT and SS conditions showed that the sensory electrical stimulation did not alter postural balance**. **Second**, evidences suggest that subjects' abilities to take advantage from electrically induced additional afferents significantly varied according their balance abilities at baseline: subjects who naturally exhibited the worst postural balance(i.e. without stimulation) benefited more from the effects of sensory electrical stimulation than subjects who naturally displayed the best postural balance.

On the basis of current knowledge related to the interaction between proprioception and postural balance, this result may seem counter-intuitive since subjects who display the best postural balance display the best ability to take advantage of proprioceptive sensory information [1] and should thus be able to further exploit additional afferents generated by the sensory electrical stimulation. In fact, these subjects did not take advantage -or only weakly- from additional sensory afferents in terms of postural balance. In return, subjects who naturally presented the worst postural balance benefited greatly from the additional afferents induced by the sensory electrical stimulation, which enabled them to improve their postural balance. In fact, the proprioceptive function of subjects who naturally presented the best

postural balance would already be very efficient by generating and exploiting fully physiological/natural afferents induced by the simple task of monopodal postural regulation. In turn, the output of the proprioceptive function of the subjects who naturally presented the worst postural balance would be less efficient and could be improved thanks to additional sensory information. Additional sensory afferents can be advantageously exploited by subjects who naturally exhibiting the worst postural balance which would optimize the output of their postural function. As part of the cutaneous stimulation (i.e., additional cutaneous afferents) this precept was already reported by Baige et al, 2020 [21] who showed that the ability to take advantage from the wearing of compression garments improves postural balance and depends on subjects' balance/proprioceptive abilities at baseline. **This raises the question of what mechanisms underlie the optimizing effects of sensory electrical stimulation on postural function in subjects who naturally had the worst postural balance.**

Previous studies showing that sensory electrical stimulation improves postural balance suggested potential changes at different levels of the sensory pathway that optimize the sensorimotor output [9–11]. However, these changes could only occur in subjects who naturally exhibiting the worst postural balance. Overall, from a neurophysiological point of view, the sensitivity of sensory sensors as well as the detection (i.e., induction), the transmission and/or the processing (i.e., integration) of generated signals could not be optimal in these subjects and the presence of additional sensory afferents could improve their postural function. Hence, the exploitation of additional signals generated by the sensory electrical stimulation could take place at levels of the induction (peripheral level) and integration (spinal and supra-spinal central level) of the signal pathway in the subjects presenting the worst postural balance.

In these subjects, regarding the signal induction, the sensory electrical stimulation could reduce the sensibility threshold of mechanoreceptors (i.e., Ia and II afferents of muscle spindles and/or Golgi tendon organs of the stimulated muscle chains) by altering the ion permeability of their membrane (making sensory neurons more likely to fire action potentials in the presence of additional signals) which would optimize potentiation and transmission of proprioceptive afferents and thus enhance the sensory contribution in postural regulation [22]. Concretely, subthreshold mechanical stimuli such as micro-segmental movement, would become detectable in the presence of sensory electrical signals. Changes in the signal detection would facilitate the integration of proprioceptive afferents and thus improve postural balance.

Regarding the signal integration, it can be analyzed at spinal and supra-spinal levels. At the spinal level, the sensory electrical stimulation affects the spinal excitability by modulating H-reflex amplitudes [23] which is likely to beneficially modulate postural balance especially during challenging postural tasks such as monopodal condition [1]. At the supra-spinal level, the signal integration can increase corticospinal excitability and thus enhance motor output of the postural function in healthy young subjects [24,25]. The signal passing through relay structures (e.g., thalamic nucleus) and leading to sensorimotor cortex would be likely to refine the descending drive since the somatosensory and motor cortex areas of the brain are inter-connected [24,26].

## **5. Conclusion**

In summary, subjects who naturally exhibited the worst postural balance benefited more from the effects of the sensory electrical stimulation than subjects who

displayed the best postural balance. It turns out that the worse the **baseline** postural balance, the greater the exploitation of additional sensory information. In practice, the sensory electrical stimulation would be of greater interest to physically diminished subjects (i.e. pathological, injured or elderly subjects) and would deserve to be particularly used in rehabilitation or reconditioning contexts.

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### **Conflict of interest statement**

The authors have no conflict of interest to declare.

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### Figure's caption

Figure 1. Scatterplots representing the correlations between a) COPs\_CONT and  $\Delta$ COPs, b) COPx\_CONT and  $\Delta$ COPx, c) COPy\_CONT and  $\Delta$ COPy.

One individual was identified as an outlier. He is represented by a transparent red circle on the ordinate boxplot and on the scatterplot. The blue line represents the regression line without taking into account the outlier. COPs\_CONT, COPx\_CONT, COPy\_CONT: COP parameters (surface, mean velocity on the mediolateral and antero-posterior axes) in the control condition;  $\Delta$ COPs,  $\Delta$ COPx;  $\Delta$ COPy: absolute differences of COP parameters between the control and the sensory conditions ( $\Delta = \text{CONT} - \text{SS}$ ).

