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Short Communication

Comparing intensities and modalities within the sensory attenuation paradigm: Preliminary evidence

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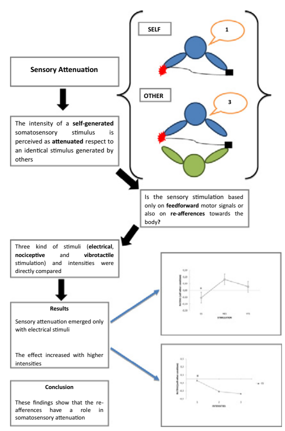
GRAPHICAL ABSTRACT



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ABSTRACT

It is well-documented that the intensity of a self-generated somatosensory stimulus is perceived to be attenuated in respect to an identical stimulus generated by others. At present, it is not clear whether such a phenomenon, known as somatosensory attenuation, is based not only on feedforward motor signals but also on re-afferences towards the body. To answer this question, in the present pilot investigation on twelve healthy subjects, three types of stimulations (sensory non-nociceptive electrical – ES, nociceptive electrical – NES, and vibrotactile – VTS) and intensities (1 = sensory threshold ∗ 2.5 + 2 mA, 2 = sensory threshold ∗ 2.5 + 3 mA, 3 = sensory threshold ∗ 2.5 + 4 mA for ES and NES; 1 = sensory threshold ∗ 2 *Hz*, 2 = sensory threshold ∗ 3 *Hz*, 3 = sensory threshold ∗ 4 *Hz* for VTS) have been directly compared in a somatosensory attenuation paradigm. The results show that the attenuation effect emerged only with electrical stimuli and that it increased with higher intensities. These pilot findings suggest that, depending on the type and the intensity of stimulation, re-afferences can have a role in somatosensory attenuation. Additionally, it is possible to speculate the effect is present only with electrical stimuli because those stimuli are prospectively judged as potentially dangerous. This, in turn, would optimize planning successful reactions to incoming threatening stimuli.
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Introduction

It is often thought that the sensory consequences of our own willed actions are unimportant and therefore should be discarded.

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Indeed, this is not trivial but, rather, well known in the scientific literature as sensory attenuation. Self-directed, intended stimuli are attenuated compared to the same stimuli generated by others (both phenomenologically and anatomo-functionally [1–5]).

Sensory attenuation is vital for survival, since attenuation of self-generated stimuli allows enhanced salience of unexpected external events. This, in turn, makes us able to distinguish between sensations generated by our own actions and sensations resulting from external causes. It is notable that despite these considerations, which suggest the universality of such phenomena among sensory domains, current findings remain scant. Indeed, sensory attenuation has been clearly demonstrated within auditory and tactile domains (e.g., [6–8]) but few data are available within the visual domain [9,10]. With respect to the interpretation of such a phenomenon, a first explanation states that it depends entirely on motor-related signals which would modulate the activity evoked by the incoming sensory signals. Such a hypothesis is rooted in evidence showing that various levels within the motor hierarchy affect sensory attenuation. For instance, the phenomenon emerges when actual sensory consequences of a voluntary action match the predicted consequences [7–11]. Nonetheless, since the phenomenon also arises when there is no physical contact, it has also been linked to motor predictions [1,11–13]. Additionally, prior belief of authorship [14], subliminal action priming [15] or expectation of movement [16] are known to modulate sensory attenuation. However, an alternative explanation pinpoints the role of re-afferent signals towards the body which, in turn, would mask the sensory probe. Accordingly, passive movements may also attenuate self-generated stimuli [17], and the type of movement may reduce the intensity of self-generated stimuli [16]. Overall, at present, it is not clear whether and to what extent re-afferences contribute to the emergence of sensory attenuation.

Capitalizing on all of these considerations, in the present study it has been further investigated the role of re-afferences *per se* in sensory attenuation. Specifically, it has been explored whether and how sensory modality and stimulus intensity affects the emergence of the phenomenon. Three somatosensory stimulations, often used in previous studies (i.e., sensory non-nociceptive electrical, nociceptive electrical and vibrotactile) [3,9,10,17–28], and three different intensities have been directly compared within a sensory attenuation paradigm (i.e., comparing self-versus externally generated stimuli). Importantly, since the two stimulus features were equiprobable within each block, any type of efferent signal prior to action was prevented.

Subject and methods

Twelve right-handed [29] healthy participants (7 females, mean age: 21.96 years; mean education level: 16.04 years) were recruited for the experiment, and *each signed an informed consent statement to participate in the study approved by the Bioethical Committee of the University of Turin*.

Participants were seated with their hands on a table and were instructed to always keep their sight in a specific point between their hands. During the experiment, the lateral digital nerve of the right (dominant) index finger was stimulated by attached electrodes (5 cm apart) at the lateral side of the tip and base of the finger [24]. Every 20 stimulations, the experimenter slightly shifted the position of the stimulator device (to not alter the subjective sensation). In addition, for every 20 stimulations, a catch trial (i.e., a trial without stimulation) was sent to avoid response biases and to control for phantom sensations. After each stimulus, participants verbally rated the perceived intensity sensation on a 0–10 point Likert's scale, in which 0 corresponds to "no intensity", and 10 corresponds to the "maximum perceived intensity". A within-subjects design study was run. Three types of stimulation were administered:

Sensory non-nociceptive electrical stimulation (ES)

For the ES, classical disposable surface electrodes (5-mm-diameter bipolar Ag/AgCl) were attached to a constant current stimulator (Digitimer Stimulator, Model DS7 A, Class 1 with Type BF applied part, EN 60601-1, produced by Digitimer Ltd, 37 Hydeway, Welwyn Garden City, Hertfordshire, AL7 3BE- England). Preliminarily, the electrical (both nociceptive and not) threshold of each participant was detected: subjects with closed eyes verbally reported perception of a stimulus to their right index finger (3 out of 6 repetitions). Next, stimuli were fixed at three intensities: intensity 1 = sensory threshold $*$ 2.5 + 2 mA, intensity 2 = sensory threshold $*$ 2.5 + 3 mA, intensity 3 = sensory threshold $*$ 2.5 + 4 mA. It has been decided to use three different intensities for each type of stimulation to avoid the risk of a bias and/or a habituation effect and to test for a possible main effect of intensity *per se*. The three intensities were administered in a random order in two conditions: in 60 trials, the electrical stimulus was self-generated (condition SELF), and in the other 60 trials, it was externally generated (condition OTHER) for a total of 120 stimuli.

Nociceptive electrical stimulation (NES)

For the NES, nociceptive electrodes that stimulate only alpha peripheral fibres, thanks to a pushpin-like needle electrode consisting of a plastic plate (1.2 cm in diameter) and a stainless steel needle (0.5 mm in diameter), were attached to the same devices used for ES [22]. The nociceptive threshold of each participant was detected using the same procedure as for the ES. Next, stimuli were delivered at fixed multiple intensities: intensity 1 = sensory threshold $*$ 2.5 + 2 mA, intensity 2 = sensory threshold $*$ 2.5 + 3 mA, intensity 3 = sensory threshold $*$ 2.5 + 4 mA. As for ES, nociceptive stimuli were randomly administered in three intensities and in two conditions (SELF and OTHER conditions, 60 for each condition, for a total of 120 stimuli).

Vibrotactile stimulation (VTS)

For the VTS, the experimental device was a vibrotactile stimulator. The stimulator worked with a printed circuit board Arduino (www.arduino.cc), an open-source microcontroller development platform connected to a homemade processing script. As for the ES and the NES, the vibrotactile stimuli were randomly administered in three intensities (1, 2, 3) and in two conditions (SELF and OTHER condition). For VTS stimuli intensity, it has been used the same ratio scale used in ES and NES by increasing the intensity of the vibration (i.e., the frequency of revolutions of the eccentric expressed in Hz), where intensities were 1 = sensory threshold $*$ 2 *Hz*, 2 = sensory threshold $*$ 3 *Hz*, 3 = sensory threshold $*$ 4 *Hz* for VTS.

The three types of stimulation (ES, NES, VTS) were administered in separated and balanced blocks between subjects to control a possible order effect; the order of stimuli intensities (1, 2 or 3) and conditions (SELF and OTHER) was randomized between subjects.

Consequently, the subject knows the agent of the action (himself in condition SELF and the experimenter in condition OTHER) and the kind of stimulation (accordingly to the block), but he/she was not aware of the forthcoming intensity of stimulation he/she must rate.

Statistical analysis

Data analysis were conducted with Statistica 6.0. Preliminarily, data were transformed into z-scores (within subject normalization, see for details [23]). All data were normally distributed (Shapiro-

Wilk test: W > 0.794; $P > 0.124$); therefore, parametric analyses were conducted. Next, data in condition OTHER were subtracted from condition SELF; consequently, negative values indicated the presence of somatosensory attenuation.

A 3 × 3 repeated measures ANOVA with STIMULATION (ES, NES, VTS) and INTENSITY (1, 2, 3), as within subject factors, was run (*Results I*).

Since the ANOVA did not show significant results, each of the three stimulations were separately analysed using a one-way ANOVA with the within-subjects factor INTENSITY at three levels (1, 2, 3). Furthermore, the score of each stimulation was compared with 0 using one-sample *t*-tests (*Results II*).

Lastly, to compare the three stimulations, intensities for each type of stimulation (mean of intensities 1, 2, 3) were averaged; indeed, a one-way ANOVA was run with the factor STIMULATION at three levels (ES, NES, VTS) as within subjects (*Results III*).

Results and discussion

Results I

Among the three stimulations, only ES showed all negative ratings (*ES* – intensity 1 = mean: −0.041; SE: 0.030; intensity 2 = mean: −0.316; SE: 0.055; intensity 3 = mean: −0.375; SE: 0.048; *NES* – intensity 1 = mean: 0.075; SE: 0.044; intensity 2 = mean: 0.145; SE: 0.067; intensity 3 = mean: 0.075; SE: 0.070; *VTS*- intensity 1 = mean: 0.095; SE: 0.023; intensity 2 = mean: 0.085; SE: 0.035; intensity 3 = mean: −0.1; SE: 0.035), suggesting a suppression effect. The 3 × 3 repeated measures ANOVA with STIMULATION (ES, NES, VTS) and INTENSITY (1, 2, 3) as within-subject factors did not show a significant effect (F (4, 44) = 1.076, $P = 0.379$, n_p^2=0.379) (see Fig. 1).

Results II

Despite being the most intuitive analysis, the analysis described above did not reveal any effect. However, since the types of stimulation are intrinsically different, an alternative approach with respect to the 3 × 3 ANOVA could be preferable.

Sensory non-nociceptive electrical stimulation (ES) results

A one-way ANOVA with within-subjects factor INTENSITY at three levels (1, 2, 3) was run. For the ES, the main factor INTENSITY was significant (F (2, 22) = 4.263, $P = 0.0272$, $n_p^2 = 0.279$). Post-hoc analysis (using the Duncan Test) showed that ES stimulation triggered somatosensory attenuation, given that all intensities are negatives. In addition, intensity 1 (mean: −0.041; SE: 0.030) was significantly different ($P = 0.050$) from intensity 2 (mean: −0.316; SE: 0.055) and different ($P = 0.013$) from intensity 3 (mean: −0.375; SE: 0.048), but intensity 2 and 3 are not different between each other ($P = 0.724$). Finally, one-sample *t*-tests showed that while intensity 1 is not different from 0 ($P = 0.534$), intensities 2 ($P = 0.022$) and 3 ($P = 0.002$) are significantly different from 0, indicating a suppression effect.

Nociceptive electrical stimulation (NES) results

The same analysis were run for the NES as for the ES. The main factor INTENSITY was not significant (F (2, 22) = 0.0735, $P = 0.929$, $n_p^2 = 0.006$). Intensities in NES showed a very similar pattern 1 (mean: 0.075; SE: 0.044), 2 (mean: 0.145; SE: 0.067) and 3 (mean: 0.075; SE: 0.070). Importantly, all scores were positives; therefore, ratings in the OTHER condition were higher than those compared to the SELF condition. In addition, one-sample *t*-tests yielded results not significantly different from 0.

Vibrotactile stimulation (VTS) results

For the VTS, a one-way ANOVA with within-subjects factor INTENSITY at three levels (1, 2, 3) was also run. The main factor INTENSITY was significant (F (2, 22) = 4.991, $P = 0.0163$, $n_p^2 = 0.312$). Post-hoc analyses (using the Duncan Test) showed that only intensity 3 (mean: −0.1; SE: 0.035) is significantly lower ($P = 0.013$) than intensity 1 (mean: 0.095; SE: 0.023) and intensity 2 ($P = 0.013$) (mean: 0.085; SE: 0.035) but is not significantly different from 0 ($P = 0.180$).

Results III

The one-way ANOVA with intensities averaged for each kind of stimulation (mean of intensities 1, 2, 3) show that the within-subjects factor STIMULATION at three levels (ES, NES, VTS) was significant (F (2, 22) = 10.617, $P = 0.001$, $n_p^2 = 0.491$). Post-hoc analyses (using the Duncan Test) showed that only ES stimulation triggered somatosensory attenuation (mean: −0.244; SE: 0.212), and it was also significantly different from both NES ($P < 0.001$) and VTS ($P = 0.004$) (see Fig. 2).

In the present study it has been examined the role of re-afferences in somatosensory attenuation by comparing self-

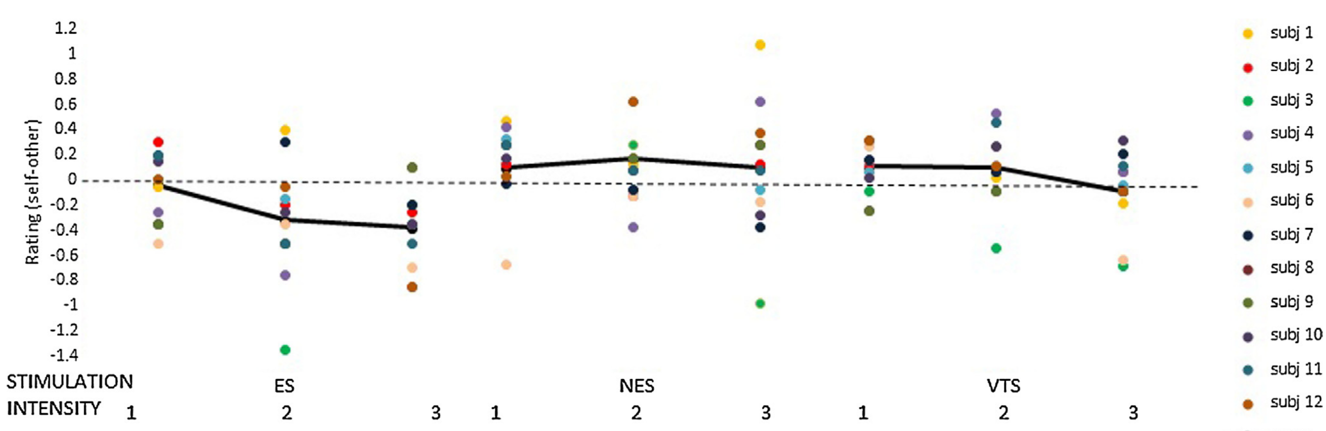

Fig. 1. Scatterplot of *Results I* showing participants' ratings (self minus other condition) separately for each stimulation. Each subject is represented by a different colour. Lines link averages of each type of stimulation. X-axis displays the three intensities (1, 2, 3) for each stimulation (ES, NES and VTS). No significant differences between stimulation and intensity were found.

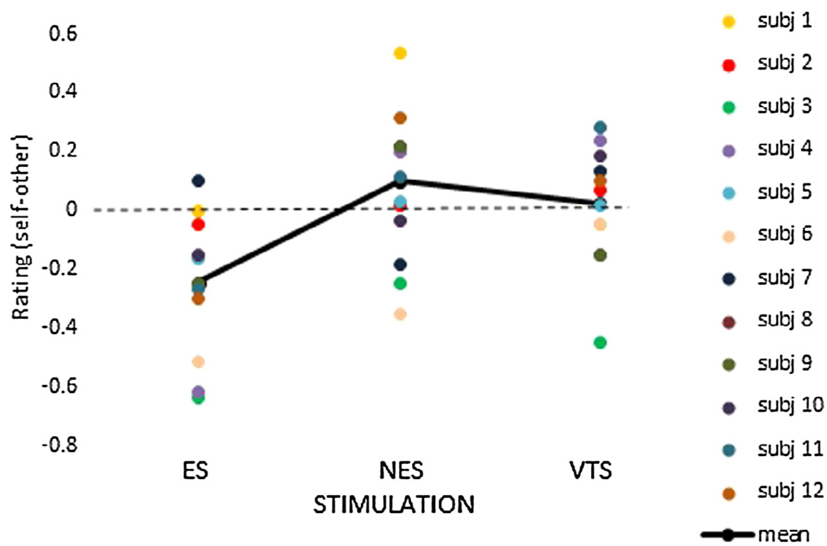

Fig. 2. Scatterplot of *Results III* showing participants' ratings (self minus other condition with intensities averaged). Each subject is represented by a different colour. X-axis displays the three stimulations (ES, NES, VTS). The line links averages of each stimulation. Only ES stimulation was significantly different from both NES ($P < 0.001$) and VTS ($P = 0.004$).

generated- versus other-generated stimulation within three types of unpredictable somatosensory stimuli and intensities. The results showed that the phenomenon was present for electrical non-nociceptive stimulation (but not for vibrotactile and nociceptive ones) and that the effect increased with the intensity. It is worth noticing that within the somatosensory domain, most of the existing literature on sensory attenuation employed electrical stimuli [25,26], several employed vibrotactile stimuli [3,27,28] and noxious stimuli [17–20,30]. However, no previous study directly compared these various kinds of stimuli. These results are consistent with some previous evidence, showing that sensory attenuation is not only linked to motor-related signals but also to the re-afferences that follow intended actions (e.g., [16,21]). Indeed, a series of previous investigations has demonstrated that the sensory attenuation could not be only explained by phenomena as, for example, the temporal predictability of the stimulus [32; see also 33] or the temporal control (i.e., the presence of an action to control the onset of the stimulus; cf. [34]). On the other hand, if, as suggested by the results from Lange [31] and Vroomen and Stekelenburg [33], the sensory attenuation can also occur in absence of action, this finding might indicate that the predictive mechanisms involved in the phenomenon are not limited to the action prediction but may also depend on external signals as, for example, our results indicate from the type of stimulation *per se*. Hence, in general, the phenomenon might depend on the optimal integrations of distinct types of information, namely, efferences and afferences, which are weighted according to the given context and to signal availabilities [33,34]. The higher sensory attenuation effect for electrical stimuli (but not for vibrotactile and, particularly, nociceptive ones) was quite unexpected. However, it is possible to speculate concerning the following interpretation of these results. Enhancing the salience of unexpected external events has a strong evolutionary meaning because it enables prompt reaction in advance to alerting signals. This ability is strongly rooted on anticipation, but in this design, this approach was not possible because stimuli were already processed. In this context, electrical stimulation could have been perceived as in between a safe stimulation (i.e., vibrotactile for which a response is too premature) and an unsafe one (i.e., nociceptive for which a response is too late). In other words, electrical stimuli, particularly the stronger ones, might be considered potentially more dangerous. Consequently, those stimuli might represent a more salient event, as demonstrated by the higher rating of the ES compared to the NES and the VTS. This hypothesis is consistent with the fact that sensory attenuation increased with higher intensities as if the cognitive system would be progressively more activated for stimuli that are potentially more dangerous.

Taken together, these results seem to indicate that re-afferences could modulate sensory attenuation, although the lack of the sensory attenuation with the nociceptive stimulation needs to be clarified.

Study limitation

The primary limitation of the study is the small sample size of the experimental group, since it is a behavioural investigation that led to a low/medium effect size. Nonetheless, since the present study is a pilot investigation, a sample size similar to previous studies on these issues was employed [35,36]. However, it is possible that the lack of effect with the nociceptive stimulation could be due to this low/medium effect size. Large sample size investigations will be necessary to overcome the limitations of this initial study.

Conclusions

In the present study, it has been demonstrated that re-afferences modulate sensory attenuation to optimize the efficacy of the reactions to different external stimuli. However, due to the limitation of this study, these results should be considered with caution. To investigate this hypothesis, future studies should gather additional behavioural and anatomo-functional evidence on how quantitative and qualitative features of re-afferences could modulate sensory attenuation.

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Conflict of Interest

The authors have declared no conflict of interest.

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