Vision of haptics tunes the somatosensory threshold

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Abstract

The interaction between different sensory modalities represents a crucial issue in the neuroscience of consciousness: when the processing of one modality is deficient, the concomitant presentation of stimuli of other spared modalities may sustain the restoring of the damaged sensory functions. In this regard, visual enhancement of touch may represent a viable tool in the rehabilitation from tactile disorders, yet the specific visual features mostly modulating the somatosensory experience remain unsettled.

In this study, healthy subjects underwent a tactile detection task during the observation of videos displaying different contents, including static gratings, meaningless motions, natural or point-lights reach-to-grasp-and-manipulate actions. Concurrently, near-threshold stimuli were delivered to the median nerve at different time-points. Subjective report was collected after each trial; the sensory detection rate was computed and compared across video conditions.

Our results indicate that the specific presence of haptic contents (i.e., vision of manipulation), either fully displayed or implied by point-lights, magnifies tactile sensitivity. The notion that such stimuli prompt an aware tactile experience opens to novel rehabilitation approaches for tactile consciousness disorders.

Keywords
touch, VET, action observation, tactile awareness, rehabilitation

Introduction

The interplay between visual information and somatosensory perception is largely documented in several studies, showing that visuo–tactile interactions play an important role in modulating both visual **(Chen et al., 2021; Lunghi et al., 2010; Macaluso et al., 2000; Macaluso et al,. 2002)** and tactile **(Fiorio et al., 2005; Konen & Haggard, 2014)** experience. Among different classes of visual stimuli delivered in combination with touch (e.g. a flashing light, see **Del Vecchio et al. 2021; Fossataro et al.; 2020[a,b])**, depictions of the human body represent the most investigated ones. Even when the observed body parts are unrelated to the stimulated body district **(Eads et al., 2015)**, body observation has been extensively reported to enhance tactile sensitivity **(Harris et al., 2007; Taylor-Clarke et al., 2004)** and spatial resolution of touch **(Kennett et al., 2001; Leo et al., 2020; Newport et al., 2002)**, with stronger effects if the observed stimulus coincides with the observer's body features **(Serino et al., 2008)**. This effect, usually named "visual enhancement of touch" (VET) **(Cardini et al., 2016; Kennett et al., 2001; Taylor-Clarke et al., 2004)**, suggests an important relationship between tactile perception and the internal representation of the body **(Haggard et al., 2003)**, whose underlying mechanisms are still largely unknown.

According to some authors, VET might arise from a top–down modulation of SI exerted by multisensory representations in the posterior parietal cortex (e.g. **Graziano et al., 2000**; **Grivaz et al. 2007; Serino & Haggard, 2010).** Another explanation, instead, identifies a role of the mirror fronto-parietal networks in VET phenomena. Because it is responsive to both touch and vision of the body in isolation, this circuitry would modulate the sensory cortices' response **(Làdavas & Farné, 2004)**. This view fits with recent evidence posing higher order somatosensory cortices within the mirror neuron network **(Avikainen et al., 2002; Del Vecchio et al., 2020; Ferri et al., 2015),** suggesting that VET might occur within or downstream posterior perisylvian regions.

Visual stimuli enhance somatosensory responses in the same regions, paralleling the behavioral effect observed in patients with deficits of tactile awareness (namely, tactile extinction). These patients might recover from their impaired sensory functions if a visual stimulus is delivered concomitantly with tactile stimulation, shedding light on the importance of such bimodal stimulation in promoting somatosensory awareness **(Di Pellegrino et al., 1997; Del Vecchio et al., 2021; Fossataro et al., 2020; Làdavas et al., 2000)**.

A yet open issue concerns which specific features of the visual stimulus mostly drive the VET phenomena. In other words, no studies systematically investigated the relative contribution of semantic contents, degree of motion, or vision of body parts in modulating the somatosensory perceptual experience, which, in principle, might also contribute to the debate about the neural mechanisms involved in VET.

In the present study, we delivered tactile stimuli (i.e., electrical median nerve stimulation at the wrist) at different timings during the observation of videos displaying real actions (reach to grasp and manipulate), point-light actions, or meaningless motion, and computed the participants' somatosensory detection rate. Such a design of the stimuli may contribute in disambiguating the role that multiple visual contents have in fostering somatosensory awareness. Indeed, contrasting actions vs meaningless motion provides insights on the effects that the semantic content of a visual stimulus exerts on sensory awareness. At the same time, the contrast between real vs point-light actions quantifies the role that body parts' vision has in promoting sensory awareness. Finally, comparing the detection rate between stimulations delivered in different phases of the same action (e.g. reaching vs. manipulation) could test whether the presence of a haptic content further interacts with the somatosensory perception.

The identification of the visual features most effective in fostering somatosensory awareness would not only contribute to the debate about the neural mechanisms sustaining VET, but may also have implications for the development of new rehabilitative procedures in the recovery of the tactile deficits often characterizing post-stroke patients, who might benefit of the application of multi-modal, tailored interventions **(Connell et al. 2008)**.

Materials and Methods

Sample size identification

An a-priori power analysis for within-subjects ANOVA was computed with G-Power 3.1 to define the sample size suitable for our study. The analysis output showed a minimum sample size of 33 subjects to obtain a significant effect on the dependent variable with an $\alpha=0.05$, a power $\beta=0.90$, and a medium effect size (Cohen's F=0.25).

Participants

Data were collected from 34 healthy subjects (27 females, 7 males, age 28±5). Six were left-handed (4 females, 2 males). Handedness was assessed with Edinburgh handedness inventory **(Oldfield, 1971)**. Subjects were informed regarding the experimental procedures, and informed consent was obtained. The present study was approved by the local Ethical Committee (Comitato Etico dell'Area Vasta Emilia Nord, 10084, 12.03.2018)**.**

Tactile stimulation

We administered an electrical tactile stimulation (1 ms duration) to the subjects' dominant limb (i.e., median nerve stimulation at the wrist) with a Digitimer DS7A stimulator. The stimulation intensity was set at the individual sensory threshold. Subjects sat comfortably on an armchair with open eyes. The detection threshold was identified with an adaptive staircase procedure. First, for each subject, the experimenter identified the subjects' motor threshold as the minimum electrical stimulus amplitude inducing an involuntary twitch of the thumb. Then, this amplitude was initially decreased in steps of 10% until the participants asserted to feel a maximum of two stimulations out of a train of six. At this point, the amplitude was increased by steps of 5% until the participant asserted to feel a minimum of four out of six stimulation. Then, the amplitude was first decreased in steps of 3% and finally increased in steps of 1% for the remainder of the staircase. The staircase was run until the subjects' percentage of detection settled at 50% (further referred to as the subject's sensory threshold ST).

Visual stimulation

A variety of stimuli was created to reproduce and isolate the different visual features potentially contributing/underlying the visual enhancement of touch.

We video-recorded both an actress and an actor during the performance of a reach-to-grasp-and-manipulate action, and then used these data to prepare the subsequent stimuli:

- a full vision of the naturalistic movement, matched with the individual participant gender and handedness (V);
- a point-light display of the same movement (PL), obtained by tracking on a frame-by-frame basis the position of 7 upper-limb markers (i.e., the knuckles of fingers, the center of the wrist, and the elbow). Such a stimulus ideally isolated the kinematic content of the movement from pictorial aspects;

- a meaningless motion stimulus (SH), obtained by shuffling the position of the point-light displays, thus keeping identical the motion content but at the same time preventing from the identification of a hand.

Finally, a static grating (GR) was used as a basic, control stimulus.. All videos lasted 11 seconds and were reproduced at 25 frames per second.

Experimental procedure

The experimental procedure was composed of two identical blocks. After the identification of the ST, subjects were administered with trials belonging to 6 different video conditions according to the type of visual stimulus and the timing of the electrical stimulation:

1. VR: natural action with the tactile stimulation delivered during the reaching phase;

2. VM: natural action with the tactile stimulation delivered during the manipulation phase;

3. PLR: point-light display with the tactile stimulation delivered during the reaching phase;

4. PLM: point-light display with the tactile stimulation delivered during the manipulation phase;

5. PLSH: point-light display with shuffled marker positions plus tactile stimulation;

6. GR: visual gratings plus tactile stimulation.

Each condition was randomly presented ten times per experimental block. Further, twelve trials were also presented (2 per video condition in each block), during which no electrical stimulation was delivered to monitor the goodness of the subjective report even in a few trials with no stimulation. In total, 144 trials were administered, equally subdivided into two blocks.

Within each condition, V and LP tactile stimulation occurred at random times during the reaching (R) or the manipulation phase (M). For GR and SH conditions, tactile stimulation might occur at any time during the video presentation. After the end of each video, the participant had to verbally report whether she/he had perceived the stimulation.

Subjects wore headphones playing a pink noise for the whole duration of the video presentation. This prevented them from hearing auditory cues related to the stimulation occurrence. Stimuli design and experimental procedures are summarized in Figure 1.

Galvanic skin response acquisition

Galvanic Skin Response (GSR) measures changes in sweat gland activity on the skin as an indication of physiological or psychological arousal **(Boucsein, 2012).** This signal was acquired to compare the level of arousal between perceived and unperceived stimulations and to evaluate whether a modulation of GSR parallel the differences in the detection rate across video conditions. Two Ag/AgCl cup electrodes were placed at the fingertip of the forefinger and the middle finger of the subjects' non-dominant limb (sampling frequency = 5 KHz), plus a ground electrode placed in correspondence to the metacarpophalangeal joint.

Statistical Analysis

We carried out a Repeated Measures ANOVA, with experimental block (two levels: block1; block2) and condition (i.e., video condition, six levels: VR, VM, PLR, PLM, GR, PLSH) as within subject factors. Post-hoc analyses were performed with Newman-Keuls tests. Further, we compared the detection rate distribution for each video condition via a one-sample t-test against 50% ($p < 0.05$), for the first and second experimental blocks, separately. A two-tailed paired t-test ($p < 0.05$) was finally used to compare the distribution of ST measured before the first and the second experimental block.

GSR analysis

Continuous GSR recording was downsampled at 1 KHz and band-pass filtered (0–500 Hz). Power line at 50 Hz was removed using a notch filter. Trials were time-locked to the delivery of tactile stimulation and segmented in the interval [-2, 4 s].

All trials were visually inspected and those contaminated by artifacts (e.g., muscular contractions, electrodes popping) were removed and excluded from further analyses. Trials were baseline-corrected by subtracting the mean of the pre-stimulus data [-2, 0 s] For each trial, we calculated the post-stimulus peak-to-peak amplitude (maximum value – minimum value in the interval [0,4 s], see **Boucsein, 2012**) and computed the mean values for each participant, grouping data according to the presented video condition (VR, VM, PLR, PLM, GR, PLSH) and the subjective report (perceived or not perceived stimulation).

We performed a Repeated Measures ANOVA, with the experimental block (two levels: block1; block2) and response (two levels: perceived, not perceived) as within-subject factors. Further, we also performed a Repeated Measures ANOVA with the experimental block (two levels: block1; block2) and condition (six levels: VR, VM, PLR, PLM, GR, PLSH) as factors, but limiting to the sole trials in which subjects reported to have perceived the stimulation. This latter analysis was aimed at evaluating whether a condition effect emerged, after accounting for the inter-block differences.

Results

Behavioral data

As the electrical stimulations were delivered at the ST, we had no means to verify the goodness of the subject report. However, evaluating the reports collected during the no-stimulation trials, subjects gave false positives in less than 10% of the trials (1±1 false positive trials), and such a rate remained constant across the two experimental blocks. For this reason, none of the subjects was excluded from subsequent analyses.

The ANOVA performed on individual detection rate indicates a main effect of both experimental block (F(1,33)=19.78, $p<0.001$, partial $\eta^2=0.37$) and condition (F(5,165)=3.86, $p=0.002$, partial $\eta^2=0.1$).

Our results indicate that video displaying actions, with either explicit or covert body features, present higher detection rates (i.e. PLR 60%, PLM 63%, VR 58%, VM 66%) compared to GR and PLSH (55%). Post-hoc analysis indicates that VM significantly differs from GR (p= 0.005), PLSH (p=0.006), and VR (p=0.036), but not PLM (p=0.3). The comparison between VM and PLR shows only a trend towards significance (p=0.094): this may be due to the absence of a clear separation between reaching and manipulation phases (no object was displayed in PLM and PLR). Finally, no significant interaction between the two main factors (i.e. experimental block and video condition, F=0.32, p=0.9, $\eta^2=0.01$) was found.

The subjective detection rate in block 1 is significantly above chance (50%), while the same is not true for block 2 with the only exception of the VM condition, which shows a trend towards significance (t(33)=0.3103, p=0.075). As the cognitive load requested to participants did not change between blocks, arousal and attentional factors might explain this difference between blocks. Notwithstanding, the detection rate distribution across conditions remains virtually superimposable between the two blocks (Figure 1, panel C). Together with the absence of any significant condition*block interaction, this notion suggests a negligible role of arousal/attentional factors in determining the reported modulations among experimental conditions. The significant main effect of block on detection rate is paralleled by a significant decrease of the individual sensory threshold between the two experimental blocks (t(33)=3.4549; p=0.0015, block1: 0.949±0.314 mA for block 2; 0.867±0.284 mA). All behavioral results are summarized in Table 1 and Figure 2.

	F	**p**	**Partial η^2**	**Observed power (α=0.05)**	**Post-hoc**
BLOCK	**19.78**	**<0.001***	**0.37**	**0.99**	
VIDEO CONDITION	**3.86**	**0.002***	**0.10**	**0.94**	**VM>GR** **VM>PLSH** **VM>VR**
BLOCK * VIDEO CONDITION	**0.32**	**0.902**	**0.01**	**0.13**	

Table 1. Statistical results. Table 1 summarizes the results of ANOVA on stimuli detection rate. Both main factors (block and video condition) are significant for the experimental procedure.

Galvanic skin response data

Following visual inspection, 18±15% of trials (18±16% for block 1 and 18±15% for block 2) were removed.

We found a main effect of both experimental block (F(1,33)=7.99, p=0.008, η^2=0.19) and report factors (F(1,33)=5.12, p=0.030, η^2=0.13), while no significant interaction was found (F(1,33)=0.58, p=0.45, η^2=0.02). This finding represents an indicator of the reliability of the subjective perceptual report, paralleling the behavioral measure with an autonomic indicator (Table S1).

When limiting the analysis to the sole perceived trials, only 26 subjects could be included as the remaining 8 subjects had at least one condition with no trials associated with an affirmative report. The ANOVA indicates nearly significant effects for both the block (F(1,25) = 4.05, p=0.06, η^2=0.14) and condition (F(5,125)=2.22, p= 0.056, η^2= 0.08) factors. However, the pattern exhibited by the GSR responses across conditions does not mirror the pattern of behavioral data, with post-hoc comparisons returning no significant contrasts among conditions (Table S2 and S3).

Discussion

This study aimed to investigate which visual features (e.g. motion, semantic content, vision of the body) are mostly effective in enhancing somatosensory sensitivity during a visuo-tactile stimulation. Our results indicate that visual stimuli including a hand-object interaction (and more generally, a haptic content) are the ones determining the largest increase of somatosensory detection, even if haptics is only implied (i.e. through light points). Other factors like motion and vision of the body parts seem to play a minor, non-specific, role.

A first, possible explanation could be that some stimuli/conditions have greater salience than others **(Galigani et al. 2021; Jacques et al. 2021; Moreau et al. 2016)**, and such increased arousal could explain the higher detection rate. However, the lack of any significant modulations on the GSR responses among conditions excludes the arousal from the list of the factors mainly responsible for the VET.

Visual and tactile information related to the body are largely demonstrated to have an effect on primary tactile processing, in terms of acceleration of tactile processing (**Tipper et al. 1998; Tipper et al. 2001**), improvement of tactile acuity (**Kennett et al. 2001**) and detection **(Taylor-Clarke et al., 2002; Taylor-Clarke et al., 2004; Press et al., 2004; Schaefer et al., 2005; Serino et al., 2007)**. Notwithstanding, the somatosensory consequences of vision of the body during the execution of actions have not been addressed with only preliminary evidence reporting amplified intensity judgements of tactile stimuli when observing a finger movement that has corresponding somatosensory effects (**Gillmeister, 2014**).

Our results point that the modulation of detection rate across conditions have to be found in the capacity of visuotactile stimuli to increase the subjects' somatosensory awareness, especially when visual stimuli display a haptic content. Thus, the debate has to move on the cortical networks sustaining the visual enhancement of touch.

Somatosensory awareness: the role of posterior perisylvian region

At the cortical level, posterior perisylvian regions and, in particular, secondary somatosensory cortex (SII) might represent the key node sustaining the enhancement of the somatosensory detection upon videos showing manipulative actions. The reasons subtending this behavior are manifold. First, it is well-established that SII (OP1 in humans **Eickhoff et al., 2006^{a,b})**, fulfills high-order somatosensory functions, such as roughness **(Pruett et al. 2001)** and shape perception **(*see* Hsiao et al., 2008)**, texture discrimination **Sathian et al., 2011**, as well as somato-motor haptic processing **(Ishida et al., 2013)**. Beyond pure somatosensation, these regions are reported to be activated by the observation of manipulative actions **(Avikainen et al., 2002, Del Vecchio et al., 2020; Ferri et al., 2015)**, thus posing this region in the mirror neuron network, with a specificity for actions requiring haptic control **(Del Vecchio et al., 2020)**. More in detail, these regions present a super-imposable time-course of responsiveness during the execution and observation of reaching-to-grasp-and-manipulation actions (see **Del Vecchio et al., 2020**). No activation was found during the reaching phase, in agreement with previous results reporting phenomena of tactile suppression during this phase of the action **(Juravle et al., 2017; Vastano et al., 2016**). Instead, posterior perisylvian regions are activated during the manipulation phase, paralleling the behavioral results obtained in this study.

Following basic somatosensory stimulation, posterior perisylvian regions exhibit a long-lasting, low-amplitude, *tonic* pattern of responsiveness **(Avanzini et al., 2016; Avanzini et al., 2018; Del Vecchio et al., 2019)**, enhanced by the concomitant presence of a visual stimulus and representing the neural correlate of tactile awareness **(Del Vecchio et al., 2021)**.

The combination of the two aforementioned mechanisms may offer an explanation to our findings, and more in general to the visual enhancement of touch. Indeed, the administration of visual stimuli containing haptic components would activate the posterior perisylvian regions since the pre-stimulus period. In turn, the later delivery of the peripheral stimulation would more likely determine a stronger tonic response, resulting in an above-chance likelihood of consciously perceiving the stimulation. Specific bimodal stimuli, then, might sustain and promote the instantiation of tactile awareness, vicariating, in turn, deficient sensory functions.

Rehabilitation of disorders of tactile awareness: new perspectives

Somatosensory impairment is a common condition after stroke **(Connell et al., 2008)**, including impaired localization at different body districts (e.g. face or wrist), stereognosis, or tactile extinction, to name a few. Current rehabilitation procedures include functional training, sensory stimulation, strategy training and task repetition **(Bowen et al., 2011)**. However, their use proved not effective in influencing at the long term on patients' disability, determining the need to further develop cognitive rehabilitation for perceptual deficits **(Brewer et al., 2013)**.

A possible role of the interaction between different sensory modalities in ameliorating sensory deficits has been already suggested **(Serino et al., 2007)** and reported, for example, for patients exhibiting tactile extinction **(Fossataro et al. 2020^{a})**. The results of our study indicate that haptics stimuli are ideal to promote tactile awareness through visuo-tactile stimulations, and thus pave the way for the construction of ideal stimuli based on prior knowledge of the cortical networks sustaining tactile awareness.

Author Contribution

Maria Del Vecchio: Conceptualization, Formal analysis, Data curation, Writing – original draft,Writing - review & editing. **Doriana De Marco**: Formal analysis, Data Curation, Writing – original draft, Writing - review & editing. **Andrea Pigorini:** Data Curation, Writing – original draft, Writing- review & editing. **Carlotta Fossataro:** Data Curation, Writing – original draft, Writing- review & editing. **Annalisa Cassisi:** Formal analysis, Data Curation, Writing – original draft, Writing - review & editing. **Pietro Avanzini:** Supervision, Funding acquisition, Writing – original draft,Writing - review & editing.

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Data and code availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in.

Ethics approval

All procedures performed in this study involving human participants were in accordance with the ethical standards of the local ethical committee “Comitato Etico Area Vasta Emilia Nord” and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

Not applicable.

Figures

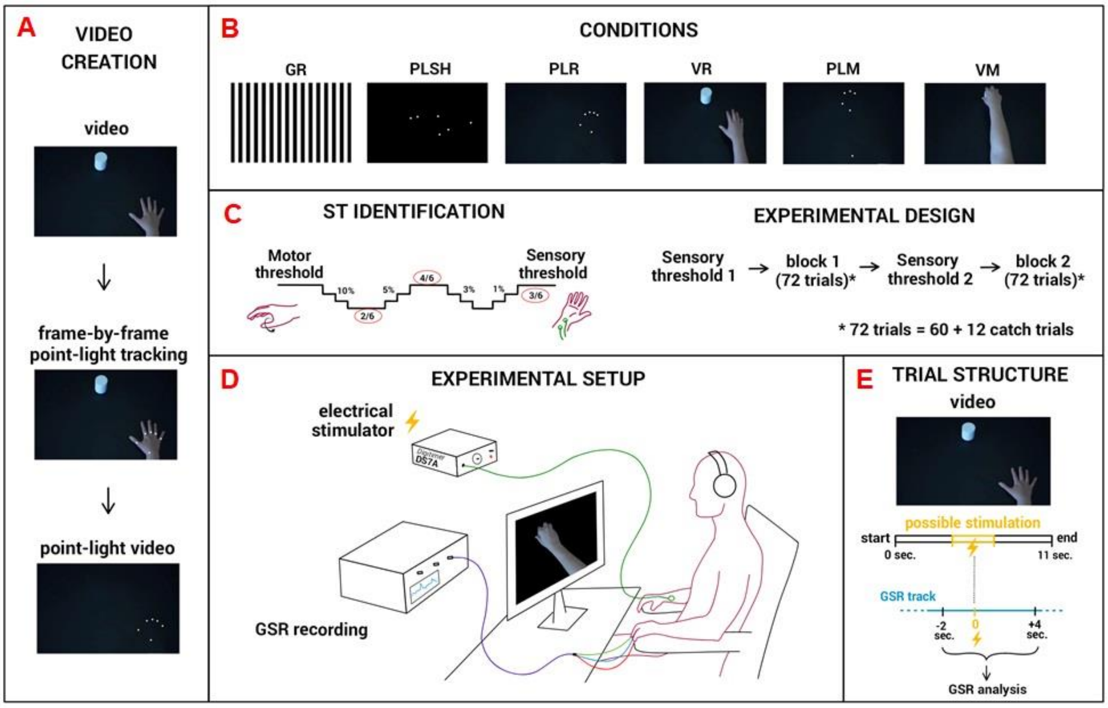

Figure 1. Stimuli and experimental procedure. (A) Point-light versions of videos were obtained by tracking on a frame-by-frame basis the position of 7 upper-limb markers (i.e. the knuckles of fingers, the center of the wrist and the elbow) with ad-hoc software in Matlab 2018a. (B) Six different video condition were randomly administered during the experimental procedure: GR (visual gratings plus tactile stimulation); PLSH (point-light display with shuffled marker positions plus tactile stimulation); PLR (point-light display with the tactile stimulation delivered during the reaching phase); PLM (point-light display with the tactile stimulation delivered during the manipulation phase); VR (natural action with the tactile stimulation delivered during the reaching phase); VM (natural action with the tactile stimulation delivered during the manipulation phase). (C) ST identification (left). After the identification of the subject's individual motor threshold, the amplitude of the stimulation was decreased in steps of 10% (until 2 out of 6 perceived stimulation). Then, the amplitude was increased by steps of 5% (until 4 out of 6 perceived stimulation). Then, the amplitude was decreased in steps of 3% and finally increased in steps of 1% for the remainder of the staircase. The staircase was interrupted when the subject reported to perceive 3 out of 6 delivered stimulations; this amplitude was indicated in the text as sensory threshold. Experimental procedure (right). The experimental procedure was composed of two analogous blocks of 60 trials (10 for each video condition) and 12 catch trials (2 for each video condition). Between the first and the second experimental block the subject's individual sensory threshold was measured as detailed before. (D) During the experiment, the subjects were seated comfortably on an armchair, wearing earphones to avoid acoustic confounds. Stimulation was delivered to the subject's dominant limb while the electrodermal activity was recorded on the other limb. (E) For each trial, a video of 11 seconds was displayed, in which the stimulation may or not (catch trials) be delivered. Galvanic skin response was aligned to the stimulation and segmented in the interval [-2, 4 s].

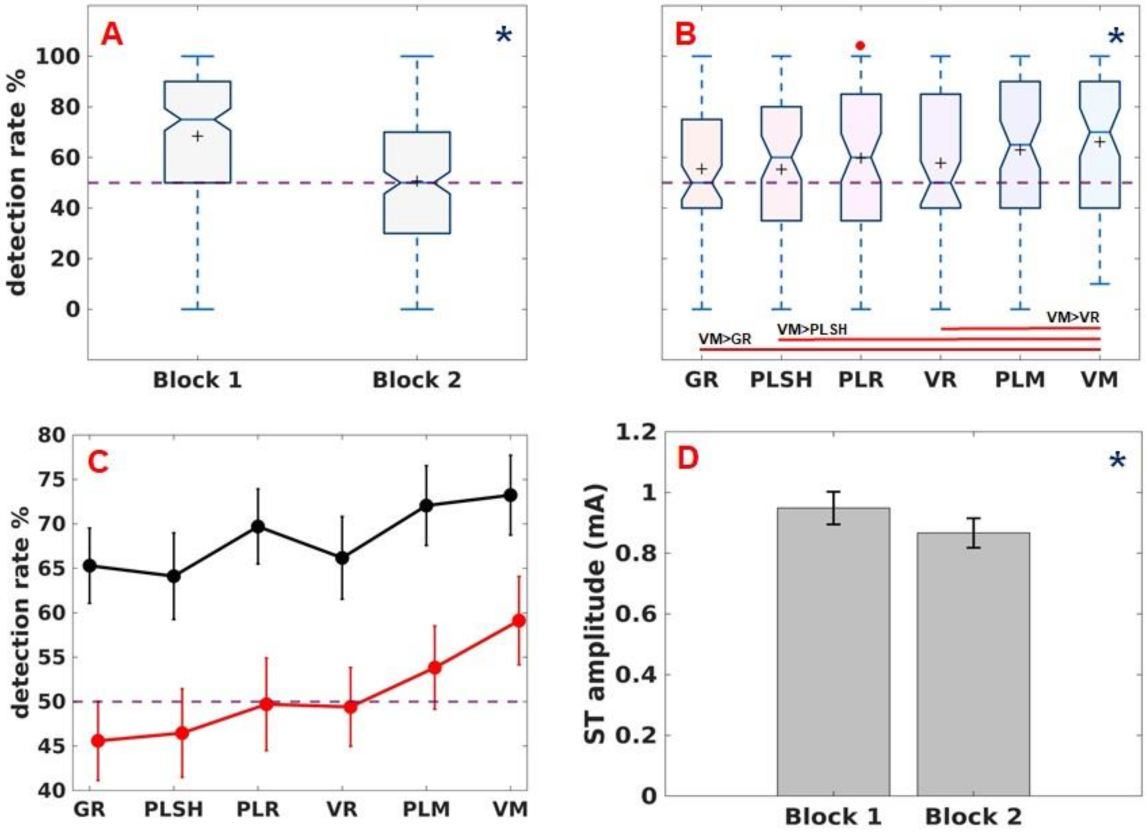

Figure 2. Behavioral results. Panel A and B show the boxplots for the distribution of the detection percentage across blocks (panel A) and video conditions (panel B). Blue asterisks indicate statistical significance for both experimental block (A) and video condition (B) (main factor, respectively p <0.001 and p = 0.002). The red circle up to the PLR condition indicates a trend toward significance (p = 0.094). Black crosses indicate the mean of percentage detection in each condition. A purple dotted line is plotted in correspondence of 50% detection rate. Panel C reports the distribution of the detection percentage for block 1 (black line) and block 2 (red line) separately. A purple dotted line is plotted in correspondence of 50% detection rate. Panel D displays the mean (± SE) of the individual sensory threshold (see Methods) for the two experimental blocks separately (two-tailed paired t test, p<0.05).

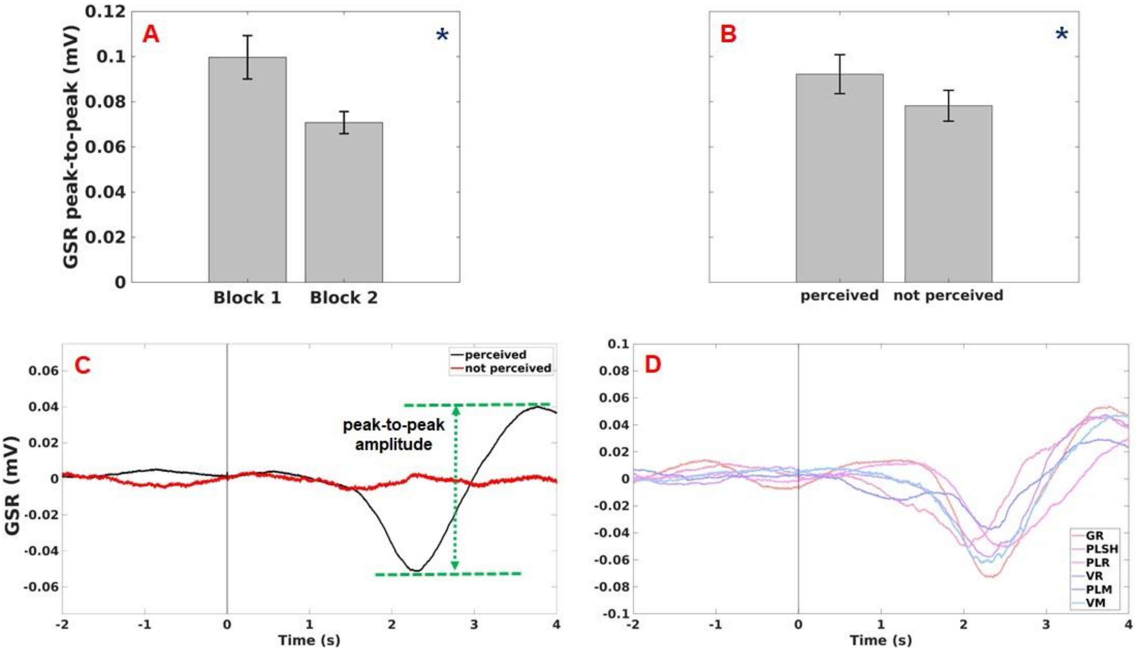

Figure 3. Galvanic skin response. Panel A and B shows GSR peak-to-peak amplitude values (mV) for non-rejected trials averaged (mean±SE) across experimental blocks (A) and subjects' response (B). Blue asterisks at the top of each panel indicate statistical significance (respectively p=0.08 and p=0.03). Panel C reports, for an exemplary subject, the mean GSR for perceived (black line) and non perceived (red line). Panel D, reports, the mean GSR trace the same subject of panel C for each video condition corresponding to an affirmative report of perception.

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Supplementary information:

	F	p	Partial η^2	Observed power (α=0,05)
INTERCEPT	**95.40**	**<0.001***	**0.74**	**1**
BLOCK	**7.99**	**0.008***	**0.19**	**0.78**
SUBJECTIVE REPORT	**5.12**	**0.03***	**0.13**	**0.59**
BLOCK * SUBJECTIVE REPORT	**0.58**	**0.45**	**0.02**	**0.11**

Table S1. GSR analysis (Block per subjective report). Table S1 summarizes the results of ANOVA for the GSR peak-to-peak amplitude (factors: Block, Subjective Report).

	F	p	Partial η^2	Observed power (α=0,05)
INTERCEPT	**57.54**	**<0.01***	**0.70**	**1**
BLOCK	**4.05**	**0.06**	**0.14**	**0.49**
VIDEO CONDITION	**2.22**	**0.06**	**0.08**	**0.71**
BLOCK * VIDEO CONDITION	**0.66**	**0.66**	**0.03**	**0.23**

Table S2. GSR analysis (Block per video condition, limited to affirmative report). Table S2 summarizes the results of ANOVA for the GSR peak-to-peak amplitude (factors: Block, peak-to-peak amplitude [mV]).

	BLOCK 1						**BLOCK 2**					
	GR	**PLSH**	**PLR**	**VR**	**PLM**	**VM**	**GR**	**PLSH**	**PLR**	**VR**	**PLM**	**VM**
mean	0.1100	0.1177	0.0958	0.1125	0.1016	0.1031	0.0853	0.0727	0.0700	0.0922	0.0658	0.0816
std	0.0897	0.1004	0.0941	0.1175	0.0890	0.0935	0.0652	0.0386	0.0330	0.0808	0.0426	0.0763

Table S3. GSR analysis. Table S3 reports GSR peak-to-peak amplitude for each block and condition (mean and standard deviation).