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Exploring the link between sensory habituation in everyday life and attentional control abilities

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Sensory habituation and attention control

Abstract

Sensory habituation, the reduction of physiological and behavioral responses to repeated stimuli, enables adaptation to environmental inputs and shares mechanisms with attentional control. Despite this overlap, the relationship between habituation and attentional processes remains underexplored.

This study investigated this link in 143 adult participants, who completed the Sensory Habituation Questionnaire (S-Hab-Q), measuring adaptation time to sensory input in everyday contexts, along with an interference control task requiring the detection of targets while ignoring global or local stimulus features. Sensory sensitivity and autistic traits were also assessed using the Sensory Perception Quotient (SPQ) and the Autism Spectrum Quotient (AQ).

The findings demonstrated that participants who take longer to habituate to external sensory stimuli were less accurate in detecting global targets when local features had to be suppressed. A similar pattern was observed in individuals with higher sensory sensitivity (SPQ). Conversely, they responded faster on non-target trials, which did not require suppression of the irrelevant stimulus dimension. A comparable pattern also emerged for individuals with higher autistic traits (AQ).

Overall, the study demonstrates a close association between individual sensory habituation profile and attentional control abilities, underscoring the importance of considering both factors in the understanding of sensory sensitivity, particularly in neurodiverse populations.

Sensory habituation and attention control

Keywords: Adaptation, Sensory disorder, Attention, Perception, Autism, Navon

Introduction

Habituation to sensory stimuli is a ubiquitous phenomenon characterized by a decrease in physiological and behavioral responses to repeated or continuous sensory stimulation, which is not simply caused by receptor adaptation or fatigue [1]. Crucially, this phenomenon shapes our perceptual experience and facilitates flexible responses to the environment by shifting repeated stimuli into the background while prioritizing new information. Robust evidence indicates that sensory habituation is present from birth, and that its development can impact subsequent, more advanced cognitive functions [2]. Infants who require less time to habituate to repeated visual stimuli obtain higher scores on developmental scales (e.g., the Bayley scale) two years later and achieve higher intelligence quotient scores at preschool and school ages [3,4]. Moreover, faster habituation rates in infancy are associated with faster processing speed [5]. While the importance of sensory habituation for higher cognitive functions has also been documented in adults [6,7], research on this topic remains limited [8].

Experimentally, one of the paradigms most commonly used to study habituation is the oddball task combined with the measurement of brain responses. In this paradigm, brain responses to repeated sensory stimulation (standard stimuli) are compared with ERP responses to rare sensory stimulation (deviant stimuli). Habituation is evident when a decrease in brain responses to standard stimuli is accompanied by an increase in brain responses to deviant stimuli [9] This difference is called mismatch negativity (MMN).

In a pioneeristic study conducted by Alho and colleagues [10], ERPs elicited by auditory and visual oddball tasks were examined in a group of adult patients with dorsolateral prefrontal lesions. All participants had normal hearing thresholds and normal-to-corrected visual acuity. The results revealed faster and enhanced early-latency potentials in patients compared to healthy controls for both standard and deviant stimuli, reflecting sensory processing. In contrast, later ERP components, which reflect more cognitive processing, such as attention deployment and stimulus identification, exhibited reduced amplitudes, especially for the deviants. The enhanced response to repeated stimuli, coupled with the attenuated response to rare stimuli, suggested that repeated stimuli were treated as novel. The absence of a decrease in the brain response to repeated stimuli and the diminished response to deviant stimuli led to attenuated MMN [9].

Some years later, Knight [11] reported the opposite pattern in patients with lesions in the primary auditory or somatosensory cortex. These patients showed reduced amplitudes of early-latency potentials generated by repeated/standard auditory or somatosensory stimuli in the respective brain sensory areas. In the same task, a control group of patients with dorsolateral prefrontal damage showed increased early-latency auditory and somatosensory potentials, as in the study by Alho and colleagues [10]. These results were interpreted as reflecting an impairment of a prefrontal mechanism that “sculpts” perceptual processing through inhibitory and excitatory inputs to posterior sensory cortices [10,11].

These pioneering studies paved the way for subsequent research demonstrating prefrontal cortex modulation over primary sensory cortices [12,13]. According to these findings, a weaker sensory brain response to a stimulus results not only from a less intense stimulation but also from prefrontal modulation of the sensory processing of stimuli repeated over time. Conversely, an amplified brain response may stem from either more intense stimulation or an altered prefrontal response [6]. Overall, prefrontal regulatory activity influences sensory responses (i.e., attenuated responses to repeated stimuli) and, consequently, perceptual experience.

This integration of top-down and bottom-up signals is mediated by attentional processes [14-16]. Indeed, individuals repeatedly exposed to environmental cues show attenuated responses not only because the brain minimizes unnecessary stimulus processing but also because these stimuli, even those that are perceptually salient, are treated as irrelevant by the attentional system, leading to successive inhibited stimulus processing and reduced allocation of resources [17]. On the other hand, rare stimuli elicit amplified brain responses not only because they emerge from the background of repeated stimuli but also because they are categorized as novel and automatically convey attentional resources [18]. Therefore, in healthy individuals, habituation goes beyond basic sensory processing. It actively shapes how we direct attention and prioritize novelty, rather than being a simple result of sensory adaptation or fatigue [8]. From a functional perspective, reduced sensory responses to repeated stimuli represent an adaptive reallocation of attentional resources to better detect novel information [19].

Given evidence in the literature suggesting a close interaction between habituation and attentional processes, both mediated by prefrontal circuits [20], we hypothesized that individuals who habituate more easily to repeated environmental stimuli would also exhibit more efficient attentional processes, particularly under limited-resource conditions, such as those requiring to control interfering information. To test this hypothesis, we administered to a sample of adults a self-report questionnaire assessing sensory habituation in everyday life, the Sensory Habituation Questionnaire (S-Hab-Q [21]), together with an attention control task. Unlike previous studies that relied on laboratory-based measures of habituation, the S-Hab-Q captures individual differences in habituation as experienced in ecological, real-world contexts. Specifically, this questionnaire asks participants to estimate the time they need to adapt to common repeated or continuous irrelevant environmental stimulation across different sensory modalities (vision, hearing, touch, smell, taste, and proprioception). Attentional control was assessed using a global-local task, which requires participants to detect target letters embedded either at the global or local level of a hierarchical stimulus. In target trials, successful performance requires coping with interference between the two stimulus dimensions (global vs. local levels) and suppressing the irrelevant dimension to correctly identify the target. We expected that individuals reporting slower habituation rates, that is, those who require a longer time to habituate to repeated or continuous irrelevant stimulation in everyday life, would also be more susceptible to the costs associated with these interfering conditions.

In addition, given the strong relationship between sensory habituation and sensory sensitivity, that is, the tendency to show amplified or reduced responses to sensory stimulation [22,23], and evidence that altered sensory habituation is common in neurodivergent populations, particularly autistic individuals (for reviews, see [24], [25]), we further examined the contribution of sensory sensitivity and autistic traits to task performance. Sensory sensitivity was assessed using the Sensory Perception Quotient questionnaire (SPQ [26]), and autistic traits were measured with the Autism-Spectrum Quotient questionnaire (AQ [27]). We expected that individuals with higher SPQ and AQ scores, reflecting greater sensory sensitivity or more pronounced autistic traits, would show attentional control difficulties similar to those observed in individuals with slower habituation rates.

Methods

Procedure

Data collection was conducted entirely online and anonymously and consisted of three sections: (1) a section collecting participants’ sociodemographic and anamnestic information, (2) a section including three self-report questionnaires (S-Hab-Q, SPQ, and AQ), and (3) the global-local task. The first two sections were administered via Google Forms platform, whereas the global-local task was administered using the PsyToolkit platform. The links to the two platforms were merged into a single message and distributed via social networks and personal communications using a snowball sampling method. The online modality was chosen to enable data collection from a larger and more diverse participant sample, not limited to university students. The survey was available online from May to December 2021.

This study was part of a larger survey focused on questionnaire scores only, which was reported in a previous publication [28], and extends that work by combining questionnaire measures with behavioral task performance to address a different research question. To this end, the questionnaires were always presented to all participants before the task.

The entire procedure and all materials were approved by the Ethics Committee of the University of Palermo (n. 48/2021), and the research was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

Participants

The inclusion criteria were that the participants were over 18 years old and were native Italian speakers. The exclusion criteria included self-reported sensory impairments, current or previous psychiatric or neurological diagnoses, or a diagnosis of neurodevelopmental disorders.

A total of 340 people took part in the survey; of these, 262 participants met the inclusion criteria and completed the questionnaires; of these, 159 participants completed both the questionnaires and the global-local task and were therefore included in the final analyses. On average, sociodemographic characteristics and questionnaire scores of participants who completed both the questionnaires and the task did not significantly differ from those who only completed the questionnaires (see Supplementary Table S1).

Questionnaires

The S-Hab-Q [21,28] is a self-report instrument consisting of 25 items designed to assess the subjective time needed to habituate to external sensory stimulation, particularly the time required to suppress the processing of irrelevant contextual perceptual stimuli. Examples of items include: "While working on the computer I keep hearing the noise of the processor for ... ", and “After touching a substance (e.g., glue, paint, or sand) I continue to feel this sensation on my body for ...”. Each item is scored on a Likert scale ranging from 0 (“very little time”) to 3 (“very much time”). The total score is calculated by summing all item scores, with higher scores reflecting slower or more difficult habituation to stimuli, and lower scores reflecting faster or easier habituation. Each item pertains to one of the following sensory domains: vision (n = 4), hearing (n = 7), touch (n = 7), smell (n = 4), taste (n = 2), or vestibular (n = 1). The questionnaire showed high internal consistency (Cronbach’s α = .88, [28]).

The 35-item version of the SPQ [26] is used to assess the subjective hyper- and hyposensitivity to environmental stimuli. Examples of items include "I notice the flickering of a desktop computer even when it is working properly”, and “I would be able to detect if a strawberry was ripe by smell alone”. The items are rated on a Likert scale ranging from 0 (“strongly agree”) to 3 (“strongly disagree”). To improve scoring consistency with the S-Hab-Q, responses to items indicating hypersensitivity (n = 29) were reverse-scored. Therefore, in the present study, higher total SPQ scores, resulting from the sum of all items, indicated greater sensory sensitivity to stimuli, whereas lower scores indicated reduced sensory sensitivity. The items cover the following sensory domains: vision (n = 6), hearing (n = 5), touch/vestibular (n = 10), smell (n = 10), and taste (n = 4). The 35-item version of the questionnaire demonstrated excellent internal consistency in previous research (Cronbach’s α = .93, [26]).

The AQ [27,31] includes 50 items designed to measure the degree of autistic traits in individuals. The AQ assesses core autistic symptoms across five subscales: Social Skills, Attention Switching, Attention to Detail, Communication, and Imagination. Example items include "I am often the last to understand the point of a joke” and “I prefer to do things with others rather than on my own”. Each item is rated on a four-point Likert scale ranging from “definitely agree” to “definitely disagree”. The scores were assigned according to the original guideline [29]. A score of 1 was assigned for responses consistent with an ASD trait, and a score of 0 was assigned for responses inconsistent with it. Therefore, higher total AQ scores indicated a greater presence of autistic traits. The questionnaire exhibited good internal consistency (Cronbach’s α= .76) and test–retest reliability over a six-month period (Pearson’s r = .79) [29].

The questionnaires were self-paced, with no time restrictions, and all items were mandatory.

The global-local task

The task was conducted on the PsyToolkit platform and was adapted from a task developed by PsyToolkit creator G. Stoet (https://www.psytoolkit.org/experiment-library/navon.html [30,31]). The stimuli consisted of large letters (6×3 cm) composed of smaller letters, displayed in white on a black background. The size of the stimuli was not adjusted to screen dimensions, in order to keep it constant across different monitors. The participants were instructed to press the "B" key as quickly as possible when the letters H or O (target letters) appeared at either the global (large) or local (small) level and to press the "N" key when neither target letter was present. The target stimuli included the following combinations: Hs, Ht, Ol, Ou, Sh, Th, Lo, and Uo. The non-target stimuli included Ss, St, Tt, Ts, Ll, Lu, Uu, and Ul. All target trials featured incongruent large and small letters, whereas non-target trials included both congruent and incongruent combinations. The task consisted of three blocks of 48 trials each. Each block included 12 stimuli featuring the target letter at the global level (e.g., Hs – global target trial), 12 stimuli featuring the target letter at the local level (e.g., Lo – local target trials), and 24 stimuli containing no target letters (e.g., “St” – non-target incongruent trial; “Ss” – non-target congruent trial), presented in a pseudorandom order. Detecting the target letters at the global level required participants to suppress the letter at the local level, and vice versa.

The inclusion of the congruent trials in the task balanced the percentage of target/non-target trials and provided a baseline condition that allowed us to quantify the incongruency effect independently of the presence of global or local targets. At the beginning of the task, participants first completed a training block of 16 trials to familiarize themselves with it.

Each stimulus remained on the screen until a response was made, with a maximum duration of 3000 ms. As soon as the participant responded, a feedback on their response appeared for 1000 ms: a smile icon for correct answers, a sad icon for incorrect answers, or the word “lento” (slow) if they exceeded the time limit (omitted response). This was followed by a 500 ms blank screen. Therefore, the response-stimulus interval (RSI) lasted 1500 ms. The feedback was displayed on every trial to maintain motivation, given the monotonous nature of the task and the fact that it was self-administered remotely. Between blocks, participants were instructed to rest for approximately two minutes, although the duration of the pauses was self-paced. The average time to complete the entire task was 6.9 minutes (SD = 1.9, range: 6-18).

Both accuracy and response times were recorded throughout the experiment. The task was designed to be performed exclusively on a computer only (not on tablets or smartphones). The participants were instructed to maintain a viewing distance of 50-60 cm from the screen. Fig. 1 provides examples of the stimuli used in the task.

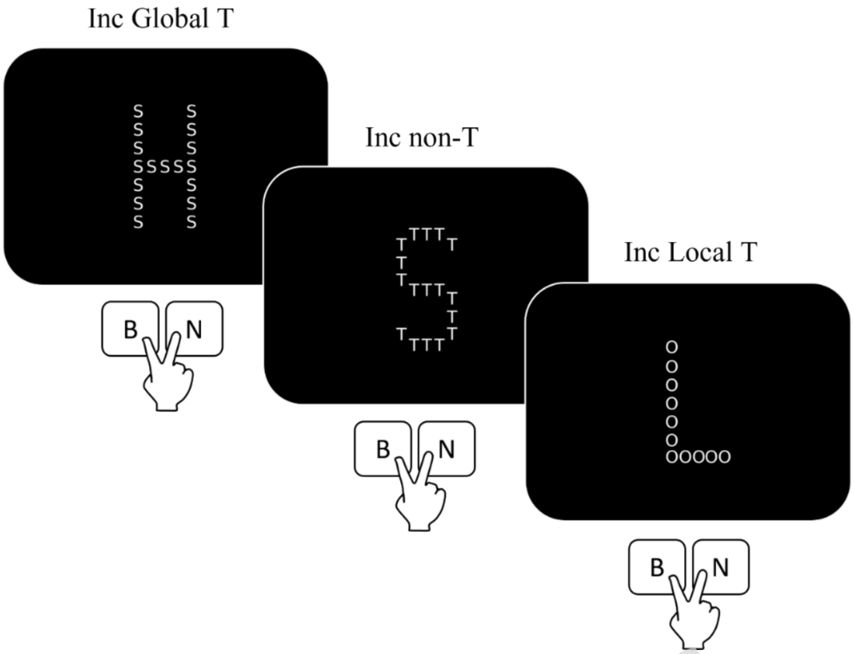

Fig. 1. Schematic representation of some descriptive trials of the global-local task. The participants were required to press the "B" key when the letters H or O, large (incongruent global target trials, Inc Global T) or small (incongruent local target trials, Inc Local T), were present, and the "N" key when the letters H or O were absent (e.g., incongruent non-target trials, Inc non-T). Each stimulus was displayed on the screen for a maximum of 3000 ms or until the button pressed.

Statistical Analyses

The mean total score for each questionnaire and subscale was computed. Task performance was analyzed with a trial-level modeling approach. Specifically, response accuracy was fitted using a generalized linear mixed-effects regression [32], implemented via the *glmer* function (binomial logit function) from the *lme4* R package (http://www.R-project.org [33,34]), as follows (in R notation): Accuracy ~ Trial type + Trial order + (Trial order | ID). The factor Trial type had four levels: congruent non-target, incongruent non-target, incongruent global target, and incongruent local target. Incongruent non-target trials were used as reference level, as target trials share this feature. Trial order (the rank-order number of each trial) was entered as covariate to account for potential learning or fatigue effects over time. The random effects structure included random intercepts and random slopes for Trial order by participant ID (see [35]). This approach allows us to estimate interference effects while accounting for individual variability via random effects.

Response times (RTs) for correct trials were analyzed using a linear mixed-effects regression, implemented via the *lmer* function of the *lme4* R package, as follows: RT ~ Trial type + Trial order + (Trial order | ID). Following Miller's findings [36], no outlier correction was applied. To attenuate the right skewness of the RT distribution analyses were performed on inverse-transformed RTs, calculated as 1000/RT [37] (see Supplementary Figure S1).

To evaluate the effect of the S-Hab-Q, SPQ, and AQ on accuracy and RTs, the total scores from each questionnaire were entered into the mixed-effects models along with an interaction term. For example, Accuracy ~ (Trial type × S-Hab-Q) + Trial order + (Trial order | ID). Each questionnaire was analyzed in separate models to isolate its specific impact on task performance and to prevent multicollinearity and overfitting.

All continuous predictors were centered (using the *scale* function) before being entered into the models to improve convergence. All *p*-values obtained across all models were jointly corrected for multiple comparisons using the Benjamini–Hochberg false discovery rate (FDR) procedure [38].

Data Exclusion and Missing Data

Overall, 14 participants were excluded because more than half of the trials in at least one block were missing, one participant was excluded for submitting multiple entries, and another was excluded for having task accuracy below 60%. For each participant, omitted trials (i.e., trials with no response within the 3000 ms time window) and anticipatory responses (< 150 ms) were excluded from both accuracy and response time analyses (0.38 trials per participant on average, SD = 0.87, range = 0-6).

Results

The association between questionnaire scores and task performance was examined in 143 participants (mean age = 30 years, SD = 12.9, range = 18-65; females = 58.3%).

The mean S-Hab-Q total score was 23.6 (SD = 7.7, range = 6-49); the mean total SPQ score was 56.6 (SD = 11.5, range = 24-92); and the mean total AQ score was 18 (SD = 6, range 3-33). All questionnaire scores showed positive correlations (S-Hab-Q and SPQ: $r = .41$, $p < .001$; S-Hab-Q and AQ: $r = .402$, $p < .001$; SPQ and AQ: $r = .226$, $p = .007$).

The overall mean task accuracy was 96.8% (SD = 17.4, range = 79-100). The mean accuracy for each trial type was as follows: 99% (SD = 9.6, range = 89-100) for the congruent non-target trials; 99% (SD = 9.7, range 82-100) for the incongruent non-target trials; 94% (SD = 23.7, range = 75-100) for the incongruent global target trials; 95.2% (SD = 21.2, range = 69-100) for the incongruent local target trials. The mean RTs for each trial type were as follows: 882 ms (SD = 206) for the congruent non-target trials; 906 ms (SD =

216) for the incongruent non-target trials; 804 ms (SD = 148) for the incongruent global target trials; 809 ms (SD = 150) for the incongruent local target trials. The data distribution is depicted in Fig. 2.

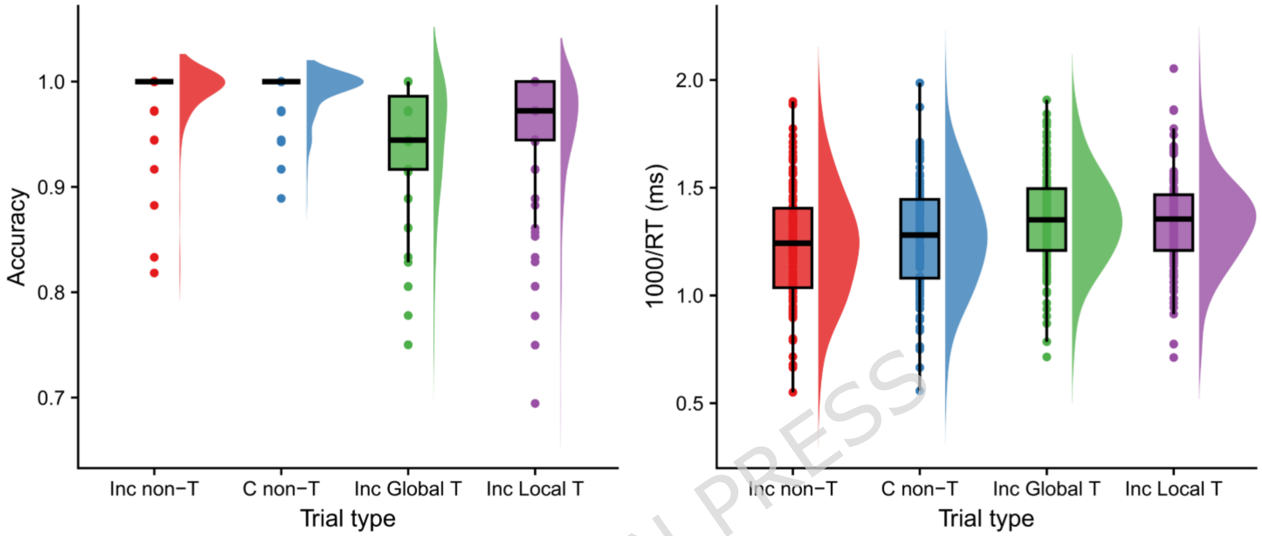

Fig. 2. Task accuracy (left panel) and inverse response times (right panel) for each trial type. Box plots visualize the median and interquartile range; violin plots represent the estimated value distribution. Inc non-T: incongruent non-target trials (reference level in the mixed-effects models); C non-T: incongruent non-target trials; Inc global T: incongruent global target trials; Inc local T: incongruent local target trials. Raw response times were transformed into speed using the formula 1000/RT, so that *higher values indicate faster responses*.

The generalized linear mixed-effects regression showed that accuracy was significantly lower in incongruent global and local target trials compared to incongruent non-target trials (Fig. 2, Supplementary Table S2 and Fig. S2). Furthermore, a significant difference emerged between global and local target trials, with higher accuracy in local trials, when global trials were taken as the reference level (*log*-odds = .25, *SE* = .08, *z* = 2.9, *p* = .004). The linear mixed-effects regression on response times revealed that RTs on incongruent global and local target trials, as well as on congruent non-target trials, were significantly faster than RTs on incongruent non-target trials (Fig. 2, Supplementary Table S3 and Fig. S3).

When questionnaire scores were entered as covariates into the model, a significant interaction effect between S-Hab-Q score and Trial type showed that accuracy in incongruent global target inversely correlated with S-Hab-Q scores (*log*-odds = -.36, *SE* = .16, *z* = -2.25, *p* = .024, FDR-corrected *p* = .043; see Supplementary Table S4 and Fig. S4). Specifically, participants with higher S-Hab-Q scores had greater differences in accuracy between incongruent global target trials and incongruent non-target trials (Fig. 3).

A significant SPQ × Trial type interaction (*log*-odds = -.36, *SE* = .14, *z* = -2.45, *p* = .014, FDR-corrected *p* = .034; see Supplementary Table S5 and Fig. S5) revealed that accuracy in incongruent global target trials inversely correlated with SPQ scores (Fig.3).

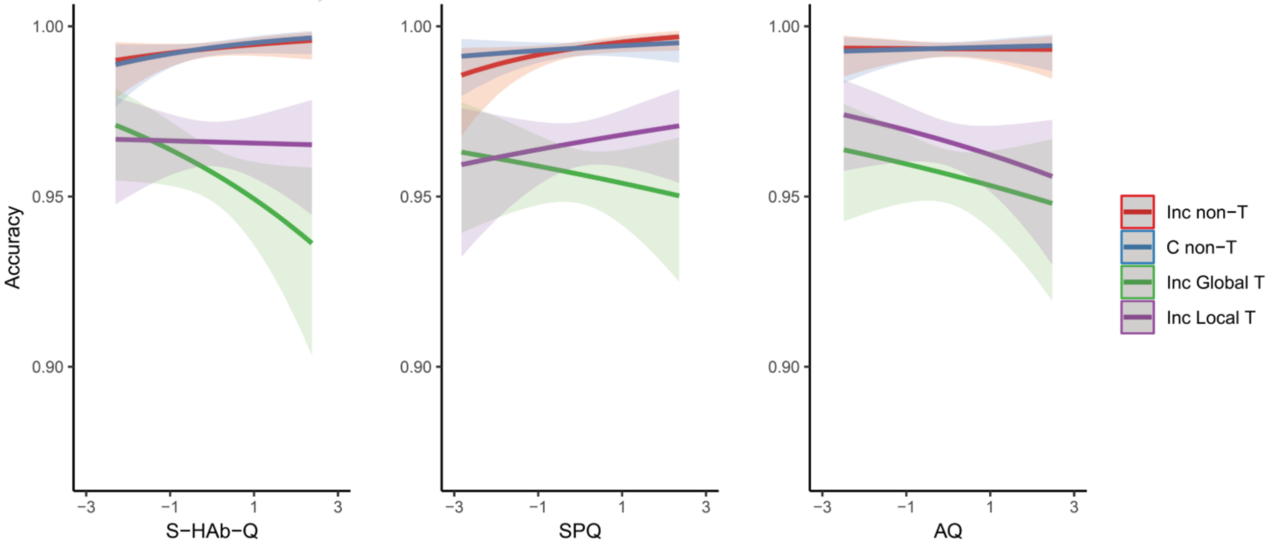

Fig. 3. Left panel: task accuracy values for each trial type predicted by S-Hab-Q scores according to the generalized linear mixed-effects model: Accuracy ~ (Trial type × S-Hab-Q) + Trial order + (Trial order | ID). Central panel: task accuracy values predicted by SPQ scores according to the generalized linear mixed-effects model: Accuracy ~ (Trial type × SPQ) + Trial order + (Trial order | ID). Right panel: task accuracy values for each trial type predicted by the AQ scores according to the generalized linear mixed-effects model: Accuracy ~ (Trial type × AQ) + Trial order + (Trial order | ID). The shaded regions show the 95% confidence intervals around the predicted values. Inc non-T: incongruent non-target trials (reference level in the mixed-effects models); C non-T: congruent non-target trials; Inc global T: incongruent global target trials; Inc local T: incongruent local target trials.

Also, a significant S-Hab-Q × Trial type interaction emerged for RTs on both global (β = -.02, SE = .005, z = -3.01, p = .002, FDR-corrected p = .005) and local (β = -.01, SE = .005, z = -2.27, p = .023, FDR-corrected p = .043) target trials, relative to incongruent non-target trials (see Supplementary Table S7 and Fig. S7). Namely, as S-Hab-Q scores increased, the RT difference between target and non-target incongruent trials was attenuated. As displayed in Fig. 4, this effect mainly reflects a positive correlation between S-Hab-Q scores and inverse RTs on non-target trials. A similar pattern, with a steeper positive slope, was found for the AQ. Namely, the AQ × Trial type interaction revealed that the RT differences between non-target and target trials decreased as AQ scores increased, for both global (β = -.02, SE = .005, z = -3.53, p < .001, FDR-corrected p < .001) and local (β = -.02, SE = .005, z = -3.82, p < .001, FDR-corrected p < .001) trials (Supplementary Table S9 and Fig. S9). As shown in Fig. 4, higher AQ scores were associated with faster RTs in both congruent and incongruent non-target trials.

When RT outliers were trimmed using an a priori criterion (i.e., values falling below Q1 − 1.5 × IQR or above Q3 + 1.5 × IQR, regardless of trial type), without applying an inverse transformation, the effect of the AQ predictor remained significant, while the effect of the S-Hab-Q did not emerge. This pattern likely reflected a reduced variability of the RT distribution following outlier removal.

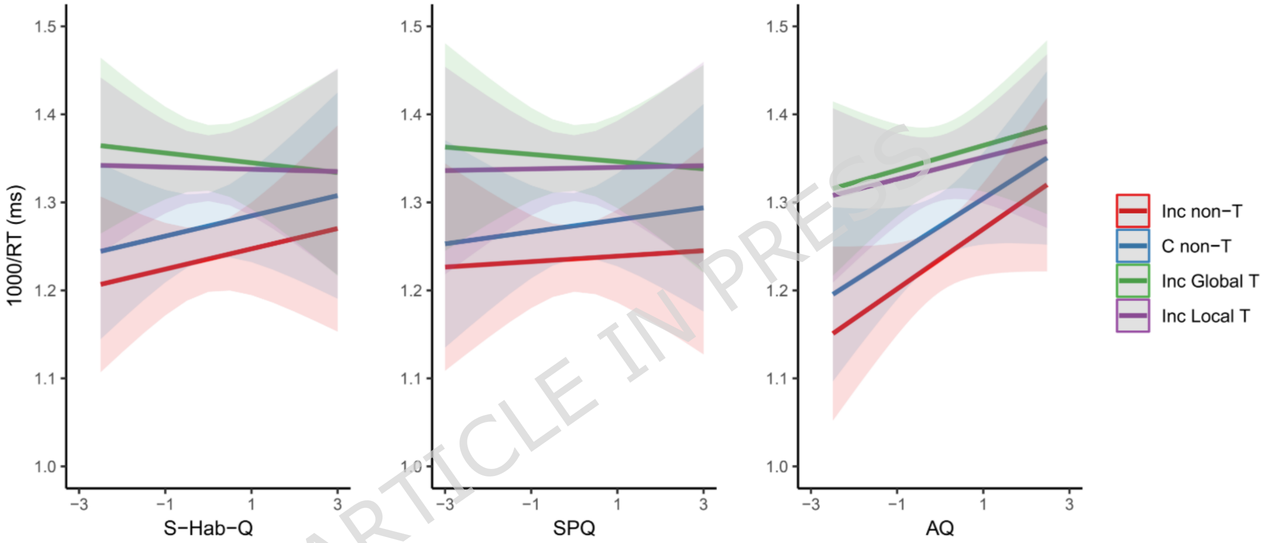

Fig. 4. Left panel: inverse response times for each trial type predicted by S-Hab-Q scores according to the linear mixed-effects model: RT ~ (Trial type × S-Hab-Q) + Trial order + (Trial order | ID). Central panel: RT predicted by SPQ scores according to the linear mixed-effects model: RT ~ (Trial type × SPQ) + Trial order + (Trial order | ID). Right panel: RT for each trial type predicted by AQ scores according to the linear mixed-effects model: RT ~ (Trial type × AQ) + Trial order + (Trial order | ID). The shaded regions show the 95% confidence intervals around the predicted values. Inc non-T: incongruent non-target trials (reference level in the mixed-effects models); C non-T: congruent non-target trials; Inc global T: incongruent global target trials; Inc local T: incongruent local target trials. Raw response times were transformed into speed using the formula 1000/RT, so that *higher values indicate faster responses.*

To investigate which specific AQ subscales were associated with faster RTs, separate models were fitted for each subscale and p-values corrected for multiple comparisons (see Supplementary Tables S10-S14). Significant effects on RTs emerged for the Attention to detail and Communication subscales. Overall, participants with higher Attention to Detail scores exhibited faster RTs ($\beta = .06$, $SE = .018$, $t = 3.19$, $p = .002$, FDR-corrected $p = .003$). A significant Attention to detail × Trial type interaction revealed that the RT differences between non-target and target trials were attenuated as the scores increased, for both global ($\beta = -.01$, $SE = .005$, $t = -2.2$, $p = .027$, FDR-corrected $p = .044$) and local ($\beta = -.02$, $SE = .005$, $t = -3.08$, $p = .002$, FDR-corrected $p = .003$) target trials. Similarly, participants with higher scores on the Communication scale showed faster RTs for non-target trials compared to participants with lower scores (global: $\beta = -.03$, $SE = .005$, $t = -5.42$, $p < .001$, FDR-corrected $p < .001$; local: $\beta = -.02$, $SE = .005$, $t = -4.72$, $p < .001$, FDR-corrected $p < .001$). These results are summarized in Supplementary Figure S10. A comparable pattern was found in the Social Skills subscale, although the effect only approached statistical significance (global: $\beta = -.01$, $SE = .005$, $t = -2.07$ $p = .038$, FDR-corrected $p = .057$; local: $\beta = -.01$, $SE = .005$, $t = -2.14$, $p = .033$, FDR-corrected $p = .05$).

No significant main effects or interactions were observed when examining the contribution of AQ scores to task accuracy (Supplementary Table S6 and Fig. S6) or the contribution of SPQ scores to task RTs (Supplementary Tables S8 and Fig. S8).

To examine the detectability of effects given the study design, and given that our primary hypothesis concerned the interaction between S-Hab-Q scores and Trial type, we conducted a post-hoc sensitivity analysis targeting this specific interaction effect. Power was estimated via 1000 Monte Carlo simulations using the *simr* package in R [39], which generated simulated datasets based on the fitted generalized linear mixed-effects model. Results indicated that, given the observed sample size, the estimated interaction effect (log-odds = -0.36) corresponded to approximately 70% power. To achieve a conventional power level of 80%, an interaction effect of approximately log-odds = -0.43 would have been required.

Discussion

The study aimed to explore the association between individual sensory habituation in everyday contexts and attentional control abilities. To this end, we tested 143 healthy adults using a self-report questionnaire (the S-Hab-Q), which assesses the time required to habituate to environmental stimulation across multiple sensory modalities, including visual, auditory, tactile, olfactory, gustatory, and proprioceptive domains. We examined the association between questionnaire scores and performance on an interference control task. To our knowledge, this is the first study to investigate how sensory habituation in daily life, as measured by a self-report questionnaire, influences attentional abilities. The findings revealed a negative association between S-Hab-Q scores and response accuracy in incongruent global target trials. Specifically, participants who generally needed more time to habituate to external stimuli showed reduced accuracy in trials requiring them to inhibit a non-target letter at the local level in favor of detecting a target at the global level. This result reflects a decreased global precedence effect, which predicts that global features are favored over local features [40]. Crucially, it supports the presence of a link between habituation processes and attention control processes [20], and suggests that individuals who report difficulties adapting to repeated or continuous environmental stimuli may have difficulties with cognitive tasks that demand the suppression of an irrelevant stimulus dimension in favor of another. This link could reflect the shared involvement of prefrontal circuits, which play pivotal roles in modulating both sensory habituation and interference control processes, as discussed in the Introduction [6].

The inverse association between habituation scores and task accuracy observed for incongruent trials with a global, rather than local, target may reflect the fact that, in our task, accuracy on global trials was overall lower than accuracy on local trials (see also Fig. 2, left panel). This effect may likely be linked to the large size of the global letters, which favored the processing of local features [41,42]. Importantly, the higher level of difficulty for global trials may have amplified the individual variability captured by the questionnaire.

Given that previous research has established that sensory habituation is linked to sensory sensitivity (the ability to regulate the intensity of perceptual responses to external or internal stimuli to match environmental demands) and autistic traits (e.g., [23]), we also examined these factors in relation to task performance. Similarly to the findings on habituation, participants with higher SPQ scores, indicating hypersensitivity to everyday stimuli, also performed worse on trials requiring the detection of the target at the global level when local information had to be ignored. The positive correlation between S-Hab-Q and SPQ scores further confirms that difficulties with sensory habituation and heightened sensory sensitivity are closely associated and that both impact attention control. Specifically, individuals with difficulties in adapting to continuous sensory input or who are highly sensitive to everyday stimulation find it more challenging to detect targets when irrelevant features must be suppressed.

Moreover, we observed that individuals who reported slower habituation rates or higher autistic traits were faster in responding on non-target trials compared to participants with lower scores (see Fig. 4). Typically, RTs to non-target (i.e., target-absent) trials are higher on average than RTs to target (i.e., target-present) trials because they require longer visual search processing and show greater inter-individual variability [43] (but see [44] for further discussion). In line with this, we found slower RTs on non-target trials, particularly for incongruent trials. The faster RTs on non-target trials observed among participants with higher S-Hab-Q or AQ scores suggest that they had an advantage in visual search under low-conflict conditions. Indeed, non-target trials did not require coping with conflict between two stimulus dimensions (i.e., the global and local levels) and suppressing one of the two. This finding is consistent with previous studies showing that autistic individuals may excel in tasks involving perceptually driven, focused attention, while exhibiting difficulties in those demanding flexible attentional shifts [45]. Furthermore, it extends the existing literature by showing that individuals who struggle to adapt to repeated or continuous irrelevant stimulation in everyday life experience difficulties in cognitive tasks requiring greater attentional control, as shown by lower accuracy for global target trials, while outperforming under low-conflict conditions, as shown by the faster responses to non-target trials.

Notably, the subscales driving the correlation between task RTs and AQ scores were Attention to Detail and Communication. This result reveals that, among the autistic traits, the tendency toward a more focused examination of stimuli is linked to a better perceptual discrimination, especially for stimuli requiring minimal shifting of selective attention, in line with the Enhanced Perceptual Functioning model proposed by Mottron et al. [46]. Similarly, lower Communication skills were linked to an advantage in visual search under low-conflict conditions. Since this scale specifically investigates pragmatic behaviors, such as difficulties in adapting conversations to relevant contextual information, this finding may reflect previous evidence showing that pragmatic skills in autistic individuals are tightly tied to executive function skills, such as cognitive flexibility and inhibitory control, regardless of their mentalizing abilities [47]. We did not find an association between task performance and the Attention Switching subscale, as might have been expected given the task requirements and the name of the scale. This null result could be due to the fact that the scale assesses the presence of repetitive behaviors, restricted interests, and insistence on sameness, and that these behaviors may not be directly related to the perceptual and/or attentional processing assessed by the task, although this hypothesis warrants further investigation.

While the findings are compelling, several limitations of the study need to be considered. First, the online modality of administration prevents control over experimental settings and procedural variables (e.g., viewing distance, duration of breaks), which may have influenced the variability of absolute RTs. Second, the use of questionnaires to assess sensory habituation and sensory sensitivity, while informative with respect to everyday experience, relies on subjective self-reports and lacks objective measures. Third, although our investigation was intended to be exploratory in nature, the sensitivity analysis indicated that smaller interaction effects between the habituation questionnaire and task accuracy may not have been detectable with the present sample size. Therefore, null findings should be interpreted with caution, and future studies would require either larger samples or study designs optimized for the detection of smaller interaction effects.

Regarding the task, two additional points should be noted. The task contains more incongruent than congruent trials, and this imbalance might have created bias in expectations and habituation to interfering conditions [48]. Therefore, future studies should control for this variable. An important concern relates to the applicability of cognitive tasks, such as the Navon paradigm, for capturing individual differences. Indeed, while the reliability of cognitive tasks used in the psychological literature is typically based on low intra- and inter-individual variability in performance, correlational studies primarily aim to capture individual differences. Interestingly, Hedge et al. (2018) quantified the ability of classical cognitive tasks to rank individual differences using the Intraclass Correlation Coefficient (ICC) [49]. Their results showed that measures such as error rates and RTs on incongruent global and local Navon trials exhibited relatively high ICC values (0.68-0.80). We may rely on this study to support our findings, although we cannot rule out the possibility that the ICC associated with our task measures could have affected them.

Overall, this study suggests that an individual’s sensory habituation profile, specifically, the self-reported time of adaptation to repeated or continuous environmental stimuli, is linked to individual attentional control abilities, particularly the ability to suppress irrelevant stimulus features in interference trials. These results are consistent with those of prior studies highlighting the role of prefrontal areas in mediating both sensory habituation and interference control [12,13]. This association is relevant when considering that sensory habituation may mediate the influence of sensory sensitivity on autistic traits [28]. Furthermore, the results have broader implications for understanding how habituation contributes to the creation of predictive models. Indeed, the predictability of a sequence of events is proportional to the extent of habituation it induces [50]. Finally, this study suggests that incorporating the assessment of sensory habituation along with sensory sensitivity may provide better insight into the mechanisms underlying neurodiverse profiles characterized by sensory atypicalities. Although the present findings were obtained from a non-clinical sample and cannot be directly translated to clinical populations, they nonetheless suggest that individuals who experience sensory overwhelm may face social difficulties and maladaptive behaviors. Future clinical research should elucidate the directionality of this interplay and clarify how these processes may modulate each other.

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Authors' contributions

P.T., V.T., L.M., and M.O. conceived and designed the study. A.S. and L.M. collected and managed the data. V.T. performed the data analysis. V.T., P.T., L.M., M.O., and G.M. interpreted the results. V.T. wrote the original draft. A.S. and G.M. contributed to the literature review. All authors critically revised the manuscript and approved the final version.

Data availability

The dataset of this article is available in the OSF repository, https://osf.io/sgyx2/?view_only=21c6971b1a254263b6048352434bb20e

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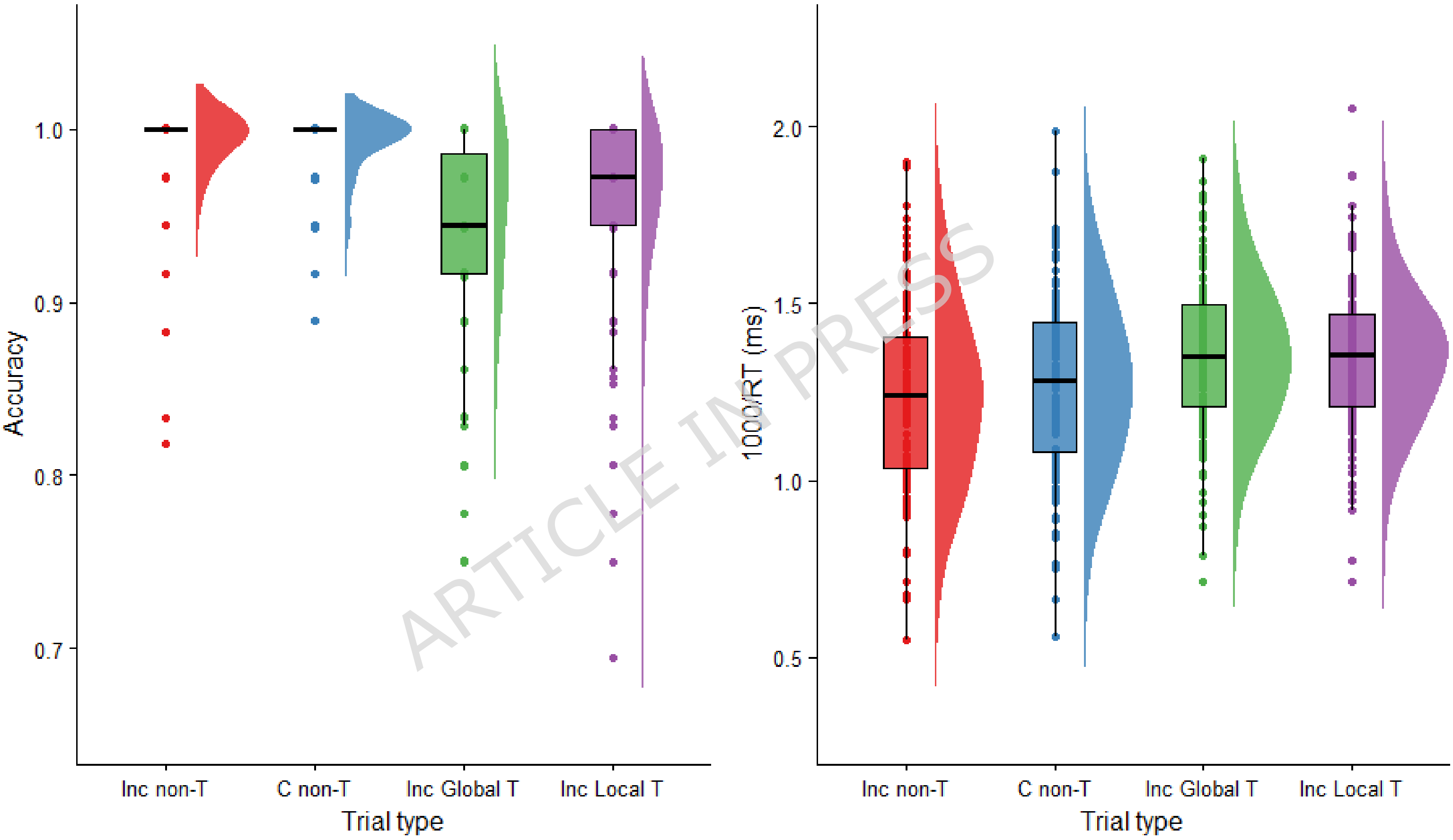
Competing interests

The author declare no competing interests.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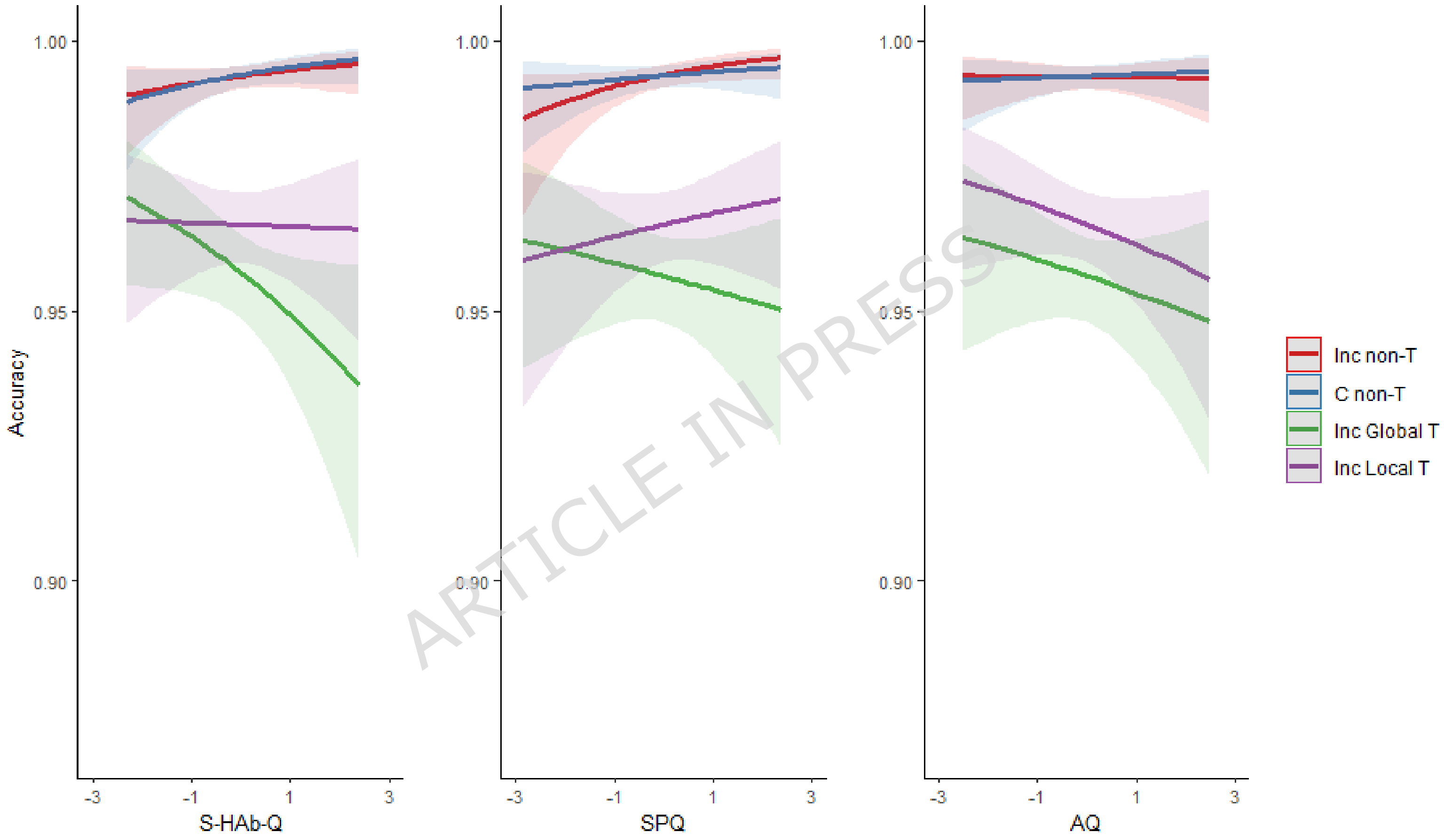
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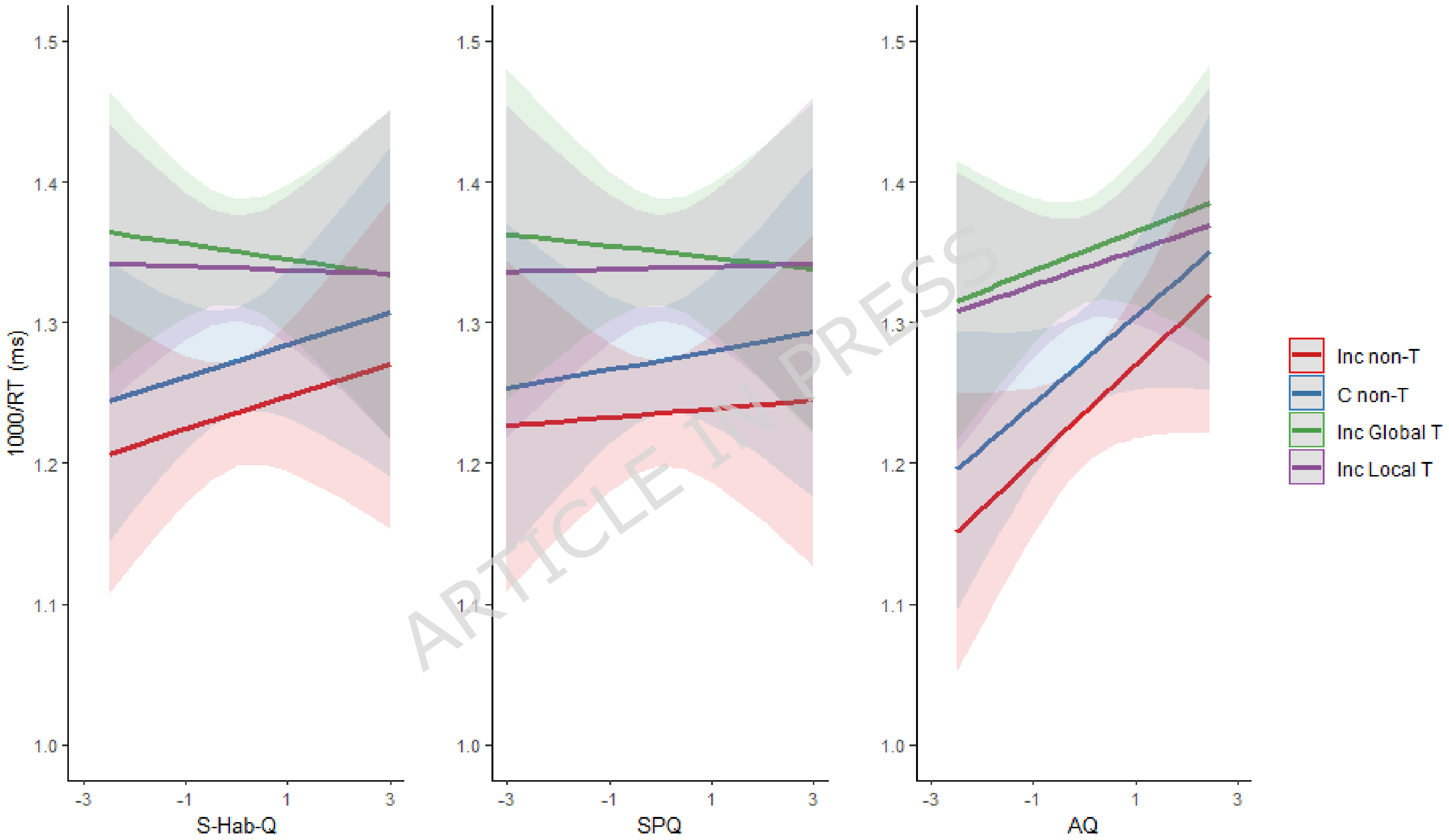
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