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Introspection during short-term memory scanning

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Abstract

The literature in metacognition has argued for many years that introspective access to our own mental content is restricted to the cognitive *states* associated with the response to a task, such as the level of confidence in a decision or the estimation of the response time; however, the cognitive *processes* that underlie such states were deemed inaccessible to participants' consciousness. Here, we ask whether participants could introspectively distinguish the cognitive processes that underlie two short-term memory tasks. For this purpose, we asked participants, on a trial-by-trial basis, to report the number of items that they mentally scanned during their short-term memory retrieval, which we have named "subjective number of scanned items." The subjective number of scanned items index was evaluated, in Experiment 1, immediately after a judgment of recency task and, in Experiment 2, after an item recognition task. Finally, in Experiment 3, both tasks were randomly mixed. The results showed that participants' introspection successfully accessed the complexity of the decisional processes.

Keywords

Introspection; memory scanning; cognitive processes; metacognition; short-term memory

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Introduction

The reliability of introspection, that is the ability to monitor the content of our own mental activity, has been much discussed within experimental psychology (Costall, 2006; Lyons, 1986). Many psychologists (Overgaard & Sandberg, 2012) and philosophers (Carruthers, 2010) accept the idea that individuals introspectively access only mental states with low cognitive complexity (e.g., perceptual states). In contrast, information of high cognitive complexity would be inaccessible to individuals' consciousness. Formally, this pessimistic view on introspection was stated in the seminal publication of Nisbett and Wilson (1977). These authors suggested that introspective access is restricted to perceptual contents (i.e., cognitive states). In contrast, the underlying sensory transformations that precede the conscious decision (i.e., cognitive processes) were deemed inaccessible to introspection. In addition, Nisbett and Wilson claimed that when participants try to introspect on processes, they make use of a priori theories about the causal relationship between stimulus and response. Although this theory was originally proposed in the field of social psychology, its logic is applicable to other domains (e.g., Johansson, Hall, Sikström, & Olsson, 2005). For instance, with respect to perceptual decisions, participants might access their confidence (Fleming, Weil, Nagy, Dolan, & Rees, 2010; Pleskac & Busemeyer, 2010) and the overall decision duration (Corallo, Sackur, Dehaene, & Sigman, 2008; Marti, Sackur, Sigman, & Dehaene, 2010; Miller,

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Vieweg, Kruize, & McLea, 2010), but not the properties of the process itself (i.e., the set of cognitive operations that precedes the perceptual decision).[1] In perspective, according to Nisbett and Wilson's theory, although cognitive states may in some context be introspectively accessed, cognitive processes are by and large inaccessible, producing only confabulatory introspective reports (Kozuch & Nichols, 2011).

Despite substantial and early objections (Ericsson & Simon, 1980; Smith & Miller, 1978; White, 1980, 1987, 1988) and recent reformulations (Wilson, 2002, 2003; Wilson & Dunn, 2004), this idea is often viewed as a canon in the literature (Overgaard, 2006; Overgaard & Sandberg, 2012). Contrary to this, we showed (Reyes & Sackur, 2014, 2017) that introspection is highly flexible, in the sense that it can combine *self-observation* and *mental monitoring*, to the effect that it can ultimately target cognitive processes. We reached this conclusion based on evidence that, in a visual search paradigm, participants introspectively differentiate attentionally guided and non-guided searches, which are features of the cognitive search process. Here, we tested whether this conclusion could generalise to other kinds of processes and modalities. We asked whether short-term memory recovery processes were accessible through introspection. Clearly, metacognition, in the form of confidence ratings, is a strong predictor of how successful individuals will be in recovering their representations from short-term memory (Rademaker, Tredway, & Tong, 2012; Vandenbroucke et al., 2014), a result that is at the core of the entire field of meta-memory research (Dunlosky & Bjork, 2008). However, this does not speak to whether or not there is introspective access to the processes that precede and guide the recovery of information.

To assess whether individuals can introspectively access memory search processes, we designed two short-term memory tasks that differed in the complexity of the retrieval process, but were nearly identical with respect to the stimuli and experimental design. The literature converges on the idea that the nature of the information required to perform a memory task determines the complexity of the recovery operation deployed (Chan, Ross, Earle, & Caplan, 2009; Dosher, 2003; Jonides et al., 2008; McElree, 2006). For instance, when short lists of items are memorised, tasks that require participants to recover the simple identity of an item (Sternberg, 1966, 1969) necessitate direct access to this information (McElree, 2001; McElree & Dosher, 1989, but see Sternberg, 2016): participants have parallel access to all items stored in short-term memory. In contrast, with the same material, memory recovery tasks of relational information (the order of presentation: Hacker, 1980; Muter, 1979) require a serial and ordered access to the set of representations in memory (McElree & Dosher, 1993). In summary, depending on the instructions, two types of cognitive processes take place. Now, knowledge of these differences comes from the classic, objective, third-person perspective of experimental cognitive psychology. Here, we ask whether participants have access to the difference of the processes involved from a first-person perspective.

In Experiment 1, we engaged participants in a judgment of recency (JOR) task. Immediately after the presentation of a list of six consonants, participants were required to determine (in a two-alternative forced-choice procedure [2AFC]) which of two letters was closer to the end of the list. The letter closer to the end of the list was considered the target and the other the distractor. Earlier studies with the JOR task (Hacker, 1980; Muter, 1979) showed that response times (RTs) increase linearly as a function of the position of the target: the closer to the end of the list, the faster the response, independent of the distractor position. This effect suggests a serial and self-terminating recovery mechanism (McElree & Dosher, 1993). In Experiment 2, we asked participants to perform an item recognition (IR) task, similar to the Sternberg rapid scanning task (Sternberg, 1966). Immediately after the presentation of a list of consonants, participants were asked to determine with a 2AFC which of the two letters was present in the list presented beforehand. In contrast to the JOR task, here only one consonant was previously presented in the list. Sternberg (1969) showed that the time it takes to decide on the presence of the target varies linearly as a function of the number of items presented. In addition, Sternberg observed that this slope was identical in target present and absent trials. This pattern was at first interpreted as evidence for a serial exhaustive scanning process; however, McElree and Dosher (1989) suggest that a direct access mechanism better explains the recovery mechanism. They showed that if we examine each set size separately, accessibility of the information (i.e., both the amount of information necessary to correctly identify the target and the speed of recovery) remained constant for each target position in the list of items. The notable exception to this finding was that the last position had higher recovery rate than the rest (McElree, 2006; Wickelgren, Corbett, & Dosher, 1980). With this exception in mind, the consensus (but see Sternberg, 2016) is now that in IR tasks, the recovery process accesses information in parallel, albeit in a way that mimics (Townsend & Wenger, 2004) a serial exhaustive process. Disregarding the intricacies of the debate over the best model in each task, the literature establishes that information recovery mechanisms are qualitatively different in the JOR and IR tasks.

Our aim here was to investigate participants' introspection of these mechanisms. To this end, in each task and on a trial-by-trial basis, we asked participants to report the number of items scanned during the memory recovery process. We called this index "subjective number of scanned items" (henceforth SNSI; Reyes & Sackur, 2014, 2017). Through this introspective question, we assessed whether

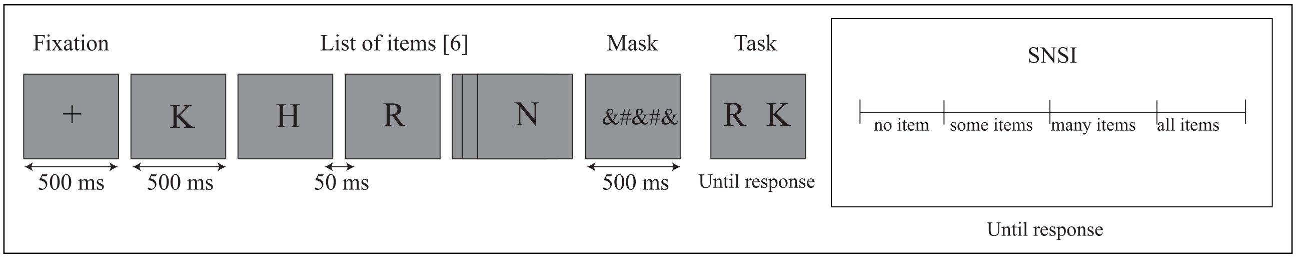

Figure 1. General structure of the JOR task. After the fixation cross, a list of six consonants and a concluding mask were presented. The task consisted of determining which of the two letters probe letters was the last in the list (e.g., in the figure, the target is the letter "R," presented in third position and accompanied by the distractor "K," presented in the first position). After this decision, participants gave, without time constraints, the subjective estimation of the number of items scanned in memory *before* identifying the target (SNSI). Labels were presented on the scale, but participants were instructed to use all the positions.

individuals are able to distinguish the type of mental operations that underlie two kinds of information retrieval from memory. In other words, through the SNSI, we operationalised the question of the limits of the introspective access to memory retrieval processes. Our prediction was that if participants were able to introspectively access their memory retrieval processes, then the two tasks should lead to dissimilar results on the SNSI: In the JOR task, we expected that SNSI would vary as a function of target position, as participants would consciously and subjectively access the serial memory scanning process. In the IR task, we expected that SNSI would only vary as a function of the global memory load. In other words, we expected SNSI to vary with respect to the list length but not as a function of target position within each list, as no actual scanning process takes place. We expect that this difference would be specific to introspection (SNSI), and not a generic property of the two tasks, that would also manifest itself in the first-order performance.

Experiment 1

Material and methods

Participants. A total of 18 normal adults, French speakers (11 women), aged between 19 and 30 years (mean age: 23 years, standard deviation [*SD*]: 3.06) participated in the study. In all the experiments, informed consent was obtained before the experimental session and participants received compensation of €10 for a 1-hr session.

Stimuli and procedure. Stimuli consisted of black consonants (size: 0.8° × 0.6°; luminance: 0.5 cd/m^2) on a uniform grey background (luminance: 44.1 cd/m^2). Stimuli were presented on a CRT screen (size 17″, resolution of 1,024 × 768 pixels, refresh rate of 100 Hz, viewing distance of ~55 cm). The experiment took place in a dark room with the monitor as the only source of light.

A trial (Figure 1) consisted of a fixation cross (500 ms) followed by a list of six letters each, presented for 500 ms with an inter-stimulus interval of 50 ms. Stimuli were drawn randomly without replacement from the set of consonants except "X." After the last letter, a mask (random string of five symbols) was presented for 500 ms. The aim was to avoid a simple match between the last letter presented and the two probe letters, which were presented to the left and right of fixation (separated by 2°), until participants' response. The two letters were drawn from the list, and participants were instructed to decide which one was closer to the end of the list. All 15 target and distractor positions combinations were tested, and the position of the target in the 2AFC task was counterbalanced across trials. To respond, participants used the "A" and "Z" keys on a standard French AZERTY keyboard, corresponding, respectively, to the left and right probe letter. Immediately after this first-order decision, a visual analog scale appeared on the screen with the introspective question: *how many consonants did you scan before you reached your decision?* This SNSI scale had four labels (in French): "no item," "some items," "many items," and "all items," but we recorded the exact position of the cursor on the scale, and participants were instructed to use the entire scale. Participants were instructed to avoid fast and automatic responses. Two training sessions preceded the main experimental blocks. During the first training session of 30 trials, the JOR task was presented without the SNSI scale, but with audio feedback on correct and incorrect responses. This phase was repeated until participants reached a criterion of 90% correct. The second training session of 30 trials introduced the SNSI scale and participants proceeded to the main experimental block without performance criterion. The experimental session, without audio feedback, contained 240 trials in eight blocks (16 repetitions × 15 target/distractor combination) with a 60-s pause between each block.

Results

First-order task. All statistical analyses were performed using SPSS V. 22. We removed trials below 100 ms and above 6,000 ms (corresponding to trials 2 *SD* slower than the mean, a traditional and conservative outlier rejection

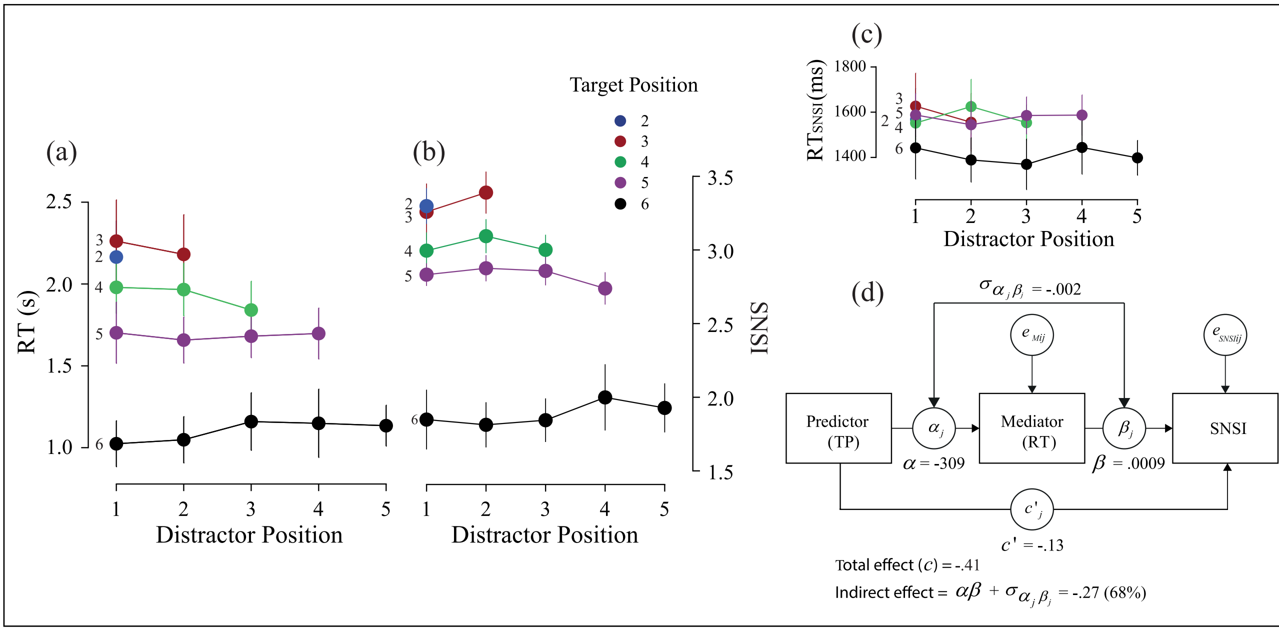

Figure 2. (a) Response time (RT) as a function of distractor and target positions. Here and in the following figures, the numbers in or near data points indicate the position of the target. Error bars, here and in the next figures, represent Cousineau–Morey within-subjects 95% confidence intervals (Cousineau, 2005; Morey, 2008). (b) subjective number of scanned items (SNSI) and (c) RT_{SNSI} as a function of the same factors. (d) Mediation model: In the figure, boxes indicate variables tested (target position [TP], RT, and SNSI), circles represent random effects for each regression (α_j , β_j , and c'_j) and under these, the associated averaged effects. Every path shows a circle for the residuals of each regression.

scheme). This range excluded 2.1% of the data (RTs min.: 276 ms; RTs max.: 5,996 ms). RTs were then log-transformed to normalise the distribution. All our analyses are based on linear mixed models (LMM), with a participant intercept and slope of distractor position as random effect. First, we ran an LMM on the RTs, with fixed effects of target position (from two to six), distractor position (from one to five), and their interaction. Results showed faster RTs for trials near the end of the list ($F(3, 223.8) = 21.43$, $p < .001$); however, there were no significant effects of distractor position ($p > .38$), and we found no interaction between these factors ($p > .40$; Figure 2a). So as to take into account simultaneously accuracy scores and RTs, we repeated this analysis on the inverse efficiency score (IES; Townsend & Ashby, 1983; see also Austen & Enns, 2003; Bruyer & Brysbaert, 2011), which is the ratio of median RTs over the proportion of correct responses for each participant and experimental condition; thus, lower values indicate better performance. The IES is here meaningful given that RTs and error rates were correlated across conditions ($r(269) = .21$, $\beta = -0.1191$, standard error [SE] = 328, $p < .001$; mean error rate for each target position—sixth: 5%, fifth: 11%, fourth: 18%, third: 28%, and second: 30%). Again, performances were higher for targets near the end of the list, regardless of distractor position: the LMM on the IES showed a significant main effect of target position ($F(3, 244) = 17.21$, $p < .001$; by considering sixth position as reference—fifth: $t(244) = 3.49$, $p < .01$; fourth: $t(244) = 4.94$, $p < .001$; third: $t(244) = 6.20$, $p < .001$; and second: $t(244) = 11.49$, $p < .001$), with no main effect of distractor position ($p > .96$) and no interaction ($p > .97$).

Second-order task. Second-order results paralleled first-order results (Figure 2b): participants reported that they subjectively scanned fewer items when the target was closer to end of the list. Introspection was not affected by the distractor position. We statistically tested this effect with an LMM on the SNSI with the same fixed and random factors as before. We found a significant main effect for the target position ($F(3, 232.0) = 13.85$, $p < .001$; sixth position as reference—fifth: $t(232.0) = 5.14$, $p < .001$; fourth: $t(232.0) = 4.98$, $p < .001$; third: $t(232.0) = 3.83$, $p < .001$; and second: $t(232.0) = 8.98$, $p < .001$), with no effect of the distractor position ($p > .41$) and no interaction ($p > .67$). Visual inspection of the results showed that introspection for the last target position presented a large decrease compared to other positions. However, when we repeated the above analysis excluding the sixth position, we still found a main effect of target position ($F(3, 146.8) = 9.79$, $p < .001$).

A possible interpretation of these results is that participants responded to the SNSI by mentally rehearsing the sequence of letters and then simply counted the number of letters between the target and the end of the list. Participants would then essentially do the same task twice. We reasoned that if this were the case, the time taken by participants to do the SNSI task would present a similar pattern as first-order RTs. However, the same LMM on the median RT for the SNSI task (RT_{SNSI}; Figure 2c) showed that none of these main effects were significant (target position: $p>.11$; distractor position: $p>.69$) nor the interaction term ($p>.98$). In addition, median RT_{SNSI} and median first-order RTs were not significantly correlated ($p>.27$). In summary, participants did not appear to perform the first-order task a second time when asked to report their introspection: they seemed to report a value that they read out from the first-order process.

It is still possible that participants did not base their introspective reports only on internal information generated during the memory scanning process. They might have also used self-observation of their own behaviour, or other internal dimension of the process, such as felt difficulty (Bryce & Bratzke, 2014). In this experiment, we only had access to RTs as an aggregate measure of these other behavioural parameters. Thus, so as to form a conservative estimate of the weight of mental monitoring in SNSI reports, we tested a multilevel mediation model on correct trials (Bauer, Preacher, & Gil, 2006; Figure 2d),[2] testing the potential mediating role of RTs in the formation of SNSI. In line with the previous analysis, we found a significant main effect of the target position on SNSI ($F(1, 16.57)=35.23$, $c=-0.41$, $p<.001$). We also confirmed that the same factor affected RTs ($F(1, 16.69)=53.15$, $\alpha=-309.3$, $p<.001$). In addition, controlling the target position main effect on SNSI, RTs presented a significant relationship with SNSI ($F(1, 15.38)=43.15$, $\beta=0.001$, $p<.001$), which is required for RTs to be considered as a potential mediator. Finally, we estimated the mediation model: after controlling the RT effect on SNSI, we found that the impact of the target position factor on SNSI was significantly reduced but not eliminated ($F(1, 22.1)=5.96$, $c'=-0.13$, $p<.05$), suggesting a partial mediation of SNSI by RTs. The size of the indirect effect ($\alpha\beta$) was −0.27 ($p<.001$, 95% confidence interval [CI=−0.47, −0.12]), which indicates that 68% of the target position effect on SNSI was mediated by RTs.

Discussion

In Experiment 1, we used a JOR task as a test bed. It has been shown that this task generates serial and self-terminating recovery processes (Chan et al., 2009; Hacker, 1980; Muter, 1979). Immediately afterward, we asked participants to report on a trial-by-trial basis how many items they had scanned during the recovery process. We considered this introspective variable (SNSI) as an index of subjective access to the complexity of the memory recovery process. Results on the first-order task agree with the literature: performance increased as targets were closer to the end of the list, without any effect of the distractor position. This pattern is consistent with a serial self-terminating process (McElree, 2006; McElree & Dosher, 1993). Results from the second-order task were strikingly similar, as SNSI decreased the later the targets appeared in the lists. Thus, it seems that participants were subjectively aware of the serial scanning process involved in the JOR task. We took a number of steps to strengthen the interpretation of the SNSI index. First, we wanted to make sure that, when asked to tell how many items they scanned, participants were not simply rehearsing the list. We reasoned that if participants had been implementing this strategy, RTs for the second-order task would positively correlate with the RTs in the first-order task. Even more stringently, we reasoned that if participants had used that, or any other rehearsing strategy, it should show as an effect of target position on RTs for the second-order task. Both analyses yielded null results, suggesting that when participants performed the SNSI task, they did not operate on the first-order stimulus or its re-representation. It seems more parsimonious to suppose that the SNSI is generated from a read-out of the internal signal produced during the first-order process.

Second, we made sure, by means of a mediation model, that results on the SNSI cannot be trivially explained by self-observation of behaviour: the relation of target position on SNSI is only *partially* mediated by RTs, meaning that participants' introspection cannot be explained *in total* by self-observation of their own motor behaviour during the first-order task. We insist that the results of the mediation model should essentially be interpreted negatively. Even in the case of a partial mediation between the RTs and the SNSIs, we do not have any evidence that such covariance is the result of a causal relationship between these variables. Indeed, it is plausible that both variables correlate simply because both are affected by the same experimental control. The only thing we can prove with certainty is that both measures are not fully identified and therefore that there is some degree of independence regarding their variabilities. In summary, the presence of a significant direct effect (32%) suggests that at least *part* of the SNSI derives from mental monitoring rather than self-observation of RTs.

In conclusion, analyses of first-order results and introspection concur in suggesting that recovery of relational information in the JOR task was achieved through an introspectively accessible scanning mechanism. Now, in Experiment 2, we tried to shift the memory process from a serial scanning mode to a direct parallel access mode while keeping the stimuli as close as possible to those of the JOR task.

Experiment 2

Material and methods

Participants. A total of 22 normal adults, French speakers (12 women), aged between 20 and 28 years (mean age: 22 years, *SD*: 2.01) participated in the study.

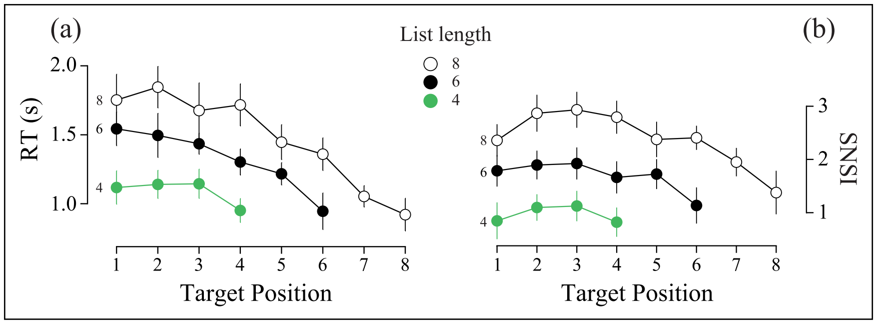

Figure 3. (a) Response time (RT) as a function of the list length and target position and (b) SNSI as a function of the same factors.

Stimuli and procedure. The stimuli do not differ from those of Experiment 1, except that we used three list lengths (4, 6, and 8). Here, participants were asked to decide which of the two letters was present in a list of consonants. Only one of these two letters was randomly selected from the list, the other letter was a consonant absent from the list. The experiment session contained 240 trials in eight blocks. In total, 10 repetitions of three list lengths (4, 6, or 8 consonants) were randomly intermixed in each block. Immediately after the first-order decision, participants responded on the SNSI scale, with exactly the same instructions as in Experiment 1. The other aspects of the stimuli, procedure, and training phases did not differ from those of Experiment 1.

Results

First-order task. To maintain homogeneity with the previous experiment, we used the same criteria for the removal of outliers (below 100 ms and above 6,000 ms), thus excluding 2.4% of the trials (RTs min.: 225 ms; RTs max.: 5,982 ms). RTs were then log-transformed. First, we analysed RTs through an LMM on RTs with fixed effects of list length (4, 6, and 8 items), target position within the list, and their interaction. As a random effect, we considered participants intercepts and target position slopes. Results indicated faster RTs for shorter list lengths (list length main effect: $F(2, 350.7)=30.9$, $p<.001$) and also faster RTs for targets closer to the end of the list (target position main effect: $F(1, 65.15)=78.1$, $p<.001$), without interaction between these effects ($p>.20$; Figure 3a). Second, as in the previous experiment, median RTs and mean error rates were significantly correlated across conditions ($r(431)=.28$, $\beta=1{,}334.9$, $SE=220$, $p<.001$; mean error rate for each list length—eight consonants: 14%; six consonants: 9%; and four consonants: 7%); therefore, they were transformed into IES. We next ran a similar LMM on IES. We observed analogous results: performances increased with shorter list lengths and with targets closer to the end of the list. We found a significant main effect for list length ($F(2, 403.2)=17.3$, $p<.001$) and for target position ($F(1, 403.5)=14.7$, $p<.001$) without interaction ($p>.12$).

Second-order task. The results of the introspective task (SNSI) seem to be similar to those found in the first-order task (Figure 3b): the number of scanned items increased as a function of list length and decreased within each list as a function of target position, except for lists of four items. However, the target position effect on the SNSI disappears by controlling the last items for lists of four and six items, but not eight items. Again, we quantified these results by means of an LMM on mean SNSI, with fixed factors of list length (4, 6, and 8), target position within the list and their interaction. We included a random participant intercept and a random target position slope. We found a significant main effect for list length ($F(2, 380.5)=63.2$, $p<.001$), a main effect for target position ($F(1, 46.1)=7.72$, $p<.01$), with an interaction ($F(2, 380.5)=3.08$, $p<.05$: four consonants [$p>.90$], six consonants [$F(1, 34.8)=12.7$, $\beta=-0.12$, $p<.01$], eight consonants [$F(1, 30.6)=20.9$, $\beta=-0.16$, $p<.001$]). None of these main effects (list length: $F(1, 19.5)=60.1$, $p<.001$; target position: $F(1, 28.7)=13.0$, $p<.01$) nor the interaction effect ($F(1, 367.6)=60.8$, $p<.001$) disappeared after controlling RTs. Second, we repeated this analysis without the last target position at each list length level. We still found that the list length factor had a significant impact on SNSI ($F(2, 310.9)=55.9$, $p<.001$). This effect was not simply explained by self-observation of RTs.[3] Interestingly, in line with our hypothesis, the target position factor was no longer significant ($p>.99$). However, the interaction between these factors was significant ($F(2, 310.9)=3.47$, $p<.05$). More precisely, SNSI did not vary when four ($p>.08$) or six ($p>.32$) consonants were presented, but it did for eight consonants ($F(1, 33.3)=7.17$, $\beta=-0.09$, $p<.05$). In summary, there seems to be no consciously accessible scanning process, as revealed by the SNSI in lists of four or six items. Yet, the last position in the list confers a special subjective status to targets, and in longer lists (eight items) participants seem to differentiate targets occurring early and late in the list.

Note that removing the last position in the list and repeating the analysis on the IES, a list length effect was observed ($F(2, 217)=11.51$, $p<.001$), but not of target position ($p<.51$) and no interaction ($p<.20$). It is important to reiterate that removing the last item in each list is

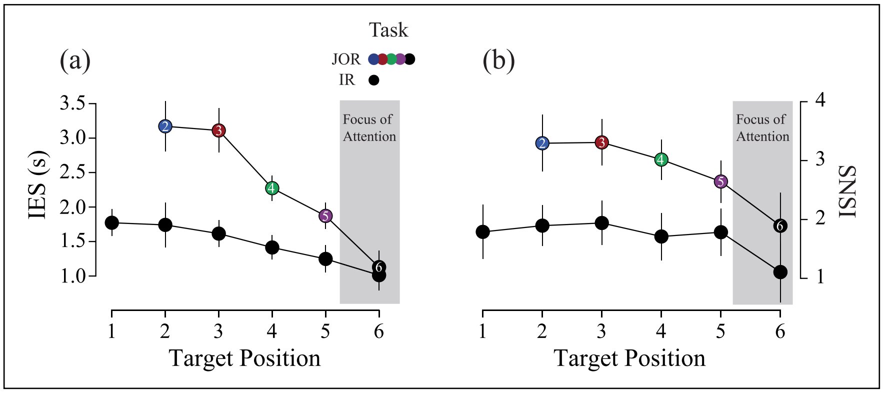

Figure 4. (a) IES (first-order task) as a function of target position in Experiments 1 (JOR) and 2 (IR): colour dots indicate the target position in the JOR task, collapsing all the distractor positions. Black dots indicate the target position in the IR task when the list length was equal to six consonants. (b) SNSI (second-order task) as a function of target position in both experiments. The analyses did not take into account the last position on the list, illustrated in the figure as "Focus of Attention."

not an arbitrary decision (see for a review McElree, 2006). McElree argues that one must distinguish information linked to residual activation of recent processing of a stimulus (i.e., information at the current focus of attention) and information stored in memory. Thus, information in the current focus of attention would have a privileged form of access, without the need of an active mechanism of information retrieval (see also Cowan, 2001).

Discussion

In this second experiment, we switched to an item identification task, with a view to modifying the cognitive processes while keeping the stimuli as close as possible to those used for the JOR task. The results we obtained on first-order performance are consistent with the literature (Sternberg, 1966, 1969); we found a decrease in performance with increasing list lengths, and similarly, a decrease with target positions at the beginning of the lists. Thus, from a strict behavioural perspective, these results are similar to those obtained on the JOR task, but previous studies suggest that they originate from distinct underlying processes (McElree, 2006). As commented above, McElree and Dosher (1989) suggested a direct access mechanism to the information, which is supported by the evidence that both the amount of information necessary to identify the target correctly and the speed of recovery for each target position in each list length is the same (but see Sternberg, 2016). Our experimental design does not include the *speed–accuracy tradeoff* (SAT) procedure of (McElree & Dosher, 1989), which precludes a direct comparison with their results.

Regarding introspection, participants reported fewer scanned items in shorter lists and when the target was the last item (or close to the end of the list in eight items lists). However, introspection was constant when we excluded the last position (except for list of eight items). The last item presented seemed to generate an automatic recovery mechanism, probably not related to the information recovery process from short-term memory, but based on the current focus of attention (McElree, 2006; Wickelgren et al., 1980). The sharp decrease of SNSI at the last position in the list suggests that the specific status associated with the last position is introspectively accessible.

After controlling the last position for each list length, we observed a different SNSI pattern. Although participants' introspection clearly differentiates perceptual loads (list length), introspection of the cognitive processes was still different from that reported in Experiment 1: the number of items scanned within lists of six and four items was the same, regardless of target position. Obviously, this is only a null result; still it seems to suggest the pattern of metacognitive response tracks the change of instructions.

To vindicate our interpretation, we applied a direct comparison to the two experiments, on the subset of trials that used the same list length (six items). Thus, we ran an LMM on participant responses with the factor of task (first order: IES | second order: SNSI), type of experiment (JOR | IR), and target position (from first to fifth position; Figure 4). This analysis did not take the last position into account for the reasons discussed above. Crucially, we found that the triple interaction was significant ($F(2, 339.0) = 5.39$, $p < .01$).[4] To ensure that this interaction could be interpreted as meaning that the difference between first- and second-order responses differed between the two tasks, we investigated the double interaction for each type of task (first order | second order). Regarding the first-order tasks (IES), we found a significant main effect of target position ($F(1, 152.2) = 80.5$, $p < .001$) and type of experiment ($F(1, 164.1) = 72.2$, $p < .001$). The interaction between these factors was also significant ($F(1, 152.2) = 23.8$, $p < .001$), characterised by a steeper decrease of IES as a function of target position in the JOR task ($F(1, 53.0) = 48.9$, $\beta = -0.47$, $p < .001$) than in the IR task ($F(1, 93.5) = 19.7$, $\beta = -0.13$, $p < .001$). Regarding the second-order task (SNSI), the interaction between the type of experiment and target position ($F(1, 113.5)=4.14$, $p<.05$) presented a different pattern: SNSI significantly decreased in the JOR task as a function of target position ($F(1, 45.0)=10.05$, $\beta=-0.17$, $p<.01$), but not in the IR task ($p>.40$). Both main effects were also significant (target position: $F(1, 36.1)=5.99$, $p<.05$; type of experiment: $F(1, 132.0)=53.7$, $p<.001$). In sum, our results suggest that participants' introspection was sensitive to a specific shift in the cognitive process generated by a simple change in the instruction in a memory recovery task.

Finally, motivated by comments from an anonymous reviewer about whether these results can be replicated in a single experimental design, we ran a last experiment, randomising the IR and JOR tasks, with lists of six items only.

Experiment 3

Material and methods

Participants, stimuli, and procedure. A total of 13 normal adults, Spanish speakers (four women), aged between 18 and 32 years (mean age: 24 years, *SD*: 3.04) participated in the study. In this third experiment, we randomised, on a trial-by-trial basis, the type of task (JOR vs IR). In contrast to prior experiments, we only used lists of six letters (500 ms each). As in the two previous experiments, a mask separated the list from the probe, which consisted of two letters at the centre of the screen. Above these two letters one of these two symbols was presented: "X" or "> | <." The first (X) indicated to participants that they had to perform an IR task, that is, determine which of the two letters was presented in the list (the letter "X" was never presented as a consonant in the lists). The second symbol (> | <) denoted that subjects had to execute a JOR task, that is, determine which of the two letters was the last presented in the list. Once participants completed the memory task, they were asked to respond on the SNSI scale. Neither the first-order task nor the introspective task was under time pressure. Before the experiment participants were trained to distinguish the task to be performed on each trial (40 trials). The main experiment consisted of six blocks of 30 trials, with a 20-s pause between each block.

Results and discussion

We used the same criteria for outliers exclusion than in Experiments 1 and 2 (below 100 ms and above 6,000 ms), yielding removal of 2.7% of the trials (RTs min.: 275 ms; RTs max.: 5,999 ms). First, we ran an LMM on responses (RTs and SNSIs) with the factor of order of response (first order: RT (log-transformed) | second order: SNSI), type of task (JOR | IR), and target position (from first to sixth position). We found that all main effects were significant (order of response: $F(1, 254.2)=814.2$, $p<.001$; type of task: $F(1, 254.2)=31.0$, $p<.001$; and target position: $F(1, 36.6)=35.4$, $p<.001$). Two double interactions (order of response × type of task: $F(1, 254.2)=8.36$, $p<.01$; type of task × target position: $F(1, 254.2)=10.5$, $p<.01$; and order of response × target position: $p>.08$) and the triple interaction were significant ($F(1, 254.2)=5.56$, $p<.05$). The same ANOVA on IES, taking into account both RTs and error rates combined yielded similar results (order of response: $F(1, 266.0)=34.8$, $p<.001$; type of task: $F(1, 266.0)=62.7$, $p<.001$; target position: $F(1, 266.0)=83.3$, $p<.001$; order of response × type of task: $F(1, 266.0)=13.1$, $p<.001$; order of response × target position: $F(1, 266.0)=21.8$, $p<.001$; type of task × target position: $F(1, 266.0)=24.4$, $p<.001$; and order of response × type of task × target position: $F(1, 266.0)=4.40$, $p<.05$).

The triple interaction means that the interaction between the target position factor and the order of response factor is different in the two tasks, which is our prediction based on the comparison of the two first experiments. Now, in the following analysis, we inspected the double interaction for each task order separately (first-order task: JOR or IR | second-order task: SNSI).

First-order responses. First-order results are comparable with those obtained in Experiments 1 and 2. To investigate RTs (log-transformed) and error rates in the JOR task (Figure 5a1), we ran an LMM with fixed effects of target position (from two to six), distractor position (from one to five), and their interaction. We included a random participant intercept and a random distractor position slope for each participant. Results showed a significant main effect of target position ($F(3, 172)=5.66$, $p<.01$). No other main effect was found. A similar analysis on error rate did not show any difference (all ps $>.23$), even though both variables were correlated (RT ~ error rate: $r^2(192)=.02$, $t=2.08$, $p<.05$). Then we analysed IR task (Figure 5a1) through an LMM on RT (log-transformed), with fixed effects of target position and a random participant intercept and a random target position slope for each participant. We found a significant decrease of RTs as a function of target position ($F(1, 64)=38.2$, $p<.001$; without last position: $F(1, 51)=24.4$, $p<.001$). A similar analysis on error rates yielded the same results ($F(1, 64)=38.7$, $p<.001$; without last position: $F(1, 51)=22.2$, $p<.001$). Both first-order variables were also correlated (RT ~ error rate: $r^2(77)=.07$, $t=2.51$, $p<.05$). Finally, by collapsing JOR and IR task and then using a similar LMM on RT, with fixed factor of target position (from two to six), task type (JOR [collapsing all distractor positions] vs IR task), and the interaction—with the same random factors—we found a significant main effect of target position ($F(1, 14.6)=56.6$, $p<.001$) and task type ($F(1, 104.2)=25.9$, $p<.001$), without interaction ($p>.09$). As for error rates, the two main effects and the interaction were significant (target position: $F(1, 127)=75.0$, $p<.001$; task type: $F(1, 127)=39.2$,

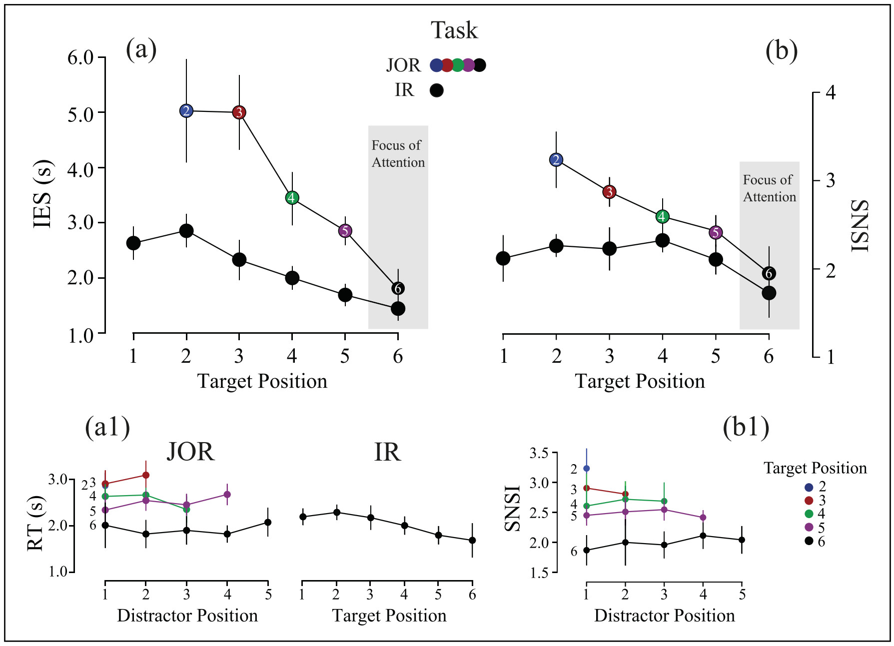

Figure 5. Results from Experiment 3: (a) IES as a function of target position in both tasks. (a1) RTs as a function of distractor position and target position in the JOR task, and RTs as a function of target position in the IR task. (b) SNSI in the JOR and IR tasks as a function of target position. (b1) SNSI as a function of distractor position and target position in the JOR task.

$p<.001$; interaction: $F(1, 127)=12.1$, $p<.01$). A deeper inspection of this interaction indicated that both in JOR task ($F(1, 62.3)=32.8$, $p<.001$) and in IR task ($F(1, 64)=38.7$, $p<.001$), the participant's error rate increase from last to first position of the list; however, this effect was steeper in JOR task (error rate~target position, IR task: $r^2(77)=.21$, $t=-4.51$, $\beta=-0.03$, $p<.001$; JOR task: $r^2(64)=.34$, $t=-5.64$, $\beta=-0.07$, $p<.001$).

To better compare both tasks, we calculated an IES index (RT and error rate were correlated: $r^2(142)=.10$, $t=3.92$, $p<.001$). An LMM was run on mean IES scores, considering target position (from first to sixth position) and task type (JOR [collapsing all distractor positions] vs IR task) as fixed factors. We found a significant main effect of target position ($F(1, 127)=76.2$, $p<.001$) and task type ($F(1, 127)=53.4$, $p<.001$). The interaction was also significant ($F(1, 127)=19.8$, $p<.001$). Regarding this interaction, a significant decrease in IES as a function of target position was observed in both tasks (JOR: $F(1, 51)=33.3$, $p<.001$; IR: $F(1, 64)=60.9$, $p<.001$), but it is steeper in the JOR task. These results confirm the previously described response pattern (Figure 5a).

Second-order task. Results indicate that the SNSI presented a distinct response pattern depending on the task. This was observed through the interaction between target position and type of task ($F(1, 127)=15.4$, $p<.001$; without the last position: $F(1, 101)=13.8$, $p<.001$). We also found a main effect of these two factors (target position: $F(1, 127)=37.9$, $p<.001$; type of task: $F(1, 127)=35.2$, $p<.001$; without the last position—target position: $F(1, 101)=13.1$, $p<.001$; type of task: $F(1, 101)=34.2$, $p<.001$). SNSI in the IR task decreased significantly as a function of target position ($F(1, 64)=4.93$, $p<.05$), but only because of the last position. If we exclude this last position, there is no significant decrease ($p<.91$). However, there was a significant decrease with target position in the JOR task ($F(1, 51)=33.1$, $p<.001$, even without the last position: $F(1, 38)=16.4$, $p<.001$; Figure 5b and b1). In short, we see again that in the IR task, the only item that has a special status with respect to introspection is the last item; the five other target positions generate the same introspective response. As opposed to that, in the JOR task, even the five before last items are clearly distinct and generate smaller introspective response as they get closer to the end of the list. The triple interaction thus can be interpreted as showing that introspection, but not first order, is flat with respect to target position in the IR task, as opposed to the JOR task. Indeed, both tasks generate improved first-order performances for targets closer to the end of the list.

Conclusion

For the last 40 years, the literature on metacognition has suggested that introspection has no access to higher complexity processes that underlie decision making. Nisbett and Wilson (1977) proposed this idea from an extensive review of experiments in experimental social psychology that showed that individuals often confabulate regarding the causes of their behaviour. Although this idea has been established as a canon in the literature (Overgaard & Sandberg, 2012)—which has received certain re-conceptualisations (Wilson, 2002, 2003; Wilson & Dunn, 2004) and certain recent experimental support (Johansson, Hall, Sikström, Tärning, & Lind, 2006; Johansson et al., 2005)—to our knowledge there is scant evidence in cognitive psychology that delves into further details on the limits of introspection with respect to the nature *(process/state)* of the targeted mental content. Above all, the question that arises is whether the limit of introspection is the result of a functional determinant of the cognitive system or the by-product of an inadequate experimentation context. Our objective was to show that introspection is able to access with some precision the nature of some short-term memory processes. We sought to achieve that goal by focusing participants' attention on the mental content of interest, an idea present in the literature for many years (Flavell, 1979; Hurlburt & Heavey, 2001), with the appropriate methodological safeguards (Goldman, 2004; Piccinini, 2003). We thus tested whether introspection is capable of distinguishing the cognitive processes underlying two short-term memory tasks. Previous experimental evidence (Hacker, 1980; McElree, 2006; Muter, 1979; Sternberg, 1966, 1969) has suggested that by a simple instruction modification (item identity task or relative position task), it was possible to shift the nature of the cognitive process deployed. Our aim was to assess whether introspection was able to detect such differences.

Our experimental design is motivated by the *script-report* procedure (Jack & Roepstorff, 2002), which makes it possible to contrast the objective first-order information with the second-order subjective report. To evaluate this, we used the SNSI, which we previously used in the context of visual search tasks (Reyes & Sackur, 2014, 2017). In Experiment 1 (JOR task), the SNSI was consistent with access to a serial mechanism of information retrieval: SNSI scores increased as a function of the target position, regardless of the distractor position. Interestingly, these differences covary with RTs to a high degree (68%). However, control analyses (analysis of the RT in the second-order SNSI task and mediation analysis) showed that although RT correlates with SNSI, there is also variability in the SNSI which is not reducible to variability of RTs. In Experiment 2 (IR task), SNSI was consistent with a direct access mechanism: We found that if we exclude the last item, SNSIs are constant with respect to target positions in lists of four and six items. This is consonant with the evidence in the literature (McElree, 2006; Wickelgren et al., 1980) suggesting that the last item in the list is processed by a different mechanism from the rest of the stimuli. We next drew a direct comparison between both experiments considering only six-item lists across the two first experiments, and with a third experiment, that had a randomised, within participants design. Both approaches demonstrate that the impact of target position yields an interaction of SNSI and first-order responses across tasks. This suggests that the difference in the processes triggered by each task, while not manifest in behavioural responses, is accessible through introspection. Again, these direct comparisons were performed with the exclusion of the last item in the lists that has presumably a privileged status of being under the attentional spotlight with respect to retrieval (McElree, 2006). We should note here two points: First, our attempt at mitigating this privileged status by means of a mask was mostly unsuccessful, suggesting that it is not due to perceptual mechanisms. Second, the fact that the SNSI tracks the special status of the last item in the lists contributes to our knowledge of the specificity of introspection. Indeed, in addition to being able to distinguish direct retrieval and sequential scanning mechanisms, introspection seems to be sensitive to the special status of the item that is under the spotlight of attention.

In perspective, our results confirm that mental monitoring of cognitive processes is possible in elementary memory tasks. Finally, it is important to mention that it is highly probable that, as in our previous studies (Reyes & Sackur, 2014, 2017), SNSI would be permeable to other sources of information. Here, only first- and second-order RTs can be contrasted. Future investigations should focus on other contaminant sources and determine the effect of these on the formation of introspective judgments. In accordance with this, confidence in the task, the level of effort, as well as expectations a priori regarding the SNSI could play an important role in the construction of second-order judgment.

We should note here that the study of introspection of memory processes is in a less favourable position than with respect to visual search processes (Reyes & Sackur, 2014, 2017). Indeed, for visual search, we could rely on the observation of eye movements as an indirect measure of the inner process of interest, to wit shifts of spatial attention. It was thus possible to show that introspection was reliably tracking attention shifts by implicitly manipulating attention with a near threshold cue, the impact of which could be established through eye-tracking (Reyes & Sackur, 2017). Here, it would seem that an analogous methodology would require the use of fast brain imaging techniques (electroencephalography [EEG] or magnetoencephalography [MEG]), as no implicit, yet observable behaviour could be shown to track memory recovery processes. Since the initial proposal by Lisman and Idiart (1995), strong evidence has been gathered to the effect that frontal theta/gamma activity correlates with short-term memory encoding and retrieval (for a review, see Sternberg, 2016). Thus, we propose that one could derive a neural index of memory processes that would explain both objective responses and introspection. It seems difficult to prove without the help of such a neural marker that the SNSI is not a surrogate for more generic decision-related introspection, such as, for instance, confidence or perceived difficulty. However, if we were able to show that SNSI tracks the neural marker of short-term memory processes better than does confidence (and that the opposite is true with respect to memory accuracy), one could in principle demonstrate the specificity of introspection in the context of memory encoding and retrieval.

One strength of this study is that we could use identical stimuli and change the nature of the processes by redefining the task, whereas in most previous studies of introspection, perceptually different stimuli were used to generate different cognitive processes. This had the unfortunate consequence that participants knew the nature of the experimental manipulation of interest, the one that was expected to cause distinct cognitive processes. In these conditions, participants may fall into using this knowledge as an ingredient for their subjective reports, yielding in effect more interpretative (confabulatory) than truly introspective reports. Here, eschewing this pitfall, we still manage to show that differences in mental processes inferred indirectly from behavioural evidence are in fact directly accessible through introspection. Yet, as explained above, further studies involving neurophysiology are necessary to fully establish the specificity of the introspection for memory processes.

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Notes

1. The common definition of a *cognitive state* refers to a mental content that accompanies the decision (e.g., the level of confidence in a decision or the perception of the response time [RT] in a cognitive task). On the contrary, *cognitive processes* refer to the transformations that occur between a stimulus and a response (Rich, 1979). Another way to introduce the concepts of cognitive *states* and *processes* is proposed by White (1980) through the distinction between "*knowing that*" and "*knowing how*," respectively.
2. This model allows us to factor out the mediating role of RTs in the target position effect on subjective number of scanned items (SNSI). The mediation model has two levels. The outcome (SNSI), the mediating variable (RTs), and the predictor (target position factor: TP) are the within-participant variables (i, Level 1), which are nested within each participant (j, Level 2). Thus, we estimated a within-participant mediation analysis model, that is, how much SNSI changes as a function of the predictor (*total effect*=c). Then, how much this change is contaminated by a mediator (*indirect effect*=$\alpha\beta$), and finally, how much the SNSI changes as a function of the predictor, after controlling the mediator effect (*direct effect*=c'). We considered that all these effects can vary randomly between Level-2 units. The main aim of this analysis was to estimate the average of these effects across participants (α, β, and c'), considering the covariance between the random effects ($\sigma_{\alpha_j \beta_j}$). To test the significance of the indirect effect, we used a Monte Carlo confidence interval method (Preacher & Selig, 2012; Selig & Preacher, 2008).
3. We applied a multilevel mediation model (Bauer, Preacher, & Gil, 2006), with RTs (log-transformed) as a potential mediator variable (without considering the last position). The multilevel mediation model, run on a trial basis and only on correct trials, confirmed a significant main effect of list length on SNSI ($F(1, 27.2)=214.6$, $c=0.37$, $p<.001$). At the same time, we confirmed that this factor also had an impact on RTs ($F(1, 25.0)=78.9$, $\alpha=0.06$, $p<.001$). After controlling the list length effect, SNSI and RTs were significantly related ($F(1, 22.6)=87.5$, $\beta=1.28$, $p<.001$). Finally, after controlling the RT effect on SNSI, we found that the impact of list length on SNSI was significantly reduced, but not eliminated ($F(1, 22.9)=106.2$, $c'=0.28$, $p<.001$). The size of the indirect effect ($\alpha\beta$) was 0.08 (95% confidence interval [CI=0.05, 0.10]), indicating that 22% of the list length effect on SNSI is mediated by RTs.
4. The triple interaction was also significant when considering the last position in the list ($F(2, 401.8)=3.76$, $p<.05$).

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