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Introspective access to implicit shifts of attention

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ABSTRACT

Literature in metacognition has systematically rejected the possibility of introspective access to complex cognitive processes. This situation derives from the difficulty of experimentally manipulating cognitive processes while abiding by the two contradictory constraints. First, participants must not be aware of the experimental manipulation, otherwise they run the risk of incorporating their knowledge of the experimental manipulation in some rational elaboration. Second, we need an external, third person perspective evidence that the experimental manipulation did impact some relevant cognitive processes. Here, we study introspection during visual searches, and we try to overcome the above dilemma, by presenting a barely visible, "pre-conscious" cue just before the search array. We aim at influencing the attentional guidance of the search processes, while participants would not notice that fact. Results show that introspection of the complexity of a search process is driven in part by subjective access to its attentional guidance.

1. Introduction

The term introspection refers to the cognitive mechanism through which individuals can access their own mental states (Flavell, 1979; Lyons, 1986). Like any other cognitive process, introspection also presents certain functional determinants (Jack & Shallice, 2001; Overgaard, 2006), that we can study experimentally in psychology (Jack & Roepstorff, 2002, 2003, 2004; Schooler, 2002) and neuroscience (Fleming & Frith, 2014). It has been proposed (Carruthers, 2010) that individuals would introspectively access only mental states with low cognitive complexity (e.g., perceptual states). On the contrary, information related to a cognitive process would remain inaccessible to consciousness. In particular, literature converges on the idea that reports about cognitive processes preceding a decision would not be truly introspective, but rather interpretative (Overgaard & Sandberg, 2012). In effect, recent evidence in social psychology (Johansson, Hall, Silkström, & Olsson, 2005; Johansson, Hall, Silkström, Tärning, & Lind, 2006; but see Petitmengin, Remillieux, Cahour, & Carter-Thomas, 2013) suggest that when participants are asked to describe the causes guiding their behavior, they systematically engage in *confabulatory* explanations.

The concern for this matter was inaugurated by cognitive psychologists in the 1960s, who – with insufficient experimental evidence – suspected that individuals could not access to higher order mental processes (Mandler, 1975; Miller, 1962; Neisser, 1967).[1] Formally, this pessimistic view on introspection was stated in the seminal publication of Nisbett and

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[1] Nisbett and Wilson (1977, p. 232) emphasize this point: "It is the *result* of thinking, not the *process* of thinking, that appears spontaneously in consciousness" (Miller, 1962, p. 56) [...] "The constructive processes [*of encoding perceptual sensations*] themselves never appear in consciousness, their products do" (Nessler, 1967, p. 301).

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Wilson (1977), in which they define the class of mental content that is accessible via introspection. These authors proposed the distinction between accessible mental contents (cognitive states) and inaccessible ones (cognitive processes). This claim comes from a systematic review of experiments in social psychology (research areas included attribution, cognitive dissonance, subliminal perception, problem solving, etc.), from which they concluded that introspective access would be restricted to the cognitive states (i.e., perceptual mental state) before or after the decision. On the contrary, information related to the cognitive processes which constitute decisions, would be inaccessible to participants (Fig. 1).

Against Nisbett and Wilson's theory, several conceptual and methodological objections have been raised (Ericsson & Simon, 1980; Smith & Miller, 1978; White, 1988). Among the most important are the following: First, Nisbett and Wilson (1977) do not propose a clear distinction between a cognitive *process* and a cognitive *state*. The authors only offer a vague definition of a cognitive process: "*causes that guided, lead to or motivate a decision*". In a subsequent article, Nisbett and Ross (1980) define a cognitive process as "*the causal relation between events or mental contents*". The lack of clarity in the definition of what is postulated as inaccessible goes over time generating confusion in the literature. A conceptual strategy to clarify this, and that additionally facilitates the design of experiments - without eluding the original problem (see Footnote 1) - is to define a cognitive process simply as "*the sensory and representational transformations that occur between a stimulus and a response*" (Reyes & Sackur, 2014). Indeed, when participants are requested to report "*the causes that motivate behavior*" it is highly probable that participants would resort to *a priori* theories (because folk epistemology associates "causes" with "theory"). This effect should be decreased when it is demanded to simply report "*the sensory transformation*" that precedes a decision (Engelbert & Carruthers, 2011). Secondly, another problematic aspect is the response mode in Nisbett and Wilson's experiments, which are often based on verbal reports. The problems associated with introspective verbal reports have been extensively discussed in the literature (Ericsson & Fox, 2011; Ericsson & Simon, 1980; Fox, Ericsson, & Best, 2011; Schooler, 2002, 2011). Many authors converge on the idea that verbal reports must involve a *translation* of the information of interest (Schooler, 2002). This opens the possibility that cultural factors, *a priori* beliefs, personality factors or aspects of the researcher-participant relationship could alter the formation of introspective judgments. The previous point is particularly relevant for the study of limits of introspection. In effect, most cognitive processes investigated by Nisbett and Wilson presented high cognitive complexity; as a consequence, they demand that participants execute high-level forms of reasoning or at least integrate many information sources. The high complexity of the task, added to the low experimental control of introspective verbal-report, are factors that favor confabulation (Ericsson & Simon, 1980). In response, recent advances in the field of introspection of mental states (Corallo, Sackur, Dehaene, & Sigman, 2008; Marti, Sackur, Sigman, & Dehaene, 2010) have all been achieved by focusing on elementary cognitive tasks, and replaced verbal reports by quantified reports. Our conceptual and experimental work is guided by the idea that the inaccessibility of cognitive processes can be overcome if we take into account both lines of objections.

Recently, we (Reyes & Sackur, 2014) and others (Marti, Bayet, & Dehaene, 2015) evidenced that under precise experimental conditions, participants' introspection was able to accurately access the basic cognitive process in visual search tasks (i.e., the mechanisms of a decision). As commented before, so as to reach this conclusion, it was necessary to resort to much simpler and controlled experimental conditions than what is generally the case in the literature supporting the inaccessibility of cognitive processes. In effect, both studies mentioned above relied on visual search as first order task, on which participants were asked to apply introspection. This task has the convenient property of being experimentally well understood and controllable (Treisman & Gelade, 1980; Wolfe, 1994). Our previous results open the possibility that the controversy about the differential access to mental content (i.e., access to cognitive processes *vs*. access to perceptual states) does not depend on the nature of such contents (Carruthers, 2010), but more on the functional aspects of the introspective mechanism itself.

In Reyes and Sackur (2014), we investigated the introspective access to the cognitive processes underlying two visual search processes. The logic of such experiments was the following: we tell the participants to participate in a visual search task, in which two conditions are presented; one simple and fast, in which the target "pops out", the other being more difficult and requiring an effortful and "serial" exploration of the visual scene. Importantly, in every trial and after every search condition we asked participants to describe the cognitive strategy that they had carried out to trigger the response. Our interest was to investigate if such subjective estimate was consistent or not with the type of underlying cognitive processing to each experimental condition, which is possible to objectively track. In detail, two experimental conditions were studied: difficult, effortful searches (conjunction searches: search L among Ts) and easy, pop-out searches (feature searches: search X among Ts). It has been repeatedly shown (Treisman & Gelade, 1980; Wolfe, 1994; Wolfe, Võ, Evans, & Greene, 2011) that these two types of searches engage attention in a markedly different way: difficult searches lead to a sequential scanning of the search array with little *exogenous* attentional guidance, while in pop-out searches, attention is directly driven to the target, as if the whole array had been processed in parallel.

In visual search there is an extensive debate about how attention is modulated. For instance, the Feature Integration Theory (FIT, Treisman & Gelade, 1980) suggests that in feature searches (FS) the visual system extracts in parallel, pre-attentively, the set of basic characteristics of the scene, which are necessary and sufficient to select the response. On the contrary, in conjunction searches (CS) attention is deployed serially one item, or group of items, at a time. In feature searches response times are independent from perceptual load since the characteristics of the target stimulus favor a pre-attentional processing. In contrast, in conjunction searches there is no such pre-attentional processing. As a consequence, response times increase as a funcion of perceptual load. Other models argue that there is a continuum of more or less efficient searches (Thornton & Gilden, 2007; Wolfe, 1994, 2007; Wolfe, Cave, & Franzel, 1989). In accordance with this, *inefficient visual searches* (e.g., search L among Ts) exhibit prominently *capacity limits*, whereas *efficient searches* (e.g., search X among Ts) do not incur

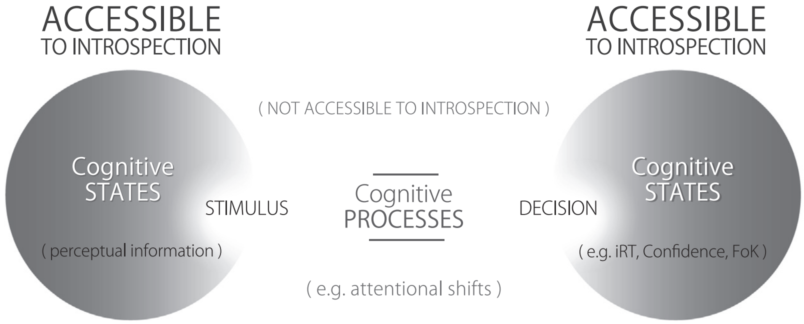

Fig. 1. Illustration for the view that cognitive processes are inaccessible to introspection, notably in Nisbett and Wilson (1977) seminal paper. The circles represent accessible mental content. The left circle encompasses all *pre-decision* subjective information about the stimulus (introspection about states before the decision, e.g., the perceptual load), and the right circle the *post-decision* subjective information (e.g., iRT: introspective response time (Corallo et al., 2008), confidence judgments (Koriat, 2012), FoK: feeling of knowing (Hart, 1965)). In between are the processes that are deemed inaccessible to introspection. This information is defined by Nisbett and Wilson (1977) as cognitive processes of high complexity. In this article we are interested in investigating the introspective accessibility of a type of well-documented cognitive process: attentional shifts in visual search tasks.

such limits. Furthermore, it is also widely admitted that easy, efficient searches evade capacity limits because they benefit from *guidance of attention* by features extracted from non-selective pathways (Cameron, Tai, Eckstein, & Carrasco, 2004; McElree & Carrasco, 1999; Wolfe, 2003; Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004; Wolfe et al., 2011). Thus, only in efficient searches response selection can benefit from the parallel feature extraction, through attentional guidance.

In perspective, under the premise that the attentional mechanism deployed in each search type determines the perceptual conscious decision, we consider that a correct description of such attentional shift should be a reflection of proper access to the underlying cognitive process in each experimental condition. The introspective task in Reyes and Sackur (2014) consisted in estimating the number of scanned items *before* the decision. We argued that this subjective report (Subjective Number of Scanned Items, SNSI) was an index of the complexity of the cognitive *processes* leading to the decision. We found evidence that participants had an adequate introspective access to internal cognitive processes, in the sense that subjective reports generally tracked experimental manipulations while they were not simply reflections of obvious contaminating sources (notably eye-movements and response time). Thus, we suggested that participants' introspection was, through the Subjective Number of Scanned Items index, tracking the attentional guidance in effect during the search process. Here, we attempt to provide a direct proof of this by controlling attention during the search process while keeping all other properties of the search stimulus exactly identical.

To achieve this, we presented a barely visible cue before 50% of the search arrays. The cue could be congruent (at the position were the target was to appear) or incongruent (at the position of a future distractor), and was meant to exogenously drive participant's attention. The strategy was to maintain all other stimuli conditions constant (notably we used a fixed set-size of 16), so that we could observe the biasing effect of the cue on introspection of the processes preceding the decision. So as to gauge the visibility of the cue we applied a questionnaire about its visibility and a behavioral visibility test. Critically, we used the following innovative procedure: we presented the visibility questionnaire and test after the first half of the experiment. As a consequence, participants had no information about cues during the first part of the experiment. This enabled us to assess the effect that the potential *presence* of a cue, as well as the effect that the *knowledge* about the potential presence of the cue, could have on introspection. The objective of the present study was to assess whether the introspection of the participants is sensitive to attentional shifts generated exogenously and without their knowledge. In summary, we tried to influence the cognitive processes involved in visual search, while trying to abide by the two somewhat contradictory constraints: on the one hand we need some external, measurable proof that our manipulation did impact the targeted cognitive process (and we hope that eye-movements could provide such a measure). But on the other hand, we need our manipulation to be unconscious or at least not spontaneously noticed, so that the introspective reports would not be tainted by rational ex-post confabulations. Similarly, we wish to reduce the possibility that participants would resort to self-observation rather than to real introspection. This is why we introduced a late (3 s post-stimulus) response window, so that participants could not rely on the observation of their own response times to build an estimate of the number of items they scanned before responding.

The general hypothesis is that individuals will be able to access this information between the stimulus and the perceptual decision, i.e., a precise change in the intermediate cognitive process. Thus, we predicted that participants' estimations would be constant and close to one item in FS, independently of the influence of the type of cue. The above answers that this condition is favored by attentional guidance generated at the time of the presentation of the stimuli, thus overriding any previous effect of cue. Conversely, the CS condition, which does not favor the characteristics of stimuli from attentional guide, will be effectively modulated by the cue, which should be evidenced through objective measures of first order (e.g., eye movement, decision time). Crucially, the SNSI will be able to capture such differences, even when the participants do not know the stimulus that triggers the attentional shift. We predicted higher SNSI scores in CS than FS, and importantly, a SNSI modulation as a function of the type of cue in CS only.

2. Material and method

2.1. Participants

20 adults, French speakers (15 women), aged between 18 and 37 (mean age: 23 years, *SD*: 3.9) participated in the study. Informed consent was obtained before the experimental session. Participants received a compensation of €10 for a 1-h session. No participant had any knowledge regarding the task, and all had normal or corrected to normal vision.

2.2. Stimuli

Stimuli (Fig. 2) consisted of a set of 16 green and red schematic letters (T, L or X, size: $0.8^\circ \times 0.6^\circ$, luminance: 0.09 cd/m^2) on a uniform grey background (luminance: 3.11 cd/m^2). Stimuli were presented on an imaginary circle (radius: 6.2°) preceded by a black fixation point at the center of the screen. Stimuli were equally spaced on the imaginary circle. On one half of the trials, a black transient cue was presented just before the stimulus array ($*$, size: $0.3^\circ \times 0.3^\circ$). When present, the cue was always at the position of a letter. Stimuli were presented on a CRT screen (size 17″, resolution of 1024×768 pixels, refresh rate of 75 Hz, viewing distance of $\approx$55 cm). The experiment took place in a dark booth with the monitor as the only source of light. Eye movements were recorded monocularly with an eye tracker (EyeLink 1000 system, SR Research, Canada), with a sampling rate of 500 Hz and a spatial accuracy better than 0.5° (Camera-Eye distance: $\sim$55 cm). Saccades were determined using a conservative algorithm (velocity threshold: 30°/s, acceleration threshold: 8000°/s2, motion threshold: 0.15°). For all participants the right eye was recorded.

2.3. Procedure

After the fixation (500 ms), stimuli were presented for 3000 ms, either preceded or not by the cue (26 ms). The task consisted in deciding the color of the target (L or X) within the set of distractors Ts, in line with our previous study (Reyes & Sackur, 2014). After presentation of the stimuli, there was a response window of 1500 ms, during which participants were requested to decide if the target presented was red ("Z" key) or green ("A" key) on a standard French keyboard. In 50% of the trials, between the fixation point and the stimuli, a cue was presented, followed by an inter-stimulus interval (13 ms). In 50% of the cue present trials, the cue anticipated the position of the target. In the other 50%, the cue was presented at the position of a distractor. In this case, the cue kept a minimum (randomized) distance in the circle of stimuli of 4 or 6 letters with respect to the position of the target. The color (red or green) and the individual orientation of each stimuli (0, 90, 180, 270°) were randomized, as well as the type of target (feature condition: X or conjunction condition: L) and the type of cue (no-cue, congruent, incongruent). Immediately after the response of the participants, a visual analog introspective scale was presented: *How many elements do you think you scanned before reaching your decision?* (Subjective Number of Scanned Items, SNSI). Two labels were presented (in French) at each end of the scale: "*no item*" and "*all items*". Participants used their right hand, without time constraints, to move the cursor and click on the scale to give their introspective estimate. Meaning and use of the introspective scale was explained before the main experiment, while during the experiment, instructions were presented in an abbreviated manner under the scale. Importantly, participants were instructed to avoid fast or automated responses and to use the whole scale.

With the objective of evaluating the visibility of the cue, after the first half of the experiment (i.e., after the fourth block), a questionnaire and an intermediary visibility test regarding the cue were presented. The aim of presenting these intermediary tests was to determine whether after they became aware of the experimental manipulation, individuals would modify their introspective performance. The questionnaire consisted in three yes-no questions. (1) *Did you see anything irregular or special during the experiment?* (2) *Did you see a stimulus between the fixation cross and the circle of stimuli?* (3) *Did you see this little black star presented just before the stimuli* (at that moment the researcher showed to participant the cue ($*$) on a piece of paper)*?* Whatever their responses, participants were then informed about the presence of the cue in 50% of the trials, while nothing about its relation to the target was said. Then, in a separate experimental block participants were presented with the same stimuli as in the main experiment, and their only task was to respond whether they saw the cue or not by means of a visibility scale, with two responses (in French): "*seen*" & "*not seen*". Participants responded without time constraints. Immediately after the visibility questionnaire and test, participants continued with 4 experimental blocks that were identical to the ones in the first half.

Before beginning the experiment, participants received training in two stages. During the first (12 trials) the visual search task was presented without the introspective scale and with an audio feedback on correct and incorrect responses. This phase was repeated until participants reached a performance of at least 90% correct (no more than 1 error). The second training (12 trials) had the objective of exercising the use of the introspective scale. After this second stage, participants proceeded to the main experimental block without performance criterion. The experimental session comprised 288 trials (144 repetitions per target type and 72 repetitions per congruent cue, 72 per incongruent cue, and 144 per no-cue) in 8

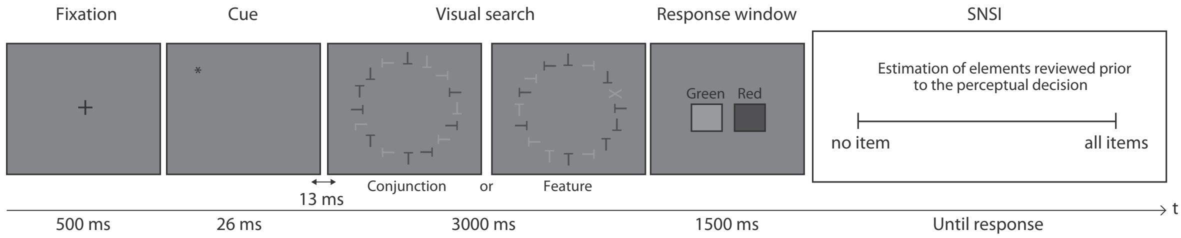

Fig. 2. General structure of the experimental task. After presentation of the fixation point, a total of 25% of the trials presented a cue that anticipated the position of the target, another 25% presented a distracting cue; that is a cue that anticipated the position of a distractor. Stimuli were presented during 3000 ms, without the possibility of a response. During this stage the subjects were asked to identify the color of the target (red or green). All trials presented a target. After presentation of the stimuli, a response window was presented for 1500 ms. Immediately after, participants were requested to estimate the number of elements reviewed prior to having identified the color of the target on a visual analog scale (SNSI).

blocks (4 blocks before/after intermediary-test) with a 60 s pause between each block. The intermediary test comprised 48 trials. The experimental session lasted 1 h.

3. Results

3.1. Visibility tests

The visibility questionnaire and the visibility test in the middle of the experiment were meant to gauge how *noticeable* and how *detectable* the cue was. All participants reported not having noticed the cue during the first half of the experiment: all three questions of the questionnaire were negatively answered by *all* participants, precluding the application of statistical tests. However and critically, when we directed participants' attention on the cue for the detection test, it was clearly detected: mean accuracy across participants was 59%. We computed a visibility d' for each participant, which was strictly positive (median $d' = 0.47$, $SD = 0.71$, t-test against 0 $(19) = 4.34$, $p < 0.001$). Response bias (median $c = 0.65$, $SD = 0.59$, t-test against 0 $(19) = 5.61$, $p < 0.001$) was also positive, corresponding to a conservative bias. In sum, these results indicate that the cue was not subliminal in the sense that it could not be reported. However, visibility was low ($d' = 0.47$) and it was clearly not spontaneously registered by participants, who all failed to notice it. We suggest that this intermediary visibility state corresponds to the pre-conscious state proposed by Dehaene, Changeux, Naccache, Sackur, and Sergent (2006). Thus any effect of the cue on introspection will be difficult to explain away by the evocation of a conscious inferential process, at least in the first half of the experiment. It cannot be the case that participants change their introspection because they think, according to some causal theory, that the presence of the cue must have an impact on their second order reports, as, precisely, they are not spontaneously aware of the presence of the cue. Furthermore, as the visibility questionnaire and test did draw attention to the presence of the cue, if conscious inferential processes were to intervene, this could be seen as a change in the effect of the cue between the first and second part of the experiment.

3.2. First order results

Motor Response times (mRTs, computed from the onset of the response window) differed between L (497.0 ms, $SE = 29.3$) and X (459.9 ms, $SE = 30.8$) conditions but there was no difference depending on cue type or between the first and second half of the experiment. This was confirmed through a repeated measure ANOVA run on median mRTs with three factors: target type (L and X) cue type (no-cue, incongruent and congruent) and pre/post (pre: first half, before the visibility test and questionnaire; post: second half), and all possible interactions. Here, as in the next analysis, participants were considered as a random factor. Results indicate only a significant main effect of target type ($F(1,19) = 12.02$, $p < 0.01$, $\eta 2_p = 0.39$) and an interaction between the pre/post factor and target type factor ($F(1,19) = 8.93$, $p < 0.01$, $\eta 2_p = 0.32$). No other significant effects were found (all $ps > 0.07$). A deeper inspection of the interaction revealed that for L condition, mRTs significantly decrease from the first to the second half of the experiment (paired t-test pre (L) *vs*. post (L): $\Delta M = 58.8$, $SD = 88.9$, $t(19) = 2.96$, $p < 0.01$), but not for the X condition ($p > 0.70$, Fig. 3A). Accuracy was high, with a mean error rate of 2% without any difference between experimental conditions (all $ps > 0.15$).

Then we calculated the latency of the first fixation on the target (the First Target Fixation Latency, FTFL, Fig. 3B). We defined a square window around the target ($0.8° \times 0.8°$), and measured FTFL with respect to the first fixation of at least 50 *ms* within this window. An ANOVA was run on median FTFL, with the same factors as for mRTs, and we found that all main effects were significant: target type (L: $M = 1064.1$ ms, $SE = 34.7$, X: $M = 524.8$ ms, $SE = 22.0$, $F(1,19) = 410.1$, $p < 0.001$, $\eta 2_p = 0.96$); cue type (no-cue: $M = 825.6$ ms, $SE = 25.1$; incongruent: $M = 864.1$ ms, $SE = 33.3$; congruent: $M = 693.8$ ms, $SE = 32.1$; $F(2,38) = 20.6$, $p < 0.001$, $\eta 2_p = 0.52$) and pre/post (pre: $M = 832.8$ ms, $SE = 28.6$, post: $M = 756.1$ ms, $SE = 28.3$; $F(1,19) = 10.1$, $p < 0.01$, $\eta 2_p = 0.35$). Importantly, a significant interaction between target and cue

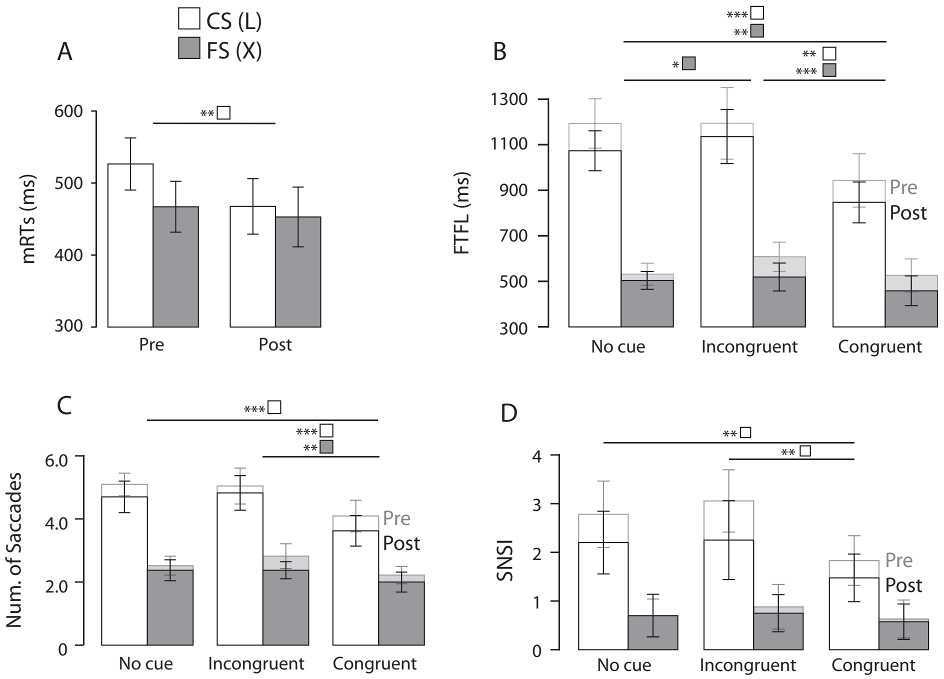

Fig. 3. (A) motor Response time (mRTs), (B) First Target Fixation Latency (FTFL), (C) Number of Saccades, and (D) Subjective Number of Scanned Items (SNSI), as a function of the type of cue and for each visual search condition. Light grey and black bars denote pre and post condition, respectively. Error bar represents ± 2 *SE*. Figures highlight only significant differences ($* = p < 0.05$; $** = p < 0.01$; $*** = p < 0.001$; see boxes for comparisons in each search condition), collapsing pre and post trials.

type was observed ($F(2,38) = 8.93$, $p < 0.01$, $\eta 2_p = 0.32$). A deeper inspection revealed that for the L condition congruent trials were faster than no-cue trials ($\Delta M = 199.4$, $SD = 209.6$, $t(19) = 4.25$, $p < 0.001$) and congruent trials were faster than incongruent trials ($\Delta M = 225.2$, $SD = 282.4$, $t(19) = 3.56$, $p < 0.01$), without differences between no-cue and incongruent trials ($p > 0.52$). Regarding X condition, we found the same differences with smaller sizes (congruent *vs.* no-cue: $\Delta M = 49.1$, $SD = 72.6$, $t(19) = 3.02$, $p < 0.01$; congruent *vs.* incongruent: $\Delta M = 90.6$, $SD = 80.8$, $t(19) = 5.016$, $p < 0.001$). In addition no-cue trials were slightly faster than incongruent trials ($\Delta M = 41.5$, $SD = 68.5$, $t(19) = 2.70$, $p < 0.05$). These results suggest that attention is in part driven by the cue, even though it is not spontaneously noticed. The differential effect of the cue in the X and L conditions demonstrates that the cue and the pop-out features of the X target concurrently affect attention. We found strictly similar results on the number of saccades during stimulus presentation (Fig. 3C).

3.3. Second order results

We analyzed the subjective number of scanned items (SNSI) as an index of participants' introspection with similar ANOVAs. Critically, SNSI was reliably modulated by the cue, but only in the L condition (Fig. 3D). A repeated measure ANOVA over median SNSI, with the same factors as above showed that the three main effects were significant: SNSI was smaller for the X than for the L condition (L: $M = 2.26$, $SE = 0.26$; X: $M = 0.69$, $SE = 0.19$, $F(1,19) = 50.0$, $p < 0.001$, $\eta 2_p = 0.72$); it was driven by the type of the cue ($F(2,38) = 14.6$, $p < 0.001$, $\eta 2_p = 0.44$), and smaller in the second half of the experiment ($F(1,19) = 11.45$, $p < 0.01$, $\eta 2_p = 0.38$). Two interactions were evidenced: pre/post factor × target type ($F(1,19) = 6.95$, $p < 0.05$, $\eta 2_p = 0.27$) and target type × cue type ($F(2,38) = 7.68$, $p < 0.01$, $\eta 2_p = 0.29$). No other effects presented statistical significance ($p > 0.37$). A deeper inspection of the second interaction revealed that SNSI significantly differed within the L condition ($L_{no\text{-}cue} = 2.50$, $L_{incongruent} = 2.62$, $L_{congruent} = 1.65$, $F(2,38) = 11.41$, $p < 0.001$, $\eta 2_p = 0.38$) but not within the X condition ($p > 0.63$). Multiple paired *t*-test comparisons indicate that for the L condition SNSI significantly decreased from no-cue to congruent cue trials ($\Delta M = 0.85$, $SD = 1.00$, $t(19) = 3.79$, $p < 0.01$), and from incongruent cue trials to congruent cue trials ($\Delta M = 0.97$, $SD = 1.07$, $t(19) = 4.07$, $p < 0.01$), however, no difference was found between no-cue and incongruent trials ($p > 0.54$).

Additionally, we investigated differences on the median response time for the SNSI task ($SNSI_{RT}$), that is, the time taken for the participants to respond on the SNSI scale. It is important to assess this point to rule out the possibility that the observed effects were due to differences in how participants behaviorally performed the introspective task. A similar repeated measure ANOVA evidenced only a significant pre/post main effect ($F(1,19) = 12.70$, $p < 0.01$, $\eta 2_p = 0.40$) reflecting a learning effect across blocks. No other main effect or interactions were found.

As the pattern of influence of the cue on SNSI is the same as the one found for the latency of the first fixation on the target, we investigated whether FTFL could explain them as a mediating variable. We restricted this analysis to the L condition, as results above showed that there was no impact of the cue on SNSI in the X condition. In fact, we found a significant linear regression between SNSI and FTFL ($r^2(119) = 0.38$, $\beta = 0.003$, $t = 8.51$, $p < 0.001$). Thus, we tested whether the main effect between cue type and SNSI it is still significant after controlling FTFL, using a mediation model. The model, run over individual trials, indicated that the cue type has a significant and negative relationship with FTFL ($r^2(2507) = 0.02$, $\beta = -98.18$, $t = -6.34$, $p < 0.001$). At the same time, FTFL and SNSI were, independently of cue type, significantly and positive related ($r^2(2507) = 0.23$, $\beta = 0.002$, $t = 27.6$, $p < 0.001$). However and importantly, after controlling FTFL, the relationship between SNSI and cue type was not significant anymore ($p > .14$). This result suggests that participants' introspection tracks attentional changes that occurred between the presentation of the stimuli and perceptual decision. However, from this last result there is still an issue left to explain: can the variability of the SNSI be an index of eye movement? In other words, the subjects could have inferred their introspective estimate from eye movement occurred during the search? So as to mitigate the worry that SNSI is simply a transformation of the number of saccades, we first note that both the FTFL (r^2 $(2507) = 0.23$, $\beta = 0.002$, $t = 27.6$, $p < 0.001$, see above) and the number of saccades (r^2 $(2507) = 0.26$, $\beta = 0.47$, $t = 29.7$, $p < 0.001$, analysis on CS trials, not averaged) correlates positively with the SNSI. The FTFL index correlated also highly with the number of saccades (r^2 $(2507) = 0.80$, $\beta = 202.9$, $t = 101.7$, $p < 0.001$). Thus, we tested whether the relationship between SNSI and the FTFL holds after controlling the number of saccades. Indeed, a mediational analysis between these variables confirms this prediction (FTFL $\sim$ SNSI controlling number of saccades: r^2 $(2505) = 0.26$, $\beta = 0.0005$, $t = 3.31$, $p < 0.001$). In other words, the SNSI captures something present in the FTFL that is not limited to the number of saccades.

Secondly, we separated trials according to the number of saccades, and then we repeated the analysis independently. SNSI always correlated positively with FTFL and we found a statistical significant effect in the case of 6 saccades (ANOVA one way, cue type main effect: $F(2.35) = 3.42$, $p < 0.05$, $\eta^2 p = 0.16$); L non-cue: $M = 3.62$, $SE = 0.35$; L incongruent: $M = 3.80$, $SE = 0.39$; L congruent: $M = 2.77$, $SE = 0.46$; paired t-test: L non-cue *vs*. L incongruent ($p = 0.60$), L incongruent *vs*. L congruent ($\Delta M = 0.96$, $SD = 1.82$, $t(16) = 2.17$, $p < 0.05$), L no-cue *vs*. L congruent ($\Delta M = 0.83$, $SD = 1.64$, $t(16) = 2.08$, $p = 0.052$)). This indicates that there is at least one case where participants' introspection reported a shift in attentional processing not attributable to eye movement.

4. Discussion

In this experiment we found that a non perceived cue presented before the target in a visual search paradigm influenced the subjective complexity of the search. This cue had no impact on the motor response times, as the responses were made during a response window after stimulus presentation, but it did impact eye movements and the time elapsed between stimuli presentation and the first fixation on the target (FTFL): a cue presented at the position of the target shortened the time for the first fixation on the target when this was a hard to find one (CS: L). In order to understand the importance of this result on the mechanisms of introspection, it is important first to discuss the status of the cue with respect to visibility.

We introduced a visibility questionnaire and a visibility test in between the first and the second half of the experiment, so as to both assess the visibility of the cue and the impact of the knowledge of its presence on participants' introspection. Remember that participants were not apprised about the presence of the cue until the end of the visibility questionnaire. Results on this questionnaire conclusively show that no participant had noticed that a cue had been presented in half of the trials. However, when informed about this fact, they could detect it with better than chance performance. Thus we conclude that while not subliminal in a strict sense, the cue was not consciously (here in the sense of spontaneously) perceived. It was thus presumably pre-conscious in the sense of Dehaene et al. (2006). Importantly, with reference to theories of introspection, it could not in any way have been used by participants in rational, explicit inferences in the introspective judgments (the Subjective Number of Scanned Items response, SNSI), as they simply did not know about its presence. Moreover, since this fact was revealed after the questionnaire, we could test whether knowing about the cue (formally, the epistemic status of the cue) would impact introspection. As we did not find any significant interaction between the pre and post questionnaire phases of the experiment and cue effects on SNSI, we tentatively conclude that the cue impacts introspection through a non-conscious effect on the source of information that introspection draws upon, and not through a modification of some ex-post rational explanation that participants build. Indeed, within each search condition (X and L), congruent and incongruent cue trials were perceptually equivalent to participants, and lead to the same motor response. Nevertheless, they lead to different introspective reports because the non-perceived cue modified the mechanisms of the search.

Now, in what way did the cue impact the search? In fact, as it is shown by the eye movement and FTFL results, the cue exogenously drew attention to its own location. Of course we do not have direct evidence for the attentional effect of the cue, but links between eye movements and attention are now solidly established (Donk & van Zoest, 2011). In consequence, the following question is prompted: is it then the ocular movement what individuals report when reporting the SNSI? We have presented results that make that interpretation improbable. However there is also literature in that direction. It is generally admitted (Haggard, 2005) that small saccades themselves are not consciously experienced. In particular, it is well known

(Deubel, Irwin, & Schneider, 1999; Hunt & Cavanagh, 2009) that observer mistake the timing of their attentional shifts for the timing of their saccades.[2] In addition, in the anti-saccade paradigm, it has been shown (Mokler & Fischer, 1999; Taylor & Hutton, 2011) that participants are often (around 50% of the time) unaware that they made an anti-saccade, even when their attention was necessarily drawn to the possibility of errors by construction of the paradigm. In summary, participants probably are not aware of their eye-movements behaviors; if they are aware of something, they most probably are aware of the visual attention behavior that precedes eye-movements.

Coming back to our results, in the case of the X condition, the incongruent (resp. congruent) cue competed with (resp. reinforced) the pop-out features of the target and slowed (resp. sped-up) the first fixation on the target. Notice that this had no effect on introspection, as in all cue conditions, the subjective number of scanned items before the decision was already at floor (median SNSI below 1): the target pops-out, meaning that it is nearly always the first item perceived. In the L condition, the cue does have a facilitatory effect in case it is congruent, because it directs attention to the correct location. It does not have any detrimental effect in case it is incongruent because it is randomly positioned, as, we may presume, the spontaneous location of participants' attention when there is no cue. Thus, we may presume that unbeknownst to participants, the cue modified the trajectory of their search, by controlling its attentional guidance (Treisman & Gelade, 1980; Wolfe, 1994). We successfully controlled the search process outside participants' awareness, so that they could not rationally elaborate on the role that the manipulation could have on their subjective reports. Given this, our results show that participants are able to report on the complexity of the search process as driven by its attentional guidance.

We do not claim that attentional guidance is the sole contributor to the SNSI index. There may be additional factors that participate in the configuration of an introspective judgment (Reyes & Sackur, 2014). For instance, the confabulation of introspection can be generated by interoceptive information related to motor changes during the search task (Deubel et al., 1999), such as muscle tension, pressure on sclera, etc. Even though this point must be treated in more detail (see introspective pluralism, Schwitzgebel, 2012), from our results we can conclude that at least some of the SNSI variability is related to the number of "attentional fixations" during visual search, independently of eye movements and motor response times. Further experiments may be focused on investigating if it is possible to replicate this effect in a covert attention paradigm, thereby ruling out that the introspective access is exclusively restricted to a motor factor related to the attentional shift.

Finally, we note that the impact of the cues might not simply be due to its drawing attention to a certain position of the search array, but also because it might have altered the processing of the target.[3] Indeed it has been shown that attention alters appearance (Carrasco, Ling, & Read, 2004), in that exogenous attention can increase the apparent contrast of a target, and also that attention causes "*prior entry*" (Spence & Parise, 2010): so that the speed of processing is increased for target at the focus of attention. This effect has been shown to be impervious to conscious attention when the cues are below the threshold for consciousness (Weiss & Scharlau, 2012). Thus it could be that congruent target were in fact more contrasted than uncued targets, in which case, our manipulation might have had a perceptual impact that participants could perceived, in spite of the fact that the cue itself remained pre-conscious. In the same line, it can be argued that the target processing may have been modified through a non-attentional facilitation of appearance effect. Bachmann (1988) explains that in the context of rapid succession of two stimuli, the processing of a first *non-specific stimulus* (i.e., the cue) may facilitate the processing and therefore the perception of a second specific stimulus (i.e., the target). Importantly, this is not an attentional facilitation effect over the second stimuli, but a subcortical facilitation process (*non-specific thalamic facilitation*). We note nevertheless that we do not find any significant effect of the cue on feature searches (FS), contrary to what might have been expected if the effect of the cue was an increase in contrast or speed up of processing. It could of course be the case that non-attentional alteration in appearance interacts with attentional features of the targets, but we acknowledge that there would then be no simple way to disentangle these effects from attentional orienting in our paradigm. Further studies would be needed to clarify this issue.

These results complement our previous results (Reyes & Sackur, 2014) that introspection can be flexibly attuned to first order processes so that, under some conditions pure mental monitoring of the search process was possible. However, in our previous study, we could not conclusively establish *what* internal source of information was used by participants. Here, we can do so, to the extent that at least some information in the SNSI index must come from an active tracking of attentional guidance during the search. Our results converge with recent results by (Marti et al., 2015) showing that participants were able to report the trajectory of their fixations during a serial search. The authors could even present evidence that the divergences between real and subjectively reconstructed eye movements were due to confusions between eye and attentional fixations. However, since the authors did not have external control on the eye movements themselves, they could not conclusively assess whether divergences between introspection and observed eye movements were due to errors of introspection (be they confabulatory or simple mistakes), or to introspection that does not match behavior. Our methodology enables us to conclude that, while certainly not infallible, introspection does access internal attentional mechanisms that are instrumental to the search process.

In their celebrated 1977 paper, Nisbett and Wilson used instances where participants introspection was driven by a cause that they did not acknowledge to show how prone to confabulation they were: according to their often quoted example, participants elaborate on the quality of the socks they chose to justify their choice, while in fact it appears that they most probably simply chose the ones on the right. Ironically, we turn the argument around: it is precisely because participants

[2] In the words of Deubel et al. (1999, p. 65): "The data show that subjects are unaware of the time when they make even a large saccade, and that they have no explicit knowledge of the retinal position of stimuli. Rather, they mistake movement of visual attention for movements or the eyes".

[3] We thank an anonymous reviewer for this suggestion.

are not aware of a cause (of which we have implicit behavioral evidences through eye movements and FTFL) that influences their search process, that we can assert that their introspection is, at least in part, veridical. Now, if introspection of inner processes is in principle veridical and based on identifiable sources of information, it means that it might be assimilated to a decision process, in the same way that perception is classically understood as a decision process. This opens exciting avenue for further research about the causes and consequences of errors of introspection (introspective false alarms and misses) as well as of correct introspections (hits and correct rejections).

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2016.10.003.

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