



Working memory capacity modulates expectancy-based strategic processing: Behavioral and electrophysiological evidence

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ARTICLE INFO

Keywords:

Stroop priming effects
Expectancy-based strategic processes
SOA intervals
Individual differences in working memory capacity
N2 ERP component

ABSTRACT

The present research measured participants' event-related brain activity while they performed a Stroop-priming task that induced the implementation of expectancy-based strategic processes. Participants identified a colored (red vs. green) target patch preceded by a prime word (GREEN or RED), with incongruent prime-target pairings being more frequent (75 %) than congruent pairs (25 %). The prime-target stimulus onset asynchrony (SOA) was manipulated at two levels: 300 vs. 700 ms. Participants also performed a change localization task to assess their working memory capacity (WMC). At the 300 ms SOA, all participants presented a Stroop-priming congruency effect (slower responses on incongruent than on congruent trials) and an increased N2 amplitude in incongruent trials, irrespective of their WMC. At the 700-ms SOA, the lower-WMC group showed again a larger negative-going waveform to incongruent targets, whereas the higher-WMC group exhibited a reversed Stroop-priming congruency effect (faster responses to incongruent targets) and the N2 component was absent.

1. Introduction

Working memory (WM) is the cognitive system that allows us to actively retain and manipulate a limited amount of internal information (e.g., [Baddeley, 1986](#)). WM function is not only important for storage and manipulation of information but also supports attentional selection: WM maintains the goal-directed focus on the relevant aspects of the environment, while actively blocking the processing of irrelevant or distracting information (e.g., [Gazzaley & Nobre, 2012](#); [Kane, Bleckley, Conway, & Engle, 2001](#); [Lavie, Hirst, de Fockert, & Viding, 2004](#)).

A line of investigation that provides direct evidence for a close association between WM and selective attention uses a methodological strategy based on "extreme-groups", in which WM capacities of a large sample of participants are first assessed by means of several WM tasks. Participants showing higher and lower scores on those tasks (e.g., first vs. fourth quartiles) are then required to perform selective attention tasks. For instance, when participants have to name the ink color of a color word in a conventional Stroop task, individuals with a high WM capacity (WMC) are usually more effective at selectively attending to the

relevant ink color and at suppressing the influence of the irrelevant name of the color word, compared to low-WMC participants. Similar differences between high-WMC and low-WMC individuals have been reported in other selective attention tasks (e.g., [Ahmed & De Fockert, 2012](#); [Conway, Tuholski, Shisler, & Engle, 1999](#); [Kane & Engle, 2003](#); [Kiefer, Ahlegian, & Spitzer, 2005](#); [Megías, Ortells, Noguera, Carmona, & Marí-Beffa, 2020](#); [Ortells, Noguera, Álvarez, Carmona, & Houghton, 2016](#); see also [Wiemers & Redick, 2018](#)).

In a similar vein, studies on cognitive ageing have shown that older adults, who often perform worse than younger individuals on WM tasks (e.g., [Gazzaley, 2012](#); [Noguera, Fernández, Álvarez, Carmona, Marí-Beffa, & Ortells, 2019](#)), tend to be more vulnerable to (and need more time to block) the influence of competing distractors in selective attention tasks, thus showing a similar pattern to that observed in younger adults with lower WMC ([Gazzaley, 2012](#); [Gazzaley, Clapp, Kelley, McEvoy, Knight & D'Esposito, 2008](#); [Jost, Bryck, Vogel, & Mayr, 2011](#); see also [Noguera et al., 2019](#)).

Another line of evidence supporting a role of WM in selective attention comes from studies that use a dual task paradigm, in which a

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<https://doi.org/10.1016/j.biopsycho.2021.108023>

Received 22 July 2020; Received in revised form 12 January 2021; Accepted 12 January 2021

Available online 15 January 2021

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WM task is combined with a selective attention task (e.g., Stroop) to measure the distractor interference in a context of varying memory load (e.g., retaining series of random vs. ordered digits). The usual finding is that distractor effects on the attention task, in terms of increased response latency and/or reduced accuracy, are greater under high compared to low WM load (e.g., De Fockert, Mizon, & D'Ubaldo, 2010; De Fockert, Rees, Frith, & Lavie, 2001; Lavie & De Fockert, 2005; see De Fockert, 2013, for a review).

Although much less investigated, there also is evidence that a reduction in the availability of WM resources, as a consequence of either cognitive ageing, having low WMC, or performing a concurrent task demanding a high load, could negatively affect facilitatory strategic processing in priming tasks. Semantic priming is said to occur when responses to a target stimulus (e.g., chair) are faster (and more accurate) when it has been preceded by a semantically related prime (e.g., table) rather than an unrelated prime (e.g., lion). These priming effects have been argued to be the result of at least two kinds of forward-acting prospective mechanisms: automatic spreading preactivation of the target representation, and controlled strategies such as expectancy generation (McNamara, 2005; Neely, 1991; for a retrospective strategic mechanism that begin to operate after the target appears, see Neely & Keefe, 1989a, 1989b). Expectancy generation is described as slow, effortful, and under conscious control and involves using the prime on a given trial to develop expectancy for specifically related targets during the interval between prime and target onset. Facilitation in target identification occurs if the target is included among the generated expectancy set (see Becker, 1980; Neely, 1977, 1991; Posner & Snyder, 1975, for more detailed descriptions of expectancy generation).

Some recent studies have demonstrated that under conditions that encourage the use of expectancy-based controlled strategies (i.e., a high proportion of related pairs), priming effects were greatly reduced (or even eliminated) for participants with low WMC, or under high WM load (e.g., Heyman, Van Rensbergen, Storms, Hutchison & Deyne, 2014; Hutchison, Heap, Neely, & Thomas, 2014). However, as these studies used a conventional facilitatory priming paradigm, in which both controlled and automatic priming processes converge with regard to their beneficial effects on target processing (i.e., faster responses on related than on unrelated trials), the above results cannot be unequivocally interpreted in terms of a decreased strategic processing. When both types of processes contribute to performance in the same direction (i.e., facilitating), it is difficult to know whether the reduced priming effects under high load conditions, or in low-WMC individuals, are really due to a less efficient use of expectancy-based strategies (but see Hutchison, 2007). Alternatively, based on several previous demonstrations that supposedly automatic priming effects (e.g., induced by subliminally present stimuli) can be modulated by attentional influences (e.g., Kiefer & Brendel, 2006; Kiefer & Martens, 2010), it is not implausible that a low WMC could also lead to a reduction of the automatic processing of the prime stimulus.

In order to overcome this potential limitation, some other studies have used alternative priming paradigms, in which strategic vs. non-strategic (automatic) prime processing can lead to qualitatively different behavioral effects (i.e., priming effects in opposite directions; e.g., Merikle & Joordens, 1997; Noguera et al., 2019; Ortells, Álvarez, Noguera, Carmona, & De Fockert, 2017; Ortells, Daza, & Fox, 2003).

An illustrative example is the Stroop-priming task developed by Merikle and colleagues to demonstrate that predictive strategies based on stimulus redundancy only occurs when observers are consciously aware that the prime identity (e.g., Merikle & Cheesman, 1987; Merikle & Daneman, 1998; Merikle & Joordens, 1997; Merikle, Joordens, & Stolz, 1995; see also Daza, Ortells, & Fox, 2002). They used a two-color sequential variant of the Stroop task, in which two color words -RED or GREEN- are used to prime responses to two target colors -also red or green-, and the incongruent prime-target pairings are much more frequent (80 % of the trials) than congruent pairings (20 %). The differential proportion of congruent vs. incongruent trials induces

participants to strategically utilize the predictive information provided by the primes to maximize performance. Since only two colors are used and incongruent prime-target pairings occurred on most of the trials, the best prediction that could be made concerning the target was that it would be the color *not named* by the prime (cf. Merikle & Cheesman, 1987; see also Merikle & Joordens, 1997). Such a predictive strategy had allowed participants to anticipate the target correctly on 80 % of the trials (having only led to incorrect anticipations on 20 % of trials), so participants' responses could be faster (and/or more accurate) on incongruent than on congruent trials.

This strategic reversal of the Stroop congruency effect is in fact, the kind of result pattern that is observed with this Stroop priming task when the prime is clearly visible (i.e., presented for a long duration and/or unmasked), such that it can be consciously identified (e.g., Merikle & Cheesman, 1987; Merikle & Daneman, 1998; Merikle & Joordens, 1997; Merikle et al., 1995), and the prime-target stimulus onset asynchrony (SOA) is long enough (e.g., 500 ms or longer) to allow the implementation of predictive strategies (e.g., Daza et al., 2002; Froufe, Cruz, & Sierra, 2009; see also Noguera et al., 2019).²

On the contrary, under task conditions that impede or make difficult the strategic processing of the prime, such as presenting it below the threshold of awareness, and/or using a short prime-target SOA (e.g., 300 ms or less), participants' performance is similar to that observed when congruent and incongruent trials are equally probable (i.e., 50/50); namely, a standard Stroop congruency effect is rather found, with faster responses on congruent than on incongruent trials (e.g., Daza et al., 2002; Merikle & Cheesman, 1987; Merikle & Joordens, 1997).³

This Stroop-priming task (with congruent to incongruent ratio (C/I) = 20/80), in combination with a concurrent verbal working memory task that demanded either a high or a low load, was recently used by Ortells et al. (2017). In order to maximize the implementation of predictive strategies in the Stroop priming task, the prime word was always presented for 100 ms and unmasked (thus always being clearly visible) and relatively long prime-target SOA of 1000 ms was used (see also Froufe et al., 2009; Noguera et al., 2019). The prime word was preceded by a sequence of either five different random digits (high load) or five repetitions of the same digit (low load), which the participants were required to memorize. After two, three, or four Stroop priming trials, participants had to decide whether or not a single probe digit was a part

² Note 1. It should be stressed that only when this Stroop priming task include a much higher proportion of incongruent (e.g., 75–80%) than of congruent prime-target pairings (e.g., 25–20%), one could observe a change in the direction of the difference in performance between incongruent and congruent trials, as a function of the strategic/conscious (reversed Stroop) vs. non-strategic or automatic processing (standard Stroop congruency) of the prime stimulus. By the contrary, when incongruent trials are less frequent (e.g., 20%) than congruent trials, the usual finding is a compatibility effect of a similar (or even greater) magnitude to that observed when congruent and incongruent trials are equally probable (i.e., 50/50). Thus, participants' responses to the target color are faster when it is preceded by the congruent color word than when it is preceded by the incongruent color word (e.g., Logan, Zbrodoff, & Williamson, 1984; Merikle & Cheesman, 1987). But the problem with this latter compatibility effect is that one cannot be sure whether it is mainly the result of either expectancy-based predictive strategies (congruent trials are much more expected than incongruent ones), automatic process (e.g., spreading activation), or a combination of both strategic and automatic influences, as it could be really the case.

³ Note 2. It is important to note that the interference (incongruent vs. congruent) effect observed in a two-color Stroop priming paradigm under task conditions that preclude a conscious/strategic prime processing, is relatively small (e.g., 15–20 ms or lesser; see for example Daza et al., 2002; Merikle & Cheesman, 1987; Merikle & Joordens, 1997; Merikle et al., 1995). This contrasts with the magnitude of the Stroop interference that usually emerges with conventional or sequential variants of the Stroop task where conflict (incongruent) trials are equally probable, or less frequent than congruent trials (e.g., Glaser & Glaser, 1982; Merikle & Cheesman, 1987).

of the previously memorized digit-set. The key finding was a reliable interaction between prime-target congruency and WM load. Reversed (strategic) Stroop effects were found under low WM load, whereas (non-strategic) Stroop congruency effects were observed under high WM load. These findings provide further evidence that a reduction in the availability of WM resources by engaging WM in an additional task of high load can lead to less efficient strategic processing of task-relevant information. Non-strategic, automatic processing prevails under such high WM load conditions.

These effects of WM load on expectancy-based strategic processing were replicated in a further study by [Ortells, De Fockert, Romera, and Fernández \(2018\)](#) with a non-verbal (spatial) WM tasks. This suggests that the effects of WM load on strategic prime processing are not domain-specific, but rather domain-general (e.g., shared attentional control resources).

A similar dependence of expectancy-based strategies on WM resources has been recently observed in a study comparing Stroop-priming effects in younger and older adults ([Noguera et al., 2019](#)): A strategic reversed Stroop effect at long SOAs (e.g., 1000 ms) was only observed in younger adults, but not in older adults (which showed lower WMC). These findings suggest that expectancy-based strategies can only be efficiently implemented if WMC is available to appropriately process the strategically relevant information.

1.1. Current study

The present research had two main aims. Firstly, we wanted to further investigate whether the implementation of controlled attentional strategies, like expectancy generation, was sensitive to individual differences in WMC.

Secondly, as far as we know, no previous study has explored whether individual differences in WM capacity can modulate electrophysiological correlates of strategic priming. Previous research examining a possible dependence of expectancy-based strategic processing on the availability of WM resources has exclusively based on behavioral measures of performance. Thus, we set up to track the time course of the neuro-cognitive mechanisms underlying the interaction between WMC and strategic attentional processing using event-related potential (ERP) recordings.

To this end, we used a Stroop-priming task similar to that of [Noguera et al. \(2019\)](#), [Ortells et al. \(2017, 2018\)](#), such that incongruent prime-target pairings were much more frequent (75 %) than congruent pairings (25 %). Rather than combining the Stroop-priming task with a concurrent WM task, this time a sample of younger adults performed the single Stroop priming task under two prime-target SOAs of 300 ms and 700 ms, which were presented in two different trial blocks counter-balanced across participants. In most of previous studies reporting qualitatively different priming effects as a function of strategic vs. non-strategic prime processing, the main factors (e.g., prime-mask SOA; prime-target SOA; WM load) have been manipulated either (a) across different participants, or (b) across different blocks (e.g., [Daza et al., 2002](#); [Merikle & Joordens, 1997](#); [Noguera et al., 2019](#); [Ortells et al., 2003](#); see also [Hutchison et al., 2014](#); [Ortells et al., 2017, 2018](#)). Block-wise (or even between-subject) manipulation of SOA has the advantage of fostering expectancy-based processes because participants can establish expectancy about occurrence of a particular target type more easily than with randomized presentation of SOA. Accordingly, in the present study we manipulated the prime-target SOA in a blocked design.

To assess WMC, participants performed the Visual Change Localization task as used previously ([Noguera et al., 2019](#); [Ortells, De Fockert, Romera, & Fernández, 2018](#)). This task is much simpler than other complex span tasks often used to assess WMC (e.g., Operation or Symmetry Span tasks), as it is shorter (less than 10 min), and does not require task switching. Despite its simplicity, performance in the Visual Change Localization task has shown strong correlations with broader measures

of higher cognitive abilities and attentional control capacities (e.g., [Castillo Escamilla et al., 2020](#); [Johnson et al., 2013](#); [Noguera et al., 2019](#)).

Based on previous findings showing consistent strategic effects with this kind of priming tasks at relatively long SOAs and/or in participants with a higher WMC (e.g., [Froufe et al., 2009](#); [Noguera et al., 2019](#); [Ortells et al., 2018](#)), we expected to find a reliable three-way interaction between Congruency, prime-target SOA, and WMC. To the extent that a relatively short SOA of 300 ms will impede the efficient implementation of expectancy-based strategies, we predict that participants, irrespective of their WMC, will show faster responses on congruent relative to incongruent trials, thus revealing non-strategic processing of the prime at the 300-ms SOA. At the longer 700-ms SOA, however, we expect to find a reversed (strategic) Stroop priming effect in participants with higher WMC (faster responses on the more frequent incongruent trials), whereas low-WMC individuals could show a Stroop-priming interference effect (or reduced reversed Stroop compared to high-WMC individuals).

In ERP recordings, the N2 ERP component typically indexes attentional conflict processing (e.g., during an incongruent trial in a Stroop task). This negative deflection has a fronto-central scalp distribution and peaks around 200–350 ms after target stimulus presentation (e.g., [Donohue, Appelbaum, McKay, & Woldorff, 2016](#); [Jongen & Jonkman, 2011](#); [Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004](#); [Tillman & Wiens, 2011](#); see [Folstein & Van Petten, 2008](#), for a review). The amplitude of the N2 component has been found to be more negative in incongruent Stroop trials compared to congruent trials (e.g., [Clayson & Larson, 2011](#); [Wendt & Luna-Rodríguez, 2009](#)). The N2 modulations have also been observed in other different sequential priming paradigms, such as response-cueing tasks inducing different response expectations (i.e., differential probability of incongruent and congruent trials; see for example, [Gajewski, Stoerig, & Falkenstein, 2008](#)) and visuo-motor response priming ([Kiefer, Liegel, Zovko, & Wentura, 2017](#); [Martens, Ansorge, & Kiefer, 2011](#)). Other studies using a negative priming paradigm, have also reported an enhanced N2 amplitude when participants respond to a probe target that was presented as an ignored distractor in a preceding prime display. This negative-going waveform in the N200 time window has been interpreted as evidence for attentional inhibition mechanisms (e.g., [Frings-Bordin, 2007](#); [Gibbons, 2006](#); [Hinojosa, Pozo, Méndez-Bértolo, & Luna, 2009](#)).

To the extent that a prime-target SOA of 300 ms impedes (or makes more difficult) an efficient development of expectancy-based strategies in our Stroop-priming task, thus leading to a congruency effect (slower responses to incongruent than to congruent targets), it would be plausible to find a more negative N2 component in incongruent compared to congruent trials for all our participants, irrespective of their WMC. On the contrary, at the SOA of 700 ms, a differential ERP pattern for participants with lower vs. higher WMC should be observed. Whereas individuals with lower WMC would again show an enlarged N2 component in incongruent trials similar to that found at the shorter 300-ms SOA, the difference in amplitude of N2 between incongruent and congruent conditions should be significantly reduced (or even eliminated) in higher WMC individuals. By means of expectancy generation, high WMC individuals should not experience a cognitive conflict in incongruent trials, as expressed by putatively reversed behavioral Stroop effects at the 700-ms SOA.

2. Materials and methods

2.1. Participants

Seventy-four right-handed undergraduate students (59 women) from the University of Almería (age range = 18–40 years; $M = 21.49$, $SD = 4.03$) received course credits for their participation in the study. All participants were native Spanish speakers with normal or corrected-to-normal vision. This sample size was greater than that used by previous

studies investigating the influence of either aging or adult differences in WMC on expectancy-based strategies with this Stroop-priming task (e.g., Froufe et al., 2009; $n = 67$; Ortells et al., 2018; $n = 44$; Noguera et al., 2019; Exp 1 and 2, $n = 52$). The experiment was conducted in compliance with the Declaration of Helsinki, and with the ethical protocols and recommendations of the "Code of Good Practices in Research", "Commission of Bioethics in Investigations from the University of Almeria". Participants were informed of the details of the experiment and signed an informed consent before their inclusion, with the protocol being approved by the Bioethics Committee in Human Research from the University of Almeria.

2.2. Stimuli and apparatus

The experiment was run on a PC using E-prime software v2.0 (Psychology Software Tools, Pittsburgh, PA). The stimuli were presented on a 17-inch CRT monitor (screen refresh rate: 16.67 ms) at a viewing distance of approximately 60 cm, and the responses were collected using mouse and joystick.

In the Change Localization task, four colored circles about 0.96° horizontally and 0.96° vertically were presented on a grey (RGB values 60, 60, 50) background screen. The four circles were randomly selected from a set of nine colors with the following RGB values: Black (0, 0, 0), Blue (0, 0, 255), Cyan (0, 255, 255), Green (0, 255, 0), Magenta (255, 0, 255), Orange (255, 113, 0), Red (255, 0, 0), Yellow (255, 255, 0) and White (255, 255, 255). The colors of the four circles were not repeated on the same screen and each one appeared randomly in one quadrant of the screen with a minimum and maximum distance respective to the central fixation point of 3.36° and 4.8° visual angle, respectively.

In the Stroop-priming task, the prime stimulus was either the word RED or GREEN (with font Courier New to size 22) written in white, whose letters occupied an approximate area of about 0.35° visual angle in width and of about 0.52° visual angle in height. The target stimulus was a rectangular patch presented in either red (255, 0, 0) or green (0, 255, 0) at fixation (7.39° horizontally and 2.6° vertically). All stimuli were presented on a black background (0, 0, 0).

2.3. Design and procedure

Participants attended a single experimental session lasting about 55–60 min. Each participant first completed the Change Localization Task (e.g., Noguera et al., 2019; Ortells et al., 2018; see also Johnson et al., 2013), which allowed to assess their WMC. In this task, each trial started with a fixation point (+) in the center of the screen that remained on the screen until the end of the trial. After 1000 ms, a sample array displaying four color circles (each circle colored in a different color) was presented for 100 ms. After a 900 ms black screen, a test array appeared, which was similar to the previous sample array except that one of the four circles had changed its color, and participants had to indicate the location of the change using the mouse (see for example Ortells et al.,

2018, Fig. 1, for a similar version of the task). Participants performed 12 practice trials followed by two experimental blocks of 32 trials per block, with a break interval between them. A variant of the Pashler/Cowan K equation (e.g., Cowan et al., 2005) was used to evaluate participants' WMC. As each stimulus array contained four circles and each test array always contained a circle that changed color, the proportion of correct responses from each participant was multiplied by four to calculate their WMC (K score). After completing the change localization task, each participant performed the Stroop-priming task (see Fig. 1).

Each experimental trial of the Stroop-priming task started with a central fixation point (variable duration between 500–1000 ms) followed by a prime word in Spanish ['VERDE' (GREEN) or 'ROJO' (RED)] in white letters displayed for 100 ms. After the prime word offset, a blank screen was presented for either 200 or 600 ms (thus resulting in a prime-target Stimulus Onset Asynchrony –SOA– interval of either 300 or 700 ms). Thereafter, a target stimulus (a central rectangle in either red or green) was shown, which remained on the screen until the response was given. Participants responded to the rectangle color by pressing one of the two buttons of a joystick with the index fingers of their two hands (hand counterbalanced across participants). The prime and target stimuli referred to either the same color (congruent trials) or different colors (incongruent trials) on 25 % and 75 % of the trials, respectively. At the beginning of the experiment, participants received information about the differential proportion of congruent and incongruent pairs, and were actively encouraged to strategically use that information to improve their performance in the task. Participants performed 24 practice trials followed by two experimental blocks (144 trials per block), one block for each SOA condition (300 and 700 ms), with the order of the two blocks being counterbalanced across participants. Each SOA block was divided into three blocks of 48 trials each (12 congruent trials and 36 incongruent trials), with breaks between them where participants could rest and move.

2.4. EEG recording and analysis

The participants were seated in a comfortable chair in a dimly lit, electrically shielded room. Scalp voltages were continuously recorded from 29 active electrodes mounted in a cap (actiCAP, Brain Products, Munich, Germany) arranged according to the international 10–10 system. An electrode between Fpz and Fz was connected to the ground, and an electrode between Fz and Cz was used as recording reference. Vertical eye movements were monitored with supra- and infraorbital electrodes. Two additional electrodes were attached over the left and right mastoids. ERP data were off-line re-referenced to averaged mastoids. All EEG electrode impedances were maintained below 5 k Ω . Brain electrical signals were digitized with a sampling rate of 250 Hz (0.1–70 Hz band-pass, 50 Hz notch filter) by an AC-coupled amplifier (Brain Amp, Brain Products, Munich, Germany). After recording, EEG data was digitally band-pass filtered (high cutoff: 25 Hz, 24 dB/octave attenuation; low cutoff: 0.2 Hz, 12 dB/octave attenuation), and segmented from 100 ms pre-target onset to 1000 ms post-target onset. The EEG was corrected for ocular/blink artifacts using independent component analysis (ICA; Makeig, Bell, Jung, Ghahremani, & Sejnowski, 1997). Remaining ocular and muscular artifacts were automatically rejected in any EEG channel (maximum amplitude in the recording epoch ± 100 μ V; maximum difference between two consecutive sampling points 50 μ V; maximum difference of two values in the epoch 200 μ V; lowest allowed activity-change 0.5 μ V in successive intervals of 100 ms) and, corresponding EEG segments were excluded from averaging. EEG data were corrected to a 100 ms baseline prior to the onset of the target (the last 100 ms of the time interval of the empty screen). Finally, electrodes were re-referenced to averaged mastoids. Artifact-free EEG segments to trials with correct responses were averaged separately for the four combinations of SOA and congruency conditions (with the mean percentage of EEG analyzable epochs per condition given in parentheses): 300-ms SOA (94 % and 94.4 % for congruent and incongruent conditions,

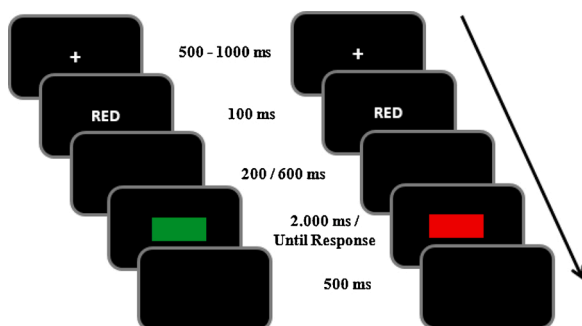


Fig. 1. Examples of incongruent (left) and congruent (right) trials in the Stroop-priming task.

respectively); 700-ms SOA (93.5 % and 94.5 % for congruent and incongruent trials, respectively).

Nine electrodes of fronto-central scalp regions (electrode sites: F3/F4, FC1/FC2, Fz, FCz, Cz, C3/C4), in which the N2 ERP component is usually largest (Donohue et al., 2016; Jongen & Jonkman, 2011; Tillman & Wiens, 2011; see Folstein & Van Petten, 2008, for a review), were selected for statistical analyses. Based on the theoretical expectations formulated in the introduction, we chose the time window of 190–290 ms post-target onset (encompassing the N200 component) for statistical analysis of the ERP data (the exact position and extension of that time window was based on visual inspection; see also Footnote 4). Mean amplitudes in the 190–290 ms post-target time range were computed for each of those electrodes. A repeated measures $2 \times 2 \times 3 \times 3$ ANOVA was performed on that time window (no reliable differences were noticeable when comparing the pattern of prime-locked ERP effects associated to the different conditions), treating congruency (congruent, incongruent), prime-target SOA (300, 700 ms), laterality (left, mid, right) and caudality (frontal, fronto-central, central) as within-participant factors (p level of .05). The Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom, when appropriate.

3. Results

3.1. Behavioral results

Trials containing an incorrect response (3.3 %) or those with reaction times (RTs) faster than 200 ms or more than 2.5 standard deviations from the overall mean RT (1.8 %) were removed from analyses. For the analysis of responses in the Stroop-priming task, mean RTs of correct responses and error rates (ER) were entered into two 2×2 Analyses of Variance (ANOVAs) with prime-target SOA (300 and 700 ms) and prime-target congruency (congruent and incongruent) as within-participant factors. Mean correct RTs and ER as a function congruency and SOA conditions are depicted in Table 1.

The ANOVA on ERs showed no significant effects [all F s < 1]. The ANOVA on RTs showed a significant main effect of congruency [$F(1, 73) = 29.87, p < 0.001, \eta^2 = 0.29$], with slower responses on incongruent (450 ms) than on congruent trials (438 ms) (i.e., a standard Stroop congruency effect). In addition, congruency interacted with prime-target SOA [$F(1, 73) = 37.7, p < 0.001, \eta^2 = 0.34$]. A further analysis of this interaction (see Table 1) showed a reliable Stroop congruency effect at 300-ms SOA [-22 ms; $t(74) = 8.74, p < 0.001, d = 0.37$], with this congruency effect being nonsignificant at the longer 700-ms SOA [-2 ms; $t < 1$].

In order to test whether the strategic use of congruency proportion in the Stroop-priming task was modulated by individual differences in WMC, we conducted an analysis of covariance (ANCOVA) treating prime-target SOA and congruency as within-participants factors, and WMC as a continuous covariate (for similar analyses, see Hutchison, 2007; Ortells et al., 2018; Richmond, Redick, & Braver, 2015). The results showed again a main effect of prime-target congruency [$F(1, 72) = 19.34, p < 0.001, \eta^2 = 0.21$], which interacted with WMC [$F(1, 72) = 13.35, p = 0.001, \eta^2 = 0.16$] and SOA [$F(1, 72) = 4.48, p = 0.038, \eta^2 = 0.06$], and most importantly, there was a significant three-way

Table 1

Mean (SD) correct reaction times (ms) and error percentages (in %) for congruent and incongruent trials in the Stroop-priming task, at 300-ms SOA and 700-ms SOA.

	Congruent	Incongruent	Stroop effect
300-ms SOA	430 (59.7) 3.0 (4)	453 (61) 3.2 (2.8)	-22 *
700-ms SOA	445 (64.5) 3.6 (3.7)	447 (63.4) 3.5 (2.8)	-2

interaction between SOA, Congruency, and WMC [$F(1, 72) = 8.95, p = 0.004, \eta^2 = 0.11$].

To decompose this latter interaction, we analyzed the Congruency \times WMC interaction separately for the 300-ms and 700-ms SOA conditions (see Fig. 2). At the 300-ms SOA condition, no reliable congruency \times WMC interaction was found [$F(1, 72) = 1.26, p > 0.266$]. Hence, participants consistently responded slower on incongruent than on congruent trials (i.e., a standard Stroop congruency effect) regardless of their WM capacity. In clear contrast, at the longer 700-ms SOA condition, there was a reliable crossover interaction between congruency and WMC [$F(1, 72) = 21.57, p < 0.001, \eta^2 = 0.23$], which shows that only participants with higher WMC were able to use an efficient strategic of congruency proportions, giving rise to a reversed strategic Stroop effect (see Table 2 for descriptive statistics; see also Fig. 3⁴). In fact, at the SOA of 700 ms, there was a reliable negative correlation between participants' WMC and the congruency effect [$r = -.48, p < 0.001$].⁵

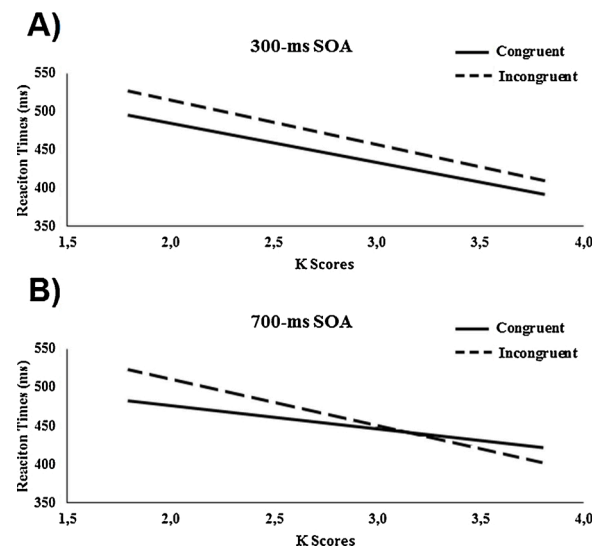


Fig. 2. Participants' response time (ms) for congruent and incongruent conditions in the Stroop-priming task as a function of WMC (K) scores under (A) 300-ms and (B) 700-ms SOA conditions.

⁴ Note 3. Whereas the ANCOVA analysis considers the full range of WMC scores, for a better visual understanding of that analysis, Fig. 3 shows participants divided into high- ($k > 3.48$), medium- ($k < 3.04$), and low-WMC ($k < 2.71$) groups by using a tertile split (see Ortells et al., 2018; Richmond et al., 2015 for a similar approach).

⁵ Note 4. To examine whether the observed findings could at least partly be affected by direct trial repetitions, we conducted a further data analysis, in which for each participant, we removed every trial reflecting more than two consecutive direct repetitions from the same condition. The overall mean of trials excluded was relatively low in the two SOA blocks (mean = 12 trials; at about 8.3% of trials), and very similar for all the participants (Min = 6 trials; Max = 16 trials). The results from these re-analyses without trials repetitions produced basically the same result pattern as that found in our original data analyses. Namely, the Congruency \times SOA interaction was again significant [$F(1, 73) = 38.27, p < 0.001, \eta^2 = 0.34$], as it was the three-way interaction between Congruency, SOA, and WMC as a covariate [$F(1, 72) = 9.65, p = 0.003, \eta^2 = 0.12$]. Further analyses of the later interaction revealed again slower responses to incongruent than to congruent targets at the shorter 300-ms SOA, irrespective of participants' WMC. In contrast, at the longer 700-ms SOA, a reliable congruency \times WMC was found ($F(1, 72) = 21.08, p < 0.001, \eta^2 = 0.23$): Whereas responses from low-WMC participants were again slower to incongruent than to congruent targets, high-WMC individuals showed an opposite priming pattern, with their responses being faster on incongruent than on congruent trials (reversed Stroop).

Table 2

Descriptive statistics for the Change Localization task and the Stroop-priming effects (incongruent minus congruent; in milliseconds) for each SOA-condition in the Stroop-priming task (300 ms and 700 ms).

	Change Localization Task			Stroop-priming Task					
	K Mean (SD)	Skew	Kurtosis	300-ms SOA			700-ms SOA		
				Stroop effect (SD)	Skew	Kurtosis	Stroop effect (SD)	Skew	Kurtosis
Overall Sample	3.08 (0.41)	-0.48	0.23	-22.54 (22.18)	0.65	0.87	-2.10 (25.89)	0.25	0.86
Low-WMC Group	2.71 (0.34)	-0.65	0.28	-29.37 (27.54)	0.57	-0.39	-14.79 (26.29)	0.90	0.27
Medium-WMC Group	3.04 (0.18)	-1.02	0.63	-19.61 (21.78)	0.03	0.60	-6.74 (18.49)	-0.10	0.16
High-WMC Group	3.48 (0.21)	-0.76	0.63	-18.52 (14.41)	0.20	0.44	+15.05 (22.89)	-0.26	-0.46

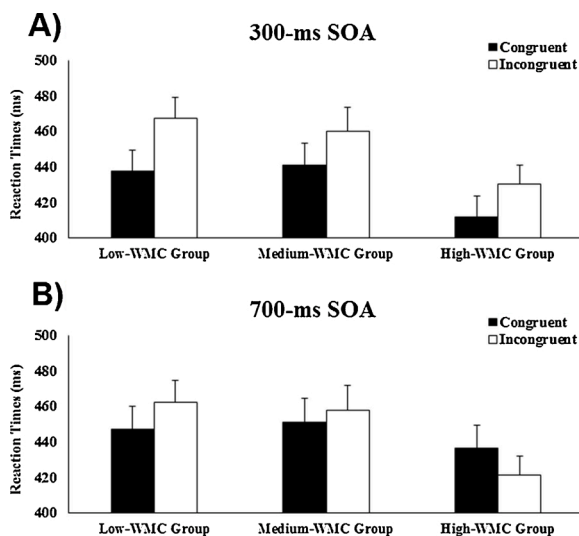


Fig. 3. Mean reaction times (and standard error of the mean) for congruent and incongruent prime-target pairs as a function of SOA condition (A: 300-ms SOA; B: 700-ms SOA) and WMC group (low-, medium-, and high-WMC).

3.2. Electrophysiological results

The ANOVA on the 190–290 post-target epoch (N2) showed significant main effects of caudality [$F(1, 72) = 25.87, p < 0.001, \eta^2 = 0.26$] and laterality [$F(1, 72) = 11.33, p < 0.001, \eta^2 = 0.13$]. The voltages were collapsed across the nine fronto-central electrode sites as neither of both interacted with either congruency or prime-target SOA. The main effect of congruency was significant [$F(1, 73) = 9.51, p = 0.003, \eta^2 = 0.12$], with the ERPs in incongruent trials being more negative than congruent trials (i.e., an enlarged N2 component in incongruent trials). The interaction between congruency and SOA was also significant [$F(1, 73) = 13.92, p = 0.001, \eta^2 = 0.16$]: At the 300 ms SOA, N2 amplitude was reliably more negative for incongruent than for congruent trials [$-0.71 \mu\text{V}; t(73) = 4.36, p < 0.001, d = 0.33$]. However, this was not the case at the 700 ms SOA, in which the voltage difference between the two-congruency conditions was not significant [$-0.05 \mu\text{V}; t < 1$; see Fig. 4].

We conducted again an ANCOVA, using WMC as a continuous covariate variable and prime-target SOA and congruency as within-participants factors. This analysis showed an interaction between SOA and Congruency [$F(1, 72) = 4.39, p = 0.04, \eta^2 = 0.06$] and, as also found in the previous analysis, a significant three-way interaction between SOA, Congruency, and WMC [$F(1, 72) = 6.9, p = 0.011, \eta^2 = 0.09$].

At the 300-ms SOA condition, no reliable congruency \times WMC interaction was found [$F(1, 72) = 0.68, p > 0.41$]: Participants consistently showed a higher negative amplitude on incongruent than on congruent trials lower on incongruent than on congruent trials (i.e., a N2 component) regardless of their WM capacity (see Fig. 5A). In contrast, at the longer 700-ms SOA condition, there was a crossover interaction between

congruency and WMC [$F(1, 72) = 5.31, p = 0.024, \eta^2 = 0.07$], such that a higher WMC was associated with a smaller negative amplitude (or a higher positive amplitude on incongruent trials) whereas lower-WMC participants showed a greater negativity in incongruent trials as at the shorter 300-ms SOA (see Fig. 5B). In addition, at the longer SOA of 700 ms, there was a reliable correlation between participants' WMC and the congruency effect [$r = .26, p = 0.024$].⁶

4. Discussion

Although WM and selective attention have traditionally been considered to be separated cognitive concepts, evidence from different lines of research has been accumulated in support of close link between these two constructs (e.g., De Fockert, 2013; Gazzaley, 2012; Kiyonaga & Egner, 2014; Zanto & Gazzaley, 2014). Numerous studies have consistently demonstrated that a reduction in the availability of WM resources, as consequence of either cognitive ageing, having lower WMC, or imposing a high load in a concurrent memory task, is associated with a worse performing in different kinds of selective attention tasks. The usual finding is a reduced ability to efficiently inhibit or suppress the processing of competing, but task-irrelevant distractors.

More recently, evidence has been reported about variations in WM

⁶ Note 5. A further visual inspection of ERP-data registered at fronto-central electrode sites (see Fig. 4) revealed an additional voltage difference between the two-congruency conditions at a relatively early time window (90–190 ms). This ERP difference emerged at the longer 700-ms, but not at the shorter 300-ms SOA, as revealed by a reliable Congruency \times SOA interaction ($F(1, 73) = 7.2, p = 0.009, \eta^2 = 0.09$). The results of a further ANCOVA showed a significant three-way interaction between these two later factors and WMC ($F(1, 72) = 6.02, p = 0.017, \eta^2 = 0.08$), which revealed that, as occurred in the later post-target epoch associated to the N2 component (190–290 ms), the ERP differences between low-WMC and high-WMC participants emerged mainly at the prime-target SOA which allowed a strategic prime processing (700 ms). Namely, lower-WMC individuals showed a more negative potential in incongruent trials, which resembles the behavioral (i.e., Stroop interference) and ERP effects (e.g., N2) usually found in Stroop conflict conditions. By contrast, individuals with a higher-WMC showed a “reversed” ERP-congruency effects, with a more negative potential to (the less frequent) congruent than to the incongruent targets. These ERP-differences between high- and low-WMC participants could be assumed to provide further evidence for a differential prime processing (strategic vs. non-strategic, respectively) in the Stroop priming task. Yet, this argument should be interpreted with caution. Whereas, overall, our findings are consistent with a supposedly more efficient (and/or faster) implementation of expectancy-based strategies in higher-WMC, relative to lower-WMC individuals, it remains unclear why prime-locked ERP activity was not modulated by WMC in the current study (see General Discussion). An alternative explanation of the ERP differences showed by high-WMC vs. low-WMC participants in an earlier time window (90–190 ms), is that they could reflect differences in sensory evoked ERP components, such as the posterior vision P100 component, an index of stimulus perception and processing (Atkinson et al., 2002; Herrmann; Earls, Curran & Mittal, 2016). But note that the ERP-congruency differences observed in our study were mainly found at fronto-central, but not at more posterior electrode sites (e.g., occipital), where the P100 ERP component is usually observed.

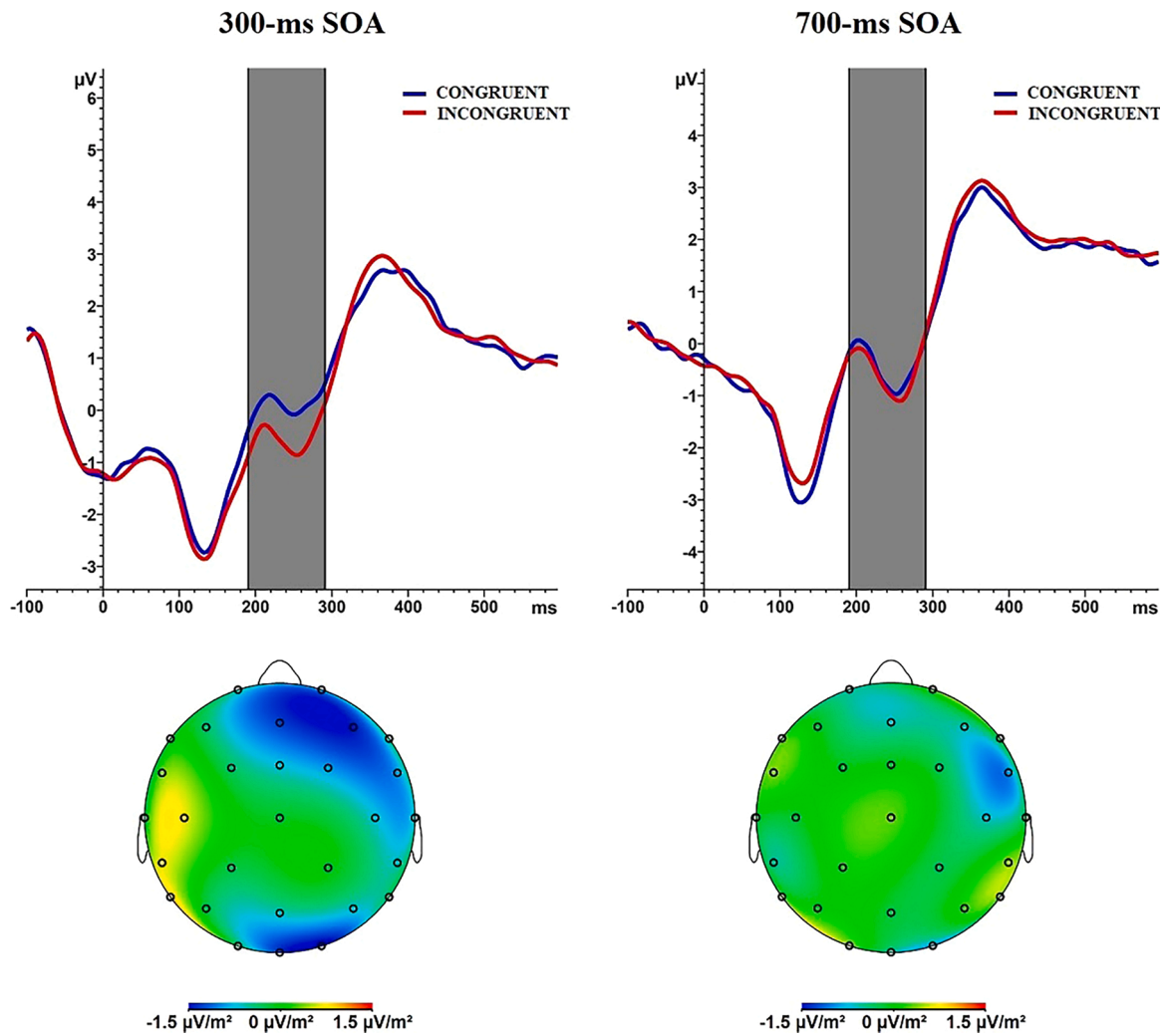


Fig. 4. Grand-averaged voltage data (collapsed across fronto-central electrode sites) in the two SOA conditions (A: 300 ms, B: 700 ms) as a function of prime-target congruency (blue: congruent, red: incongruent). The analyzed epoch lasted from 100 ms before the target onset to 600 ms post-target. Negative potentials are plotted downwards. Vertical gray shadings above the X-axes indicate the 190–290 ms and the topographic voltage maps across the 29 electrode sites, displaying the N2 conflict effects, coded in color, averaged in the same time window (incongruent minus congruent conditions).

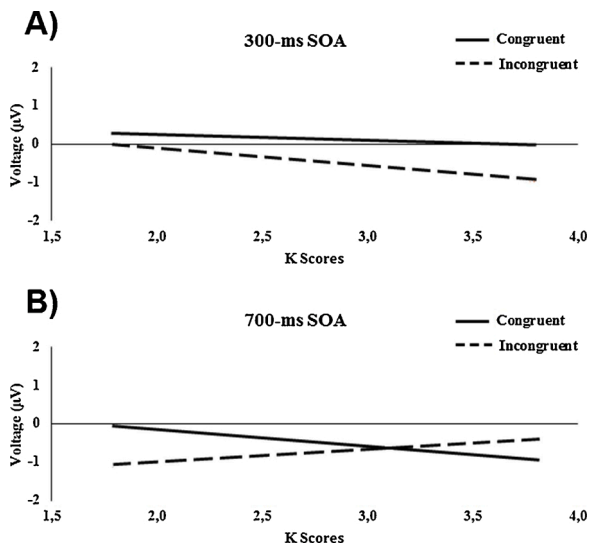


Fig. 5. Participants' voltage (μV) for congruent and incongruent conditions in the Stroop-priming task as a function of WMC (K) scores under (A) 300-ms and (B) 700-ms SOA conditions in the 190–290 ms window.

control resources may also affect forward-acting controlled attention strategies like expectancy generation. Under conditions that encourage the use of predictive strategies in different kind of cued-priming tasks (i. e., a differential proportion of related and unrelated prime-target pairings), controlled (strategic) priming effects are significantly reduced (or even reversed) for individuals with a lower-WMC (or older people), or when participants perform a concurrent WM task demanding a high load (e.g., Froufe et al., 2009; Heyman, Van Rensbergen, Storms, Hutchison, & De Deyne, 2014; Hutchison et al., 2014; Noguera et al., 2019; Ortells et al., 2018).

To our knowledge, however, no attempt has been made so far to explore whether electrophysiological (ERP) correlates of strategic (vs. non-strategic) priming effects could also be modulated by variations in WMC. This was the main goal of the present research. More concretely, we aimed to investigate whether the development of expectancy-based strategic processes could show a differential time-course in lower-WMC vs. higher-WMC individuals. Accordingly, participants' brain related-activity (ERP) was registered while they performed two consecutive trial blocks of a Stroop-priming task with a higher proportion of incongruent (75 %) than of congruent trials (25 %). The two trial blocks were identical except in the prime-target SOA (300 ms vs. 700 ms). The inclusion of both relatively short (300 ms) and longer (700 ms) SOA intervals in this kind of Stroop priming task had previously

demonstrated to be effective to induce to find qualitatively different behavioral effects (i.e., Stroop priming effects in opposite directions) resulting from a strategic vs. non-strategic (automatic) processing of the prime stimulus (e.g., Daza et al., 2002; Noguera et al., 2019; Ortells et al., 2003). Previously to the Stroop priming task, all participants performed a Visual Change Localization task to assess their WMC (e.g., Castillo Escamilla et al., 2020; Noguera et al., 2019; Ortells et al., 2018).

There were several relevant findings in our study. Firstly, the behavioral results showed a reliable three-way interaction between Congruency, prime-target SOA, and WMC, which replicates and extends the findings reported by other recent studies using similar strategic priming tasks (e.g., Ortells et al., 2018). Namely, under a relatively short prime-target SOA of 300 ms, which did not appear to be long enough to allow efficient strategic processing of the prime stimulus, all our participants, irrespective of their WMC, responded reliably slower to the incongruent compared to the congruent trials, despite they knew the former trials were much more frequent than the latter ones. Such a kind of non-strategic effect has been observed (i) in both younger and older adults at similar short SOA intervals (e.g., Noguera et al., 2019); (ii) in elderly populations with Alzheimer dementia even a much longer SOAs (e.g., Froufe et al., 2009); (iii) when the prime stimulus is briefly presented and immediately postmasked to impede its conscious identification (e.g., Daza et al., 2002; Merikle & Joordens, 1997); or (iv) when participants are required to perform a concurrent memory task demanding a high load (e.g., Ortells et al., 2017, 2018).

On the contrary, when the prime-target SOA was lengthened to 700 ms in our study, participants responded faster to the (more expected) incongruent targets than to congruent targets. This strategic reversal of the Stroop congruency is the behavioral effect that one usually finds in this Stroop priming paradigm when participants can consciously identify the prime, and the prime-target SOA is enough long to allow them to use the predictive information provided by the prime word to anticipate the target color (e.g., Daza et al., 2002; Froufe et al., 2009; Merikle & Cheesman, 1987; Merikle & Joordens, 1997; Noguera et al., 2019; see also Ortells et al., 2017). The present study replicates and extends those findings in demonstrating that such reversed strategic effect emerged only in participants with higher WMC (i.e., those scoring better in the change localization task), but not in lower WMC individuals, as revealed by a significant interaction between Congruency and WMC at the 700-ms SOA.

Further support of this dependence of strategic processing on WM resources can be found in a recent study by Noguera et al. (2019); Experiments 1–2), who also used the change localization task to assess WMC of both young and healthy older participants. At a prime-target SOA of 400 ms, both age groups responded slower to incongruent than to congruent targets, but at a longer 1000-ms SOA, only the younger participants showed a reversed (strategic) effect in the Stroop priming task. The older group, who scored worse in the WMC task, showed again a non-strategic Stroop congruency effect. The fact that our long prime-target SOA interval was 300 ms shorter than the 1000-ms SOA used by Noguera et al. (2019) could explain why our young participants did not show an overall reversed Stroop, as was the case in Noguera et al.' study. While we cannot completely rule out this possibility, note that the young groups in the experiments by Noguera et al. had scored in the WMC task much better (Exp 1: $K = 3,25$; Exp 2: $K = 3,18$) than our young participants ($K = 3,08$). These differences in WMC scores can also explain why Ortells et al. (2018) found a strategic effect in the low WM load condition by the overall sample of participants only in Experiment 2 (+21 ms), but a non-significant Stroop congruency (–4 ms) in Experiment 1, despite the same Stroop priming task and prime-target SOA (1000 ms) were used in the two experiments. Interestingly, whereas participants in Experiment 2 had a relatively high mean K score (3,28), as in Noguera et al.' study, the overall participants' K score in Experiment 1 by Ortells et al. (2018) was clearly lower (3,09), a WMC score very similar to that found in our study.

The inability of low-WMC participants to show a reversed Stroop

effect at the longer 700-ms SOA, resembles the absence of strategic priming effects showed by older individuals in several prior studies using similar priming tasks (e.g., Froufe et al., 2009; Noguera et al., 2019). In order to account for impaired cognitive control shown by older adults and several clinical populations (e.g., schizophrenia patients), Braver and colleagues have proposed that goal directed behavior would be the result of a dual-mechanisms cognitive control (DMC): proactive and reactive control (e.g., Braver et al., 2001; Braver, Burgess, and Gray, 2007; see Braver, 2012, for a review). Proactive control reflects an effortful (resource demanding) and preparatory mode of control, which involves maintaining goal-relevant contextual information in an accessible state and using predictive cues to prepare a specific response to an upcoming target. In contrast, the reactive control does not require continuous monitoring (and maintenance) of contextual cues, but instead depends on the target information to automatically retrieve the appropriate actions from long-term memory. By using different cue-probe tasks (e.g., the AX-Continuous Performance Test, AX-CPT), numerous studies have reported evidence that older adults, as well as younger adults with low WMC, are less likely to efficiently use a proactive cognitive control mode than young adults high in WMC (e.g., Braver, Gray, & Burgess, 2007; Redick, 2014; Redick & Engle, 2011; Richmond et al., 2015; Wiemers & Redick, 2018).

The proactive control involved in maintaining an expected response in a cue-probe task (AX-CPT) in the DMC model, corresponds closely to the forward-acting attention strategy (expectancy generation) invoked to explain controlled semantic priming. This prospective expectancy mechanism is assumed to be under conscious control, effortful, relatively slow, and involves using the prime to develop an expectancy for specific related targets during the SOA interval between prime and target onset in a priming task (Becker, 1980; Neely, 1977; Posner & Snyder, 1975; for a review see Neely, 1991). Note on this respect that the differences in performance showed by high- vs. low-WMC individuals, are mainly observed in controlled priming effects which depend on prospective (or proactive) expectancy mechanisms, but not in priming effects resulting from a non-strategic (automatic) prime processing (e.g., Heyman et al., 2014; Hutchison, 2007; Hutchison et al., 2014; Neely, 1991).

These lines of argument could be used to explain why our high-WMC vs. low-WMC participants showed a different (opposite) priming pattern at 700-ms SOA, but not at the shorter 300-ms SOA. To the extent that the later SOA interval would impede an adequate implementation of prospective (or proactive) controlled strategies in our study, we would expect to find a fairly similar non-strategic Stroop-priming effect irrespective of participants' WMC. We indeed found this result pattern, as all our participants responded consistently slower to the incongruent than to congruent targets, despite foreknowing the former were much more frequent than the later ones.

On the contrary, when the prime-target SOA was lengthened to 700 ms, thus making more probable that participants could rely on expectancy-based proactive control strategies (i.e., when environmental cues are helpful), it is not unreasonable that only participants with a high-WMC, but not those with lower-WMC, showed a reliable reversal of Stroop priming effect. Note in fact, that the size of this strategic priming at the longer 700-ms SOA reliably correlated with participants' scores in the change localization task.

Similar differences between high- vs. low-WMC individuals in the use of predictive strategies to guide response selection to subsequent targets have been observed with other cued attention paradigms, as the antisaccade task (e.g., Kane, Bleckley, Conway, & Engel, 2001; Ortells et al., 2016; Noguera et al., 2019; Unsworth, Schrock, & Engle, 2004).

In either case, the fact that our participants with a lower-WMC showed no evidence for expectancy use at the longer 700-ms SOA, responding slower to the incongruent than to congruent trials, does not necessarily demonstrate that they mainly relied on reactive (rather than proactive) control strategies. Our study does not allow to determine whether low-WMC individuals are indeed unable to implement

expectancy-based strategies that would overcome automatized response tendencies, or rather they can generate expectancies, but these could take longer than in high-WMC individuals. The current design is unable to distinguish between these two possibilities, which could be addressed by future experiments specifically designed to examine them. Yet, the results of some recent studies in our labs suggest that a reduced WM capacity, resulting for example from aging, would mainly affect the instantiation (time course) of predictive strategies. For example, Noguera et al. (2019) found healthy older people were unable to show strategic priming effects (e.g., a reversed Stroop) at a relatively long SOA of 1000 ms. However, they showed strategic priming effects of a comparable magnitude to those by young adults, when the prime-target SOA was lengthened to 2000 ms.

Regarding our ERP findings, they are clearly consistent with the behavioral results. At the shorter SOA of 300 ms, in which our participants consistently responded slower on incongruent than on congruent trials (i.e., standard Stroop congruency effect; see Fig. 2A), we found a negative deflection at fronto-central electrode sites in the time window between 190–290 ms (see Fig. 4). This ERP modulation (N2) is typically assumed to index attentional conflict processing, as their amplitude is more negative in conflicting (e.g., an incongruent Stroop trial) as compared to non-conflict conditions in the attention task (e.g., Clayson & Larson, 2011; Donohue et al., 2016; Ridderinkhof et al., 2004; see Folstein & Van Petten, 2008, for a review).

Although the N2 component (and some other late ERP components, such as N450; see for example Kalamala, Ociepka, & Chuderski, 2020; Larson, Kaufman, & Perlstein, 2009) is usually found in ERP studies using a conventional Stroop task where both irrelevant (e.g., word) and irrelevant (color ink) stimulus features are simultaneously presented, some previous work has reported similar N2 modulations using sequential variants of Stroop-like tasks (e.g., Gajewski et al., 2008). Congruency effects on the N2 have been also observed during visuo-motor priming paradigms, suggesting that this ERP components indexes resolution of response conflicts (Kiefer et al., 2017; Martens et al., 2011). To the extent that showing slower RTs to an incongruent target at 300-ms SOA would reflect a non-strategic processing of the prime word in our Stroop priming task, we expect to find a fairly similar N2 modulation in all our participants, irrespective of their WMC. Our results are clearly consistent with these predictions, as revealed by the lack of a reliable interaction between congruency and WMC ($F < 1$) at this shorter SOA. Thus, both low- and high-WMC participants showed a greater N2 amplitude on incongruent than on congruent trials (see Fig. 4).

At the longer 700-ms SOA, however, the observed ERP pattern was reliably affected by individual differences in WMC. Thus, participants with a lower WMC showed again an enlarged N2 component in incongruent trials, as under the shorter 300-ms SOA. This supposedly non-strategic ERP pattern was comparable with the behavioral Stroop congruency effect at the corresponding SOAs. In clear contrast, the N2 component was completely absent in participants with a higher WMC, with similar amplitude for both incongruent and congruent trials. The elimination of the N2 effect at 700-ms SOA in participants with high WMC seems to confirm that, after a longer SOA interval, they were able to strategically process the prime and prepare to respond to the opposite color, thus counteracting the supposedly automatic interference effect.

5. Limitations and future directions

The elimination of the N2 ERP component (which was associated to a reversed behavioral Stroop congruency) observed at the 700ms-SOA in higher WMC participants was assumed to reflect a more efficient implementation of expectancy-based strategies by these individuals.

Note however that the participants in our study were informed about the greater proportion of incongruent relative to congruent prime-target pairings, and actively encouraged for using predictive strategies (e.g., preparing to respond to the opposite-incongruent color to that of the

prime word) to improve their performance. Consequently, it is not implausible that high- and low-WMC groups showed some differential EEG effects during preparation preceding the target onset (i.e., prime-locked ERP activity registered in the interval between the color prime word and the target), particularly at the longest 700 ms-SOA. For example, given that participants responded with different hands to the two targets, it remains possible that they begin to prepare a concrete response (e.g., a right-hand response to a red target) on presentation of the opposite prime color word (GREEN). If so, we could see an increased frontal negativity prior to the target onset at the longest 700-ms SOA, particularly in higher WMC participants, which might even be lateralized to the contralateral side (lateralized readiness potential; e.g. C3 for a right-hand response). To test such hypothesis, we conducted further analyses in different time windows preceding the target onset (e.g., from –400 to –200 ms; from –200 ms to 0 ms), treating WMC as a continuous covariate. Yet, no reliable effect related to WMC was found, thus suggesting that a similar preparatory EEG activity (e.g., response preparation on presentation of the prime word) for both higher-WMC and lower-WMC individuals. Whether individual differences in WMC could modulate some prime-locked ERP activity during the SOA period at prime-target SOA intervals longer than those used in the present study, it remains an open issue for future research.

The use of relatively longer prime-target SOAs in the Stroop priming task could also allow us to distinguish between WMC effects on the formation/generation of expectations and effects on the strategic use/exploitation of the expectations to maximize performance. The current task design is not capable of disentangling between these two possibilities. Some prior work on normal aging has reported that not only the ability to inhibit irrelevant information, but also the ability to implement forward-acting control strategies (i.e., expectancy generation) would be delayed in time, rather than abolished (e.g., Gazzaley et al., 2008; Noguera et al., 2019). An interesting issue to be addressed by future research is whether low-WMC individuals could be able to efficiently generate predictive expectations and counteract the automatic (Stroop congruency) effects in our task when the prime-target SOA is lengthened (e.g., at 1000 ms or longer).

It should be noted that WMC was a measured (i.e., performance in the Change Localization task), rather than manipulated, variable. The differences observed in the Stroop priming task as a function of WMC, could at least partly reflect other potential differences between participants (e.g., motivational factors, perceptual ability, speed of processing, etc.). If, for example, prospective controlled mechanisms such as expectancy generation are assumed to depend on the ability to quickly recognize primes, high-WMC individuals could be better able to quickly recognize the prime words, allowing for a greater contextual influence from the primes in the priming task (see Hutchison et al., 2014, for a similar line of argument). Participants with a higher-WMC showed, in fact, decreased reaction times in all experimental conditions (see Figs. 2 and 3), as revealed by a reliable negative correlation between participants' scores in the Change Localization test and their overall mean RTs (averaged across congruency and SOA conditions) in the Stroop priming task [$r = -.35, p = 0.002$]. We did not register, however, additional measurements from our participants that would allow us to determine whether low- and high-WMC participants in our study did also differ in other processes, as for example, motivation, or processing-speed. Further studies aimed to provide more direct evidence on the role of WMC on strategic (vs. non-strategic) prime processing, could examine variations in Stroop priming effects across short and longer SOAs, while directly manipulating working memory load.

6. Conclusions

Overall, the present results replicate and extend some prior demonstrations that reduced availability of WM resources (i.e., having lower WMC) not only affects the ability to inhibit irrelevant information in selective attention tasks, but it also leads to less efficient strategic

processing of goal-relevant information (e.g., Heyman et al., 2014; Hutchison et al., 2014; Ortells et al., 2017, 2018; see also Noguera et al., 2019).

The Stroop priming paradigm used in the present research had consistently demonstrated to be effective to show qualitatively different (i.e., opposite) behavioral effects resulting from a strategic vs. non-strategic prime processing (e.g., Daza et al., 2002; Merikle & Cheesman, 1987; Merikle & Joordens, 1997; Noguera et al., 2019; Ortells et al., 2017, 2018). Yet, to our knowledge, this is the first time that a Stroop priming paradigm is used in an EEG study in an attempt to determine whether a differential electrophysiological (ERP) pattern can also be observed depending on the way (i.e., strategic vs. non-strategic) the prime stimulus is processed.

A second, and even more relevant contribution of the current study is that it provides the first evidence of a fairly different ERP pattern of the N2 ERP component reflecting resolution of response conflict in a Stroop-priming task as a function of individual differences in WMC. Whether a similar ERP modulation could be observed when participants perform a concurrent WM task of high vs. low load, remains an interesting matter for future research.

Declaration of Competing Interest

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

Acknowledgement

This research was supported by Grant PSI2017-83135-P from the Spanish Ministry of Economy and Competitiveness.

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