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# **Attention in schizophrenia: impaired inhibitory control, faulty attentional resources, or both?**

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## ABSTRACT

While the literature regarding the existence of difficulties in inhibition in schizophrenia is relatively consistent, it is not clear whether these difficulties reflect any specific deficit in an inhibitory control process or whether they are the result of deficits in the systems that regulate inhibitory control, such as attentional resources. This also raises the issue of attentional resources in schizophrenia, which offers a somewhat puzzling and sometimes contradictory picture. In this study, these issues were investigated by means of a paradigm in which the need for inhibitory control and the need for correct allocation of attentional resources varied parametrically. Twenty-six outpatients with a diagnosis of schizophrenia and 26 matched controls completed a visual search task during which distractors were presented and had to be inhibited. At the same time, they also completed an auditory target detection task of varying difficulty. The results show that the patients had difficulties both in inhibiting distractors and in correctly allocating attention to the two tasks. The results also show that these two difficulties were not related. This leads to the conclusion that schizophrenia involves both defective inhibitory control and faulty management of attentional resources, and that the former does not result from the latter. Furthermore, these effects seem to be neither dependent on processing speed, nor related to medication.

**Key words:** schizophrenia; attention; resistance to interference; inhibition; attentional resources; divided attention.

## 1. INTRODUCTION

Schizophrenia is a chronic mental disorder with attention deficits being some of its most pervasive neurocognitive features. Attention deficits can predict functional outcomes (Green et al., 2000; Nuechterlein et al., 2011). This comes as no surprise because, as a central mechanism for the control of information processing, attention operates to activate processes that enhance the processing of relevant signals, inhibits irrelevant signals in a way that strengthens resistance to interference and distractibility, and coordinates the realization of concurrent tasks by distributing processing resources (Michael et al., 2014). These processes are critical for learning and other complex everyday activities, and their malfunctioning may have serious consequences.

Decreased inhibition of interfering information seems to be a hallmark of cognitive disturbances in schizophrenia. Taken individually, recent studies provide a rather puzzling picture of inhibitory control in schizophrenia. Indeed, some have found no differences between patients with schizophrenia and controls (e.g., Birkett et al., 2006), while others have found poorer performance in patients (Caprile et al., 2015; Galaverna et al., 2012; Laurens et al., 2015), and yet others have reported that inhibitory control in schizophrenia might be reduced only under certain circumstances (Boucart et al., 1998). Such discrepancies may be due to the clinical and biological heterogeneity of schizophrenic disorders, or to specific features of individual studies rather than to schizophrenia *per se*. A meta-analysis has shown that patients with schizophrenia are not only slower than controls, but that they also produce more errors in tasks involving inhibitory control (Westerhausen et al., 2011).

Despite this finding, a question still persists: is inhibitory control disturbed in schizophrenia, or is decreased performance in tasks involving inhibitory control an epiphenomenon of another disturbance? Henik and Salo (2004) suggested that patients with schizophrenia can adequately activate inhibitory control, but only if sufficient attentional resources are available. Patients could, however, face difficulties when multiple attentional demands occur. Indeed, theoretical models suggest that inhibitory control requires cognitive resources if it is to reach high levels of efficiency, and this assumption is supported by studies showing that decreased resource availability (e.g., due to performing a secondary task) reduces efficiency in such a way that distracting signals have a greater effect (Michael et al., 2006; 2014). This naturally points to the desirability of studying attentional resource availability and dual-tasking in schizophrenia.

Conversely, little has been done to investigate the management of attentional resources and, to our knowledge, no meta-analysis has ever been published on this issue. This leaves us with scarce and in some ways contradictory evidence. For instance, it has been suggested that as cognitive load increases, patients with schizophrenia exhibit poorer performance than controls and that this indicates resource limitations (Schwartz et al., 1989; Nuechterlein et al., 1984). There is indeed evidence that the availability of attentional resources or the ability to allocate them to multiple tasks is weakened in this disorder (Ahlers et al., 2014; Granholm et al., 1996; Gray et al., 2014; Lin et al., 2015; Shen et al. 2013). The idea of the existence of difficulties in correctly allocating attentional resources was also supported by the findings of Fuller and Jahanshahi (1999). These authors asked their participants to perform two simultaneous motor tasks and showed that, compared to the controls, the performance of patients with schizophrenia increased in the first task while it decreased in the second one. This probably suggests that the patients diverted an excessive quantity of resources away from the second

task and allocated more than required to the first one, thus resulting in unbalanced patterns of performance compared to the controls. It has also been suggested that there is a possible failure to regulate attentional resources over time in schizophrenia in situations in which significant time constraints are present and when it is necessary to process a relatively large number of items (Michael et al., 2016). However, this is only a part of the picture. Allen (1982) and Huang et al. (2019) found that patients with schizophrenia performed worse than controls in a divided attention task, without any proportional fall-off in performance compared to controls. This may suggest that poorer performance may have its origin in globally slower information processing (Knowles et al., 2010) rather than in the limited availability of attentional resources. Finally, a small increase in performance under dual-tasking conditions was also reported by Birkett et al. (2006). This seems to indicate that performing multiple tasks may sometimes help mobilize available but otherwise dormant attentional resources. It is thus difficult to draw any clear conclusions from these inconsistent findings.

The aim of the present study was to investigate the issues left unresolved by the above-mentioned literature, namely (i) whether inhibitory control *per se* is weakened in schizophrenia, or (ii) whether inefficient inhibitory control might be due to some form of faulty management of attentional resources, or (iii) whether there are problems involving both inhibitory control and the management of resources, in which case deficiencies in the latter can hardly be considered responsible for the efficiency of the former. A visual search task was carried out during which participants searched for a target among a varying number of items. In half the trials, a salient distractor was present in order to assess resistance to interference and hence inhibitory control. This task was performed simultaneously with an auditory target detection task of varying difficulty in order to assess limitations in attentional resources. The

influence of the latter on the former indicated the way attentional resources regulated inhibitory control. Finally, two companion reaction time tasks (simple and choice reaction time tasks, i.e. SRT and CRT) were also completed in order to control for a general slowing of information processing (methodological and statistical details about the companion tasks are presented as supplementary material).

On the basis of theoretical models suggesting a hierarchical organization of attentional resources and inhibitory control (with inhibition depending on the availability of attentional resources; Kane & Engel, 2003; Michael et al., 2006), three distinct and mutually exclusive hypotheses can be formulated (summarized in Table 1):

1. If inhibitory control is impaired but attentional resources are not faulty, then the effect of the distractor would be larger in patients than in controls (i.e., significant group X distractor condition interaction). **This would be due to difficulties in resisting to interference from the irrelevant distracting item. However, the normal availability of attentional resources would not modulate inhibitory control because of the latter's impairment. Therefore,** the fall-off in performance as the difficulty of the concurrent auditory task increases would follow the same pattern as in controls (i.e., no group X auditory task difficulty interaction and no group X distractor condition X auditory task difficulty interaction).

2. If attentional resources are faulty but inhibitory control is normal, then the fall-off in performance as the difficulty of the concurrent auditory task increases would be steeper in patients than in controls (i.e., significant group X auditory task difficulty interaction). **Indeed, mobilizing the necessary amount of resources in order to complete the secondary task would withdraw the already diminished resource pool away from the primary visual task, resulting in difficulty managing both concurrent tasks. And the greater the difficulty of the secondary task, the greater the failure would be. Yet, the outlined theoretical models suggest a**

hierarchical dependence of inhibition on resources. This predicts that, in case of faulty resources, inhibitory control would also suffer since available resources would not be sufficient for it to be fully operational. As a consequence, the distractor effect would globally be larger than in controls due to the non-availability of resources to manage it (i.e., significant group X distractor condition interaction). The hierarchical dependence of inhibition on resources also predicts a third effect in case of faulty resources and normal inhibition. The greater the need for resources, the more difficult would be to modulate inhibition. Therefore, the distractor effect in patients would increasingly depart from that of the controls as the difficulty of the concurrent auditory task increases (i.e., significant group X distractor condition X auditory task difficulty interaction). This would show that the greater the need for resources, the greater the difficulty in modulating inhibition. All interactions involving group would therefore be significant.

3. If inhibitory control is impaired and attentional resources are faulty, then the effect of the distractor would be larger in patients than in controls (i.e., significant group X distractor condition interaction), and the fall-off in performance as the difficulty of the concurrent auditory task increases would be steeper in patients than in controls (i.e., significant group X auditory task difficulty interaction). The reasons are the same as those presented in hypotheses 1 and 2. However, the non-availability of attentional resources would not be a cause of faulty inhibitory control and could not modulate an already impaired inhibitory process. There would therefore be no relation between them (i.e., no significant group X distractor condition X auditory task difficulty interaction).

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## 2. METHODS

*2.1. Participants:* (a) Twenty-six outpatients (9 females, 17 males; Table 1) who met DSM-V criteria for schizophrenia and were clinically stable. They were recruited at the Centre Hospitalier Le Vinatier, Lyon, France. Their mean age was  $31.4 \pm 10.4$  (range: 20 to 51), their mean level of education (not available for 3 patients) was  $13.1 \pm 1.9$  years and the average duration of illness was  $12.9 \pm 6.8$  years. Their mean total score on the Positive and Negative Symptoms Scale (PANSS) was  $56.9 \pm 12.3$ . They were all receiving long-term neuroleptic treatment, administered in a standard dose, with the mean chlorpromazine equivalent being  $644\text{mg/day} \pm 578$  (range: 20 to 2100; Woods, 2003). The mean Verbal Comprehension Index and the mean Perceptual Reasoning Index obtained on the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008) were  $99.9 \pm 17.8$  and  $94.5 \pm 18.1$ , respectively. None of the patients had any history of known neurological disorders. (b) Twenty-six control participants (9 females, 17 males) with a mean age of  $31.1 \pm 10.4$  years (range: 18 to 59) and a mean level of education (not available for 6 controls) of  $13.1 \pm 1.3$  years. They had no history of current or past psychiatric treatment, no history of diagnosable substance abuse, and no history of neurological disorders. The two groups did not differ on age ( $t(50)=.13$ ;  $p > .90$ , bicaudal) or on mean level of education ( $t(41)=.1$ ;  $p > .94$ , bicaudal). All participants reported normal or corrected-to-normal vision and hearing and gave their written informed consent for their participation. We complied with the APA ethical standards, and this research on human subjects was approved by the Comité de Protection des Personnes Sud-Est VI (N° AU863-AFSSAPS : 2010-A00980-39), France. The research was also conducted in accordance with the Helsinki Declaration.

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## 2.2. Stimuli and apparatus

The task used in the present study is illustrated in Figure 1.

Primary visual search task: The stimuli were white outlined squares (luminance  $37.37 \text{ cd/m}^2$ ) presented on a black background (luminance  $0.034 \text{ cd/m}^2$ ). At a viewing distance of 30 cm, the angular size of each square was  $0.5^\circ \times 0.5^\circ$ . Each square had a gap and was rotated clockwise through  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$  or  $270^\circ$ . The target orientations were  $90^\circ$  or  $270^\circ$ , while that of non-targets was  $0^\circ$  or  $180^\circ$ . To make the target salient, it was placed inside a white outlined  $1^\circ \times 1^\circ$  diamond (luminance  $37.37 \text{ cd/m}^2$ ). To make a non-target (i.e., the critical distractor) salient, it was placed inside a white outlined circle (luminance  $37.37 \text{ cd/m}^2$ ) with a radius of  $1^\circ$ . The same apparatus and software as before were used.

Concurrent auditory task: The stimuli in the auditory task were the numbers 0 to 9. They were recorded as an mp3 file and played back using speakers at a rate of 1 per second. The stimuli were arranged in series of 10 numbers, with all the numbers being presented randomly and once only within each series. Each new series started only when the previous series had ended, but there was no indication in the mp3 file to signal the end of one series and the beginning of the next. Instead, a continuous flow was perceived. This arrangement prevented participants from developing detection and response strategies. The mp3 file was played

through a second ACER Extensa 7630 computer equipped with two 572703 Dacomex speakers.

### *2.3. Procedure*

Diagnostic interviews were carried out by a senior psychiatrist according to the DSM-V criteria (French version of the 4th edition; American Psychiatric Association, 2015) for schizophrenia. Psychotic symptomatology was assessed using the Positive And Negative Symptoms Scale (PANSS). After giving their written informed consent, the patients completed two separate sessions. During the first one, the WAIS-IV was completed in order to assess the Verbal Comprehension Index and the Perceptual Reasoning Index. During the second session, they completed the computerized tasks. They had to sit on a chair facing a computer monitor. The SRT and CRT tasks were completed first, followed by the main Experiment. The controls completed only the computerized tasks once they had given their written informed consent. Instructions were given for each task, followed by a short training session for each of them.

Visual Search Task with Auditory Background: The stimuli were randomly distributed inside an imaginary  $7.8^\circ \times 7.8^\circ$  square, and the search display remained visible until a response was given. The whole session started with 10 training trials showing all possible conditions. A trial started with the appearance of a central fixation point displayed for 1000 ms. Then, the search display was presented. Two conditions were manipulated throughout the study, each occurring with equal probability: (a) in the baseline condition, only the target was placed in the center of the salient surround (diamond); (b) in the distractor condition, in addition to the salient distractor, one of the non-target items was placed in the center of the salient surround (circle) in order to indicate a critical distractor to be avoided. The display consisted of either 6

or 10 items, including the target (and the distractor, in the corresponding condition). The presence of the distractor (present vs. absent) and the display size (6 vs. 10 items) varied randomly from trial to trial. The participants were asked to indicate the location of the target's gap (right or left) by pressing one of two pre-defined response keys on the computer keyboard as quickly as possible. The next trial started 500 ms after a response had been given. RTs and errors were recorded by the computer. Overall, the visual task consisted of 240 trials (3 identical blocks of 20 trials per condition and display size). The subdivision into 3 blocks was related to the concurrent auditory task. The participants had to complete this concurrent auditory task, the difficulty of which varied: (a) they had to listen to the auditory list but without responding to it (i.e., 0 targets); (b) they had to detect a single target (the number 2) by making a verbal response ("stop" response; i.e., 1 target condition); (c) they had to detect three targets (numbers 2, 4 and 6) by making the same verbal response (i.e., 3 targets condition). The auditory target(s) was (were) presented in a completely random and unpredictable order. The three degrees of difficulty were presented in three separate blocks during which the participants performed the same visual task (i.e., the visual task remained constant, since the aim was to assess the effects of a secondary task). The three blocks were balanced in a Latin-square design across participants. To optimize time-sharing between the visual and auditory tasks, the auditory items were played continuously from the beginning of the block right through to the end, without interruption. Furthermore, the high presentation rate of the auditory items (1 per second) was intended to make the task demanding in terms of resources, because it has been shown that if one stream of stimuli is presented at a high rate, another stream cannot be handled efficiently at the same time. This method (Michael et al., 2014) was therefore a straightforward means of drawing resources away from the visual task and observing the effects of reduced resource availability. The participants were informed that the two tasks (visual and auditory) were equally important, and that one should not be favored

over the other. Their responses were recorded by the experimenter, who was sitting at some distance from the participant and had the full list of auditory stimuli. Based on the results of a pilot study as well as on previous research (Michael et al., 2014), target detections were considered correct if the response was given within 2 seconds. The participants were fully informed of these criteria.

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### 3. RESULTS

*3.1. Auditory task:* a detection accuracy score was computed by subtracting the percentage of false positives (erroneous detections) from the percentage of hits (correctly detected targets). This score was subjected to an analysis of variance (ANOVA), with the number of targets to be detected (1 vs. 3) as the within-subjects factor, and the group (controls vs. patients) as the between-groups factor. The main effect of group was significant ( $F(1,50) = 9.2, p < .004, \eta_p^2 = .16$ ), with patients performing less well than controls (89% vs 95%). The main effect of the number of targets to be detected was significant ( $F(1,50) = 59.1, p < .0001, \eta_p^2 = .54$ ), with detection accuracy being higher when 1 target had to be detected (97.6%) rather than 3 (87.4%). From these results, it is apparent that, as expected, increasing the number of auditory targets increased the task demands in terms of the required resources and therefore resulted in poorer performance. The group X number of targets to be detected interaction was also significant ( $F(1,50) = 7.8, p < .007, \eta_p^2 = .14$ ; Figure 2). Bonferroni-corrected comparisons (the threshold  $p$ -value for four comparisons is .013) showed that performance decreased as the number of targets to be detected increased both in controls (1 target 98.6% vs 3 targets 91.4%, difference = 7.2%,  $p < .001$ , Cohen's  $d = .76$ ) and patients (1 target 96.7% vs 3 targets 81.3%,

difference = 15.4%,  $p < .0001$ , Cohen's  $d = 1.32$ ). It should be noted that the patients' performance fell by more than twice as much as that of the controls when passing from 1 to 3 targets to be detected, with a ratio of  $\approx 2.14$ . No difference was found between the groups when 1 target had to be detected (patients 96.7% vs controls 98.6%,  $p = .11$ ), whilst a difference was observed for 3 targets (patients 81.3% vs controls 91.4%,  $p < .003$ , Cohen's  $d = .86$ ).

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### 3.2. Visual Search Task:

The number of errors and medians of correct RTs were analyzed. Medians were preferred to means because of the intra-subject and between-participants variability in RTs classically observed in detection and visual search tasks.

*Errors:* The mean percentage of errors was 2% for the controls and 2.4% for the patients. This low percentage is not surprising since the stimuli remained on the screen until a response was given. The percentage of correct responses was subjected to an analysis of variance (ANOVA), with the distractor condition (absent vs. present), display size (6 items vs. 10 items) and auditory task difficulty (0, 1 or 3 targets for detection) as within-participants factors, and group (controls vs. patients) as the between-groups factor. The Greenhouse-Geisser correction was applied since the assumption of sphericity was not met. No **significant** result was found.

*Response Times:* Response times shorter than 100 ms and longer than 2000 ms were discarded. Discarded trials accounted for less than 0.5% of the total number of trials. Since both the simple and choice RT tasks revealed that patients took longer overall to respond than controls, it was necessary to eliminate any interference in this slowing-down of information processing. Response Times obtained in both these tasks were averaged and then subtracted from the median RT for correct responses obtained in each visual search task condition. This excludes all processes involved in both tasks from the analyses, i.e. central and peripheral detection of signals, orienting toward them, decision processes that make it possible to choose the correct response, and giving a response. The remaining time thus reflects visual search and attentional processes. An analysis of variance (ANOVA) was carried out on visual search times, with the distractor condition (absent vs. present), display size (6 items vs. 10 items) and auditory task difficulty (0, 1 or 3 targets for detection) as within-participants factors, and group (controls vs. patients) as the between-groups factor. The Greenhouse-Geisser correction was applied since the assumption of sphericity was not met. Only **significant** effects involving group will be reported. The main effect of group was significant ( $F(1, 50) = 10.3, p < .002, \eta_p^2 = .17$ ), with patients exhibiting slower visual search times than controls (patients 353 ms vs controls 263 ms, respectively). The group X distractor condition interaction was significant ( $F(1, 50) = 5.2, p < .026, \eta_p^2 = .10$ ). The presence of the distractor increased visual search times in both groups, but this increment was much larger in patients (247 ms) than in controls (195 ms), giving a ratio of  $\approx 1.27$ . The group X auditory task difficulty interaction was also significant ( $F(2, 100) = 8.3, p < .003, \eta_p^2 = .14$ ; Figure 3 left panel). Bonferroni-corrected comparisons (the threshold  $p$ -value for 3 comparisons being .016) showed that the patients did not differ from controls when 0 (patients 284 ms vs controls 234 ms) or 1 (patients 310 ms vs controls 257 ms) auditory targets had to be detected ( $p = .022$  and  $p = .046$ , respectively), but that their visual search times were much longer than those of the controls when 3 auditory

targets had to be detected (patients 465 ms vs controls 299 ms;  $p < .002$ , Cohen's  $d = .96$ ). When the difference in visual search times between 1 and 3 targets was inspected, it was found to be quite disproportionate in the patients (155 ms) as compared to the controls (42 ms), giving a ratio of  $\approx 3.7$ . The group X distractor condition X auditory task difficulty interaction was not significant ( $F(2, 100) = .32, p > .61$ ). No other effects involving the group were observed.

### 3.3. Complementary analyses

Since some cognitive models posit that inhibitory control is hierarchically dependent on available attentional resources, two indices were computed on the basis of the visual search task data in order to further investigate this link. The Inhibition Difficulty Index (ID) was derived by computing the main effect of the presence of a distractor (i.e., difference between distractor-absent and distractor-present trials) on RT and proportions of errors,  $z$ -transforming these effects, and then averaging the  $z$ -scores in order to obtain a single value. The higher the score, the weaker inhibition was. The Resources Difficulty Index (RD) was derived by computing the main effect of the number of auditory targets on RT and proportions of errors in the visual task, and proportions of errors in the auditory task. The  $\alpha$  regression slope<sup>1</sup> was used to obtain a single value for each of these dependent variables. These values were then  $z$ -transformed and averaged in order to obtain a single value. The higher the score, the greater the difficulty became as the number of auditory targets for detection increased. A simple linear regression analysis confirmed that, in line with the cognitive models, the RD was indeed predictive of the ID only for controls ( $\beta = .47$ ,  $SEM = .18$ ;  $t(24) = 2.6, p < .016$ ; Adj.  $R^2 = .19$ ). No such relationship was found in the performance of patients with schizophrenia

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<sup>1</sup>  $\alpha = \text{covariance}(x,y)/\text{variance}(x)$ , where  $x$  is the number of targets to be detected (0, 1 or 3) and  $y$  is the visual search time.



( $\beta = .18$ ,  $SEM = .166$ ;  $t(24) = .90$ ,  $p > .37$ ;  $Adj. R^2 = .007$ ). The results are presented in Figure 3 (right panel).

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### *3.5. Correlation analyses*

Pearson correlations were conducted on the patients' results to identify correlations between medication, on one hand, and performance in the SRT and CRT tasks, and the ID and the RD indices, on the other. No correlation was observed.

## **DISCUSSION**

Even if inhibitory control and attentional resources are usually assessed separately from each other on the basis of different paradigms, theoretical models of attention suggest that inhibition needs resources if it is to be fully efficient (Michael et al., 2006; 2014). Whilst the literature concerning the existence of difficulties in inhibition in schizophrenia is fairly consistent (Westerhausen et al., 2011), it is not clear whether these difficulties reflect any specific deficit in a process of inhibitory control, or whether they are the result of faulty systems that regulate inhibitory control, such as attentional resources (Henik & Salo, 2004). This also raises the issue of attentional resources in schizophrenia, which offers a somewhat puzzling and sometimes contradictory picture. The aim of the present study was to investigate

these issues by means of a single paradigm in which the need for inhibitory control and the correct allocation of attentional resources varied parametrically.

The results provide a largely direct and clear picture. First, task-irrelevant visual distractors occurring randomly during the visual search task produced effects of attentional capture that were as much as 27% larger in patients with schizophrenia than in controls. This is suggestive of decreased inhibitory control and tallies quite well with the large body of scientific literature and with those meta-analyses that have shown that inhibitory control is, indeed, weakened in schizophrenia (Caprile et al., 2015; Galaverna et al., 2012; Laurens et al., 2015; Westerhausen et al., 2011).

Second, a secondary auditory target detection task slowed visual search times in both patients and controls. No difference between the two groups was observed when 0 or 1 auditory targets were to be detected, even though performance was poorer for 1 target (easy dual task) than for 0 targets (single task). Similarly, the two groups did not differ in their ability to detect only 1 target in the auditory task. As suggested in a previous investigation using a similar experimental protocol (Michael et al., 2014), a single predefined target can be detected entirely using perceptual information (i.e., reacting to a specific sound) without further processing. This demands only a small amount of attentional resources, as reflected in the slowing in performance (Kahneman, 1973). It seems that, in schizophrenia, performing such a simple activity is not a problem, thus suggesting that patients have sufficient attentional resources to allow them to perform both tasks correctly, and that they seemingly mobilize and allocate resources adequately. However, increasing the difficulty of the secondary task to 3 targets produced a disproportionate slowing in the patients with schizophrenia as compared to the controls. Detecting 3 predefined targets can therefore no longer result from simple

perceptual information. Some extra cognitive processing is needed in order to determine whether each new item is one of the targets or not. Here, mobilizing the amount of resources required in order to complete the secondary task withdraws very large quantities away from the primary visual task. It is also interesting to note that this disproportionate slowing in visual search time in patients was also accompanied by a similarly disproportionate fall-off in detection accuracy in the auditory task. Indeed, passing from 1 to 3 targets for detection produced a decline in performance in the patients that was twice as large as that observed in the controls. This clearly suggests that allocating attentional resources to the auditory task did not result in perfect performance in that task, while performance in the visual task was also impaired. The patients performed both tasks less well than the controls, suggesting a deficit in their attentional resources. Taken together, these results may help explain the inconsistencies reported in the literature. As mentioned earlier, some dual-task investigations (Allen, 1982; Huang et al., 2019) have found no difference between patients with schizophrenia and controls apart from a general slowing-down of processing speed, while others (Ahlers et al., 2014; Fuller & Jahanshahi, 1999; Granholm et al., 1996; Gray et al., 2014; Lin et al., 2015; Shen et al. 2013) have reported a disproportionate decline in performance. In our study, no group difference was found in easy dual tasks, whilst a large difference was found in more difficult dual tasks, with general processing speed being controlled for at all times. It is possible that those investigations that failed to find any difference may have used tasks that were much too easy to manage, even with faulty and residual attentional resources, whilst those that did find such a difference used tasks that were more likely to mobilize large quantities of attentional resources. In such cases, residual resources would not be sufficient to perform the tasks adequately.

Now that we have described the existence of both impaired inhibitory control and faulty attentional resources in our schizophrenia sample, we turn to the million-dollar question: does the former result from the latter? Some empirical data and cognitive models assume that inhibitory control needs resources to operate (Kane & Engel, 2003; Michael et al., 2006; 2014). If this were the case, then faulty resources would impact inhibition in such a way that it would also be weakened. In the field of schizophrenia research, such a hypothesis has indeed been proposed on the basis of a review of the Stroop effect (Henik & Salo, 2004). This hypothesis states that inhibitory control is not disturbed in schizophrenia. It is weakened only when attentional resources are missing. However, any hierarchical dependence of inhibition on resources, in addition to weakened inhibition and weakened resources, also predicts that the distractor effect in patients would become increasingly pronounced as the difficulty of the auditory task increases (i.e., significant group X distractor condition X auditory task difficulty interaction), thus showing that the greater the need for resources, the more difficult it is to modulate inhibition (this corresponds to hypothesis 2 as detailed in the introduction). This was not found, and the interaction of interest was far from being significant. Such a finding does not permit us to infer that problems in inhibitory control are due to faulty attentional resources. On the contrary, the whole pattern of results observed here corresponds better to the idea of a deficit of both inhibition and attentional resources (hypothesis 3 as detailed in the introduction). In fact, the non-availability of attentional resources would not be a cause of faulty inhibitory control and there is therefore no relation between them. Indeed, our complementary analyses showed that the effect of the difficulty of the auditory task was not predictive of the distractor effect in patients with schizophrenia, whilst it was in controls, as had been expected on the basis of cognitive models.

Taking all the results into account, we may safely conclude that our sample of schizophrenia patients did indeed exhibit impaired inhibitory control and faulty attentional resources. However the former does not result from the latter. These effects are not dependent on processing speed and, in patients with schizophrenia, are seemingly not related to medication. Future research could use dual tasks of varying difficulties when investigating attentional resources in schizophrenia. Such a manipulation could help bring about an understanding of the way faulty inhibition and resources may contribute to symptomatology and to the cognitive diagnostic classification of schizophrenia.

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**Conflict of interest:** None.

**Data linking:** <https://recherche.univ-lyon2.fr/etmeco/data/Michael-et-alSchz.xls.zip>

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## FIGURE LEGENDS

**Figure 1:** Illustration of the visual search task with concurrent auditory detection task used in the present study. Participants searched for a target placed inside a diamond. In half the trials, a salient distractor was presented and was located inside a circle. This task was completed three times, each time with an auditory background consisting of random numbers. In one block, the participants had to ignore the auditory background (i.e., 0 targets, single task), in another they had to detect the number 2 (i.e., 1 target, easy dual task), and in another the numbers 2, 4 and 6 (i.e., 3 targets, difficult dual task). The three blocks were counter-balanced across participants in a Latin-square design.

**Figure 2:** Results (mean detection accuracy  $\pm$  SEM) from the auditory target detection task as a function of the group.

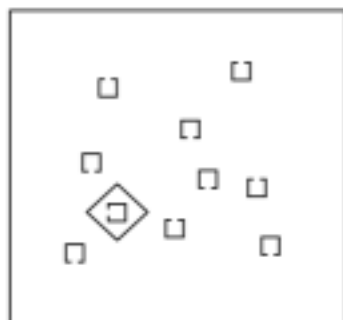
**Figure 3:** Left panel. Mean visual search times ( $\pm$  SEM) as a function of the group and the number of auditory targets that had to be detected. Right panel. Regression plots showing the relationship between the normalized Resources Difficulty Index and the Inhibition Difficulty Index. The higher the score, the greater the difficulties exhibited by the individual. This predictive relationship was significant only in controls.



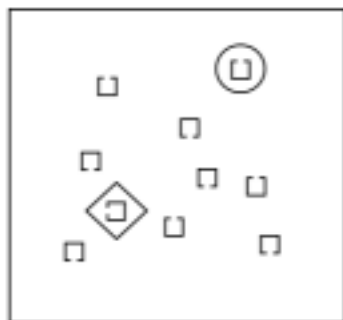
1000 ms  
fixation



Until  
response

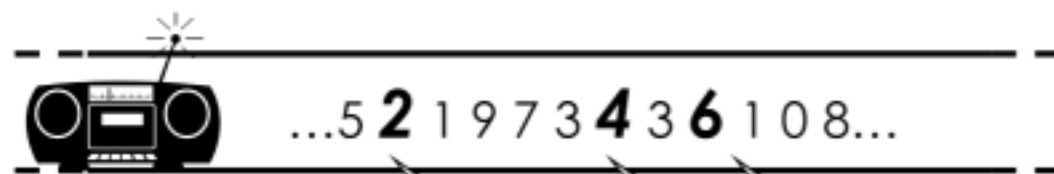
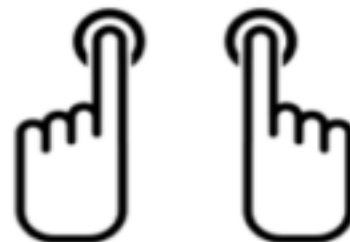


distractor  
absent



distractor  
present

Response



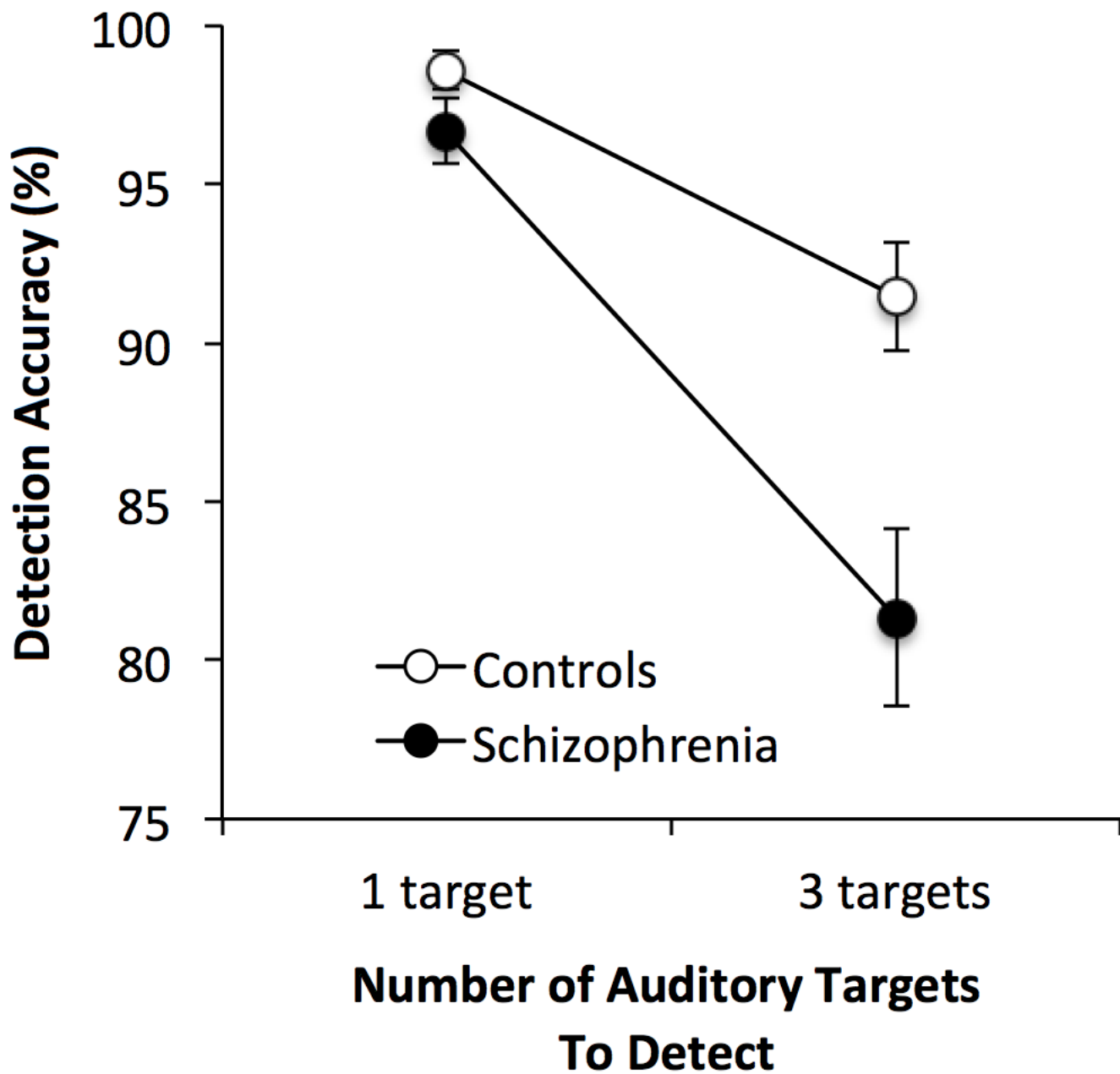
0, 1 or 3  
auditory targets

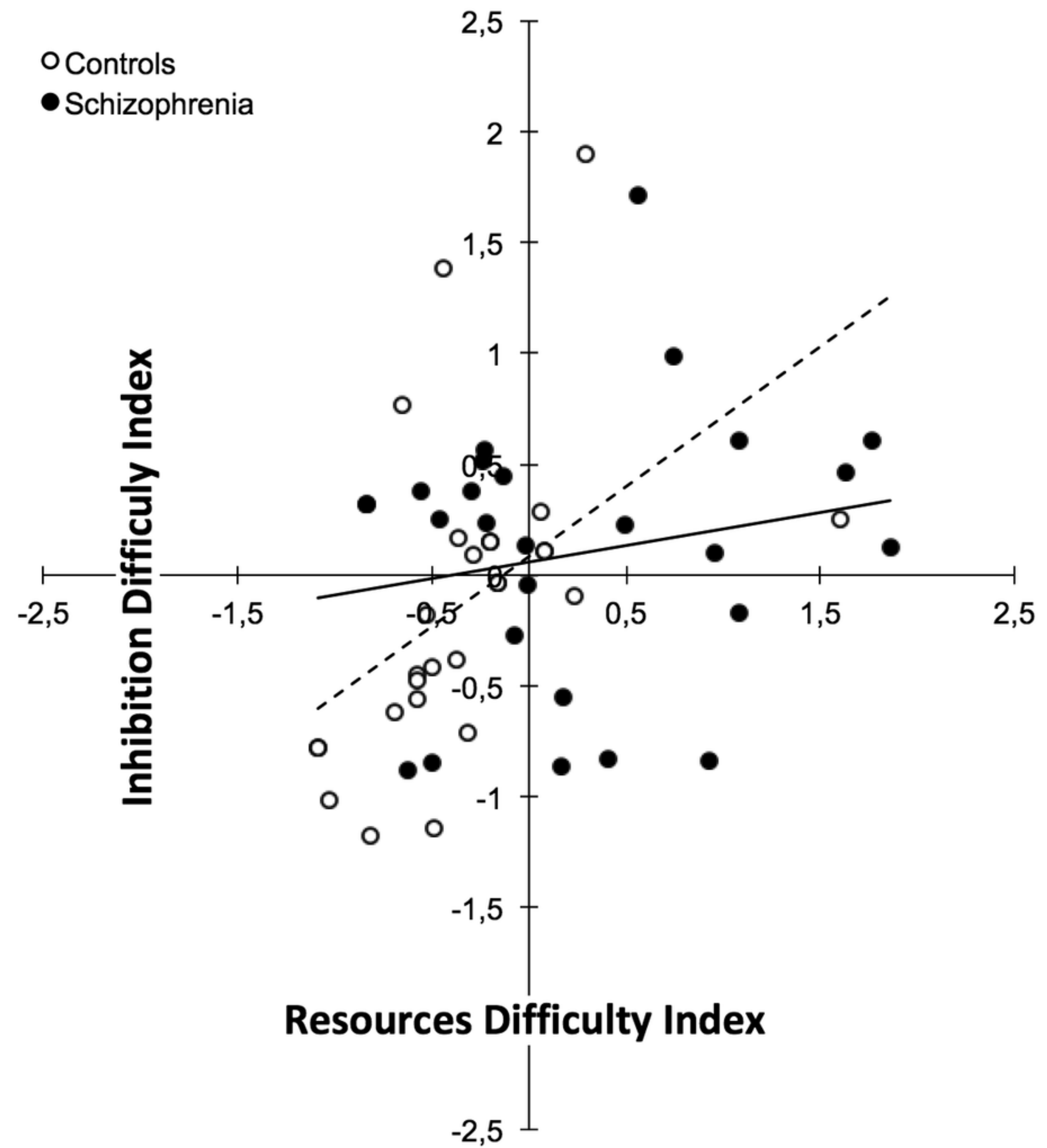
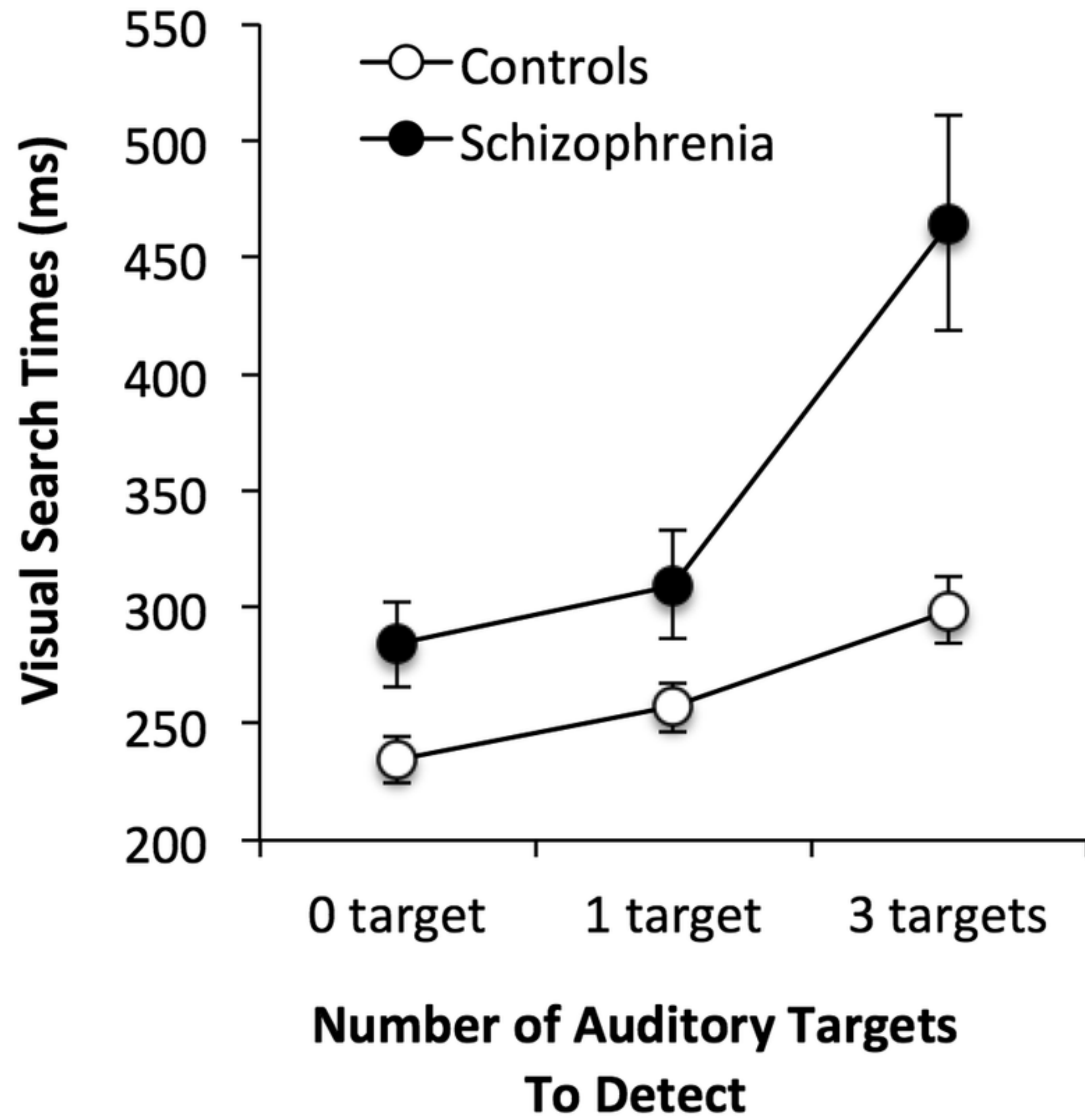
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**Table 1.** Three mutually exclusive hypotheses concerning inhibitory control and attentional resources in schizophrenia.

|  | <b>Impaired inhibition, preserved resources</b> | <b>Preserved inhibition, faulty resources</b> | <b>Impaired inhibition, faulty resources</b> |
|--|---|---|--|
| <b>group x distractor condition</b>                            | expected  | expected                                      | expected                                     |
| <b>group x auditory task difficulty</b>                        | not expected                                    | expected                                      | expected                                     |
| <b>group x distractor condition x auditory task difficulty</b> | not expected                                    | expected                                      | not expected                                 |

**Table 2.** Characteristics of the two groups.

|                                    | <b>Controls</b> | <b>Schizophrenia patients</b> |
|------------------------------------|-----------------|-------------------------------|
| <i>N</i> (men/women)               | 26 (17/9)       | 26 (17/9)                     |
| Age in years                       | 31.1 (10.4)     | 31.4 (9.5)                    |
| Years of education                 | 13.1 (1.3)      | 13.1 (1.9)                    |
| Duration of illness in years       |                 | 12.9 (6.8)                    |
| PANSS Positive                     |                 | 13.3 (3.6)                    |
| PANSS Negative                     |                 | 15.7 (5.03)                   |
| PANSS Psychopathology              |                 | 27.96 (6.6)                   |
| PANNS Total                        |                 | 56.9 (12.3)                   |
| WAIS-IV Verbal Comprehension Index |                 | 99.9 (17.8)                   |
| WAIS-IV Perceptual Reasoning Index |                 | 94.5 (18.1)                   |
| Suicide attempt ( <i>N</i> )       |                 | 8/26                          |
| Addictive behavior ( <i>N</i> )    |                 | 20/26                         |

PANSS, Positive and Negative Symptoms Scale; WAIS-IV, Wechsler Adult Intelligence Scale IV.