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Stroke damages attentional maintenance in working memory

Gaën PLANCHER^{1,2}, Bernadette NAEGELE³, Victoria GUINET⁴, Sophie PORTRAT⁵, & Pascale COLLIOT¹

¹ Université Lumière Lyon 2, Laboratoire d'Étude des Mécanismes Cognitifs, Bron, France

² Institut Universitaire de France (IUF)

³ Service de Neurologie Vasculaire, CHU Grenoble Alpes, France

⁴ Department of Functional Neurology and Epileptology, Hospices Civils de Lyon, Bron, France

⁵ Université Savoie Mont-Blanc, Université Grenoble Alpes, CNRS, LPNC, Grenoble, France

Author Note

Correspondence concerning this article should be addressed to: gaen.plancher@univ-lyon2.fr
Université Lumière Lyon 2, Laboratoire d'Étude des Mécanismes Cognitifs.

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Abstract

Stroke is the main cause of acquired disability in adults and specific deficits in working memory (WM) are among the most common cognitive consequences. In neuropsychological routine, WM is most of the time investigated in the framework of the multicomponent model (Baddeley & Hitch, 1974). Using a more recent theoretical WM model, the Time-Based-Resource-Sharing (TBRS) model (Barrouillet, Portrat, & Camos, 2011), the aim of the present study was to investigate in young post-stroke patients to which extent attentional maintenance is impaired in WM. To address this question, we discarded other factors known to directly influence WM performance, i.e. processing speed and short-term memory span. We proposed to 53 post-stroke patients and to 63 healthy controls a complex-span paradigm in which participants were asked to alternate between the memorization of a series of images and a concurrent parity judgment task of a series of digits. To investigate the attentional maintenance processes, we manipulated the cognitive load (CL) of the concurrent task. CL effect is typically interpreted as the involvement of attentional maintenance processes. The task was adapted to each participant according to their processing speed and memory span. As expected, the results showed higher recall performance in healthy controls compared to post-stroke patients. Consistent with the literature, we also observed higher performance when the CL was low compared to high. However, the improvement in recall at low CL was smaller for post-stroke patients compared to controls, suggesting that post-stroke WM deficit could be in part due to a deficit of the attentional maintenance processes.

Word count: 2748

Introduction

After a stroke, young patients often suffer from cognitive impairment leading to poor quality of life, frequently affecting working memory (WM), attention, and processing speed (Lugtmeijer et al., 2021; Schaapsmeeders et al., 2013). Most of the time, when they return to active life, these young patients experience great difficulties in the activities that involve WM and require significant attentional resources. In this respect, a prospective cohort study showed that decline in WM predicted poor functional outcome 11 years after the stroke (Synhaeve et al., 2015). It is thus crucial to understand more precisely the origin of WM impairments, partly to provide a targeted rehabilitation adapted to each patient, a better quality of life, and avoid an important societal cost. One manner to better understand WM functioning is to simultaneously study WM and attention by focusing on the cognitive load effect on memory performance. It has been mainly done in young healthy adults, but not in young post-stroke patients. In clinical routine, WM difficulties are assessed through classical neuropsychological tests which do not necessarily take into account the recent theoretical development of WM. Three limits can be formulated regarding this approach. First, these tests do not allow to properly investigate the specific cognitive mechanisms behind the impairment. Second, they rarely make possible the investigation of WM and attention in interaction; although recent theoretical WM models assume that WM and attention are intimately related (e.g. Barrouillet, Portrat, & Camos, 2011; Cowan, 2005). Finally, time is not always well controlled in neuropsychological tests, whereas we know that processing speed impacts cognitive performance (Su, Wuang, Lin, & Su, 2015). The aim of the present study was to investigate how attentional maintenance is impaired in WM after a stroke, while controlling for factors that may directly influence WM performance (i.e., processing speed and short-term memory (STM) span).

WM is the keystone of general cognitive achievement. It can be classically defined as the ability to temporarily hold information while manipulating other information. Recently, some theoretical WM models postulate that attention plays a central role in WM. One of the most prominent of these theories is the Time-Based-Resource-Sharing (TBRS) model (Barrouillet, et al., 2011; Plancher & Barrouillet, 2019). This model assumes that processing and storage compete for a unique attentional resource shared within a unitary system resulting in a perfect trade-off between the two functions. Because this resource is limited it has to be shared between the two functions, and since a central bottleneck constrains cognition, processing and maintenance take place in a sequential manner. According to the model, WM traces suffer from temporal decay and interference as soon as attention is switched away.

Consequently, to avoid memory loss, attention has to be frequently redirected on memory traces. This process is called attentional refreshing. The attentional refreshing is viewed as a domain-general maintenance mechanism relying on attention to keep mental representations active and has been described as a minimal executive function (Raye, Johnson, Mitchell, Greene & Johnson, 2007; Camos et al., 2018). It should be noted that several studies suggest that verbal rehearsal is distinct from attentional refreshing (e.g. Camos, Lagner, & Barrouillet, 2009).

Importantly, the cognitive load (CL) effect is assumed to reflect the use of attentional refreshing (Barrouillet et al., 2011), with no interaction with verbal rehearsal. It is typically observed in complex span tasks in which to-be-remembered items are presented for further serial recall, each of these items being followed by a series of to-be-processed distractors that constitutes an intervening task. Many studies showed that recall performance is a function of the ratio between the time during which processing these distractors occupies attention and the total time allowed to process them. Because maintenance activities are prevented when the processing component of the task occupies attention, the higher the CL of the intervening task, the lower the recall performance. Concretely, in a complex span task, the CL of the intervening task can be operationalized with a reduced time allowed to process a fixed number of distractors.

In the present study, we compared the CL effect on post-stroke patients and healthy control subjects. Participants had to perform a complex span task adapted to their STM span and processing speed, where they alternated between the memorization of a series of images and a concurrent parity judgment task of series of digits. Consistent with the literature, we expected lower memory performance for patients compared to controls and better memory performance when the CL of the concurrent task was lower. However, if patients have a specific deficit of attentional refreshing, the memory improvement with lower CL should be smaller in post-stroke patients compared to controls.

Method

Participants

This study included 116 participants: 53 patients (15 women) within 2 years of a first-ever ischemic stroke admitted to the neurovascular unit of Grenoble CHU (18 had a left-hemisphere stroke - one anterior and 18 posterior -, 28 had a right-hemisphere stroke, - five anterior and 23 posterior -, one had a mesencephalic stroke, and the other were bilateral), and 63 healthy

controls (24 women). All participants gave written informed consent to participate in this study which was conducted in compliance with the Declaration of Helsinki. The mean age of patients was 47.9 (SD = 11.36) and 49 (SD = 10.69) for controls. All participants were required to have normal or corrected-to-normal vision, French native language, no motor deficit, no speech disorder, and no spatial neglect. No patient has received cognitive rehabilitation therapy at any time. Demographical characteristics and scores at neuropsychological assessment are reported in Table 1. There were no significant differences in age or education level between patients and controls. Intellectual quotients were within the normal range for both groups.

Insert Table 1 about here

Material and Procedure

The experiment was composed of three different parts: a STM task to measure the span of each participant, a parity task to measure their processing speed, and a complex span task. The first task used a progressive span procedure in which participants were presented with paper images (from 3 to 7) for three seconds each and had to recall them in serial order at the end of the series. The images were selected from databases (LEXIS, DO 80, PEGV). Each image represented a concrete stimulus easily identifiable (e.g., corn, train, shark). Each series successfully recalled was followed by a longer series while each failed series was followed by a smaller one. Each participant performed 10 trials. The span was determined by considering the higher series with two consecutive successes. In the second task (parity judgement), digits were first presented on a sheet of paper and participants had to say aloud as fast as possible whether every digit randomly chosen from 1 to 9 was odd or even. The same task composed of 20 trials was then performed on a computer using response keys in order to extract individual processing speed. Only participants with a correct response rate of 80% or more were included in the study.

The complex span task combined the STM task and the parity task and was calibrated to each participant according to their span and processing speed. The images used were selected from the same databases, but none of them was presented during the STM task. Three digits were presented after each image. All the participants were instructed to name the images and to press keys as fast as possible to decide whether every digit was odd or even. When a question mark was presented at the end of the trial, they had to recall aloud the images in the correct order. Each trial began with an asterisk centrally displayed on screen for 500 ms, followed by

a 100-ms delay and a series of either three, four or five images according to the memory span of the participant. Each image was presented for 1500 ms, followed by a 100-ms delay, then by three digits successively displayed for 700 ms, and finally by a delay that varied according to the CL condition. Each CL was computed for each participant according to his processing speed. For the low CL condition, the mean processing speed was divided by 0.385 and for the high CL it was divided by 0.625. For example, if a participant had a mean processing speed of 784 ms at the parity task, the delay after each digit was of 2036 ms and 1254 ms for the low and high CL respectively. The participants were presented with 20 trials in a random order (10 for each CL condition). Before the experimental test, they performed a training session composed of one trial per CL condition with two images each.

Results

An analysis of variance was carried out on the percentage of images recalled in correct order with the group (control or patient) as between-subjects variable and the CL (low or high) as within-subjects variable. As predicted, the main effect of group was significant ($F(1, 114) = 8.14, p < .001; \eta^2p = .07; 95\% \text{ CI } [2.32, 12.84]$) such that patients obtained lower performance ($M = 76.75\%, SD = 18.08$) than controls ($M = 84.33\%, SD = 13.54$). The main effect of CL also proved significant ($F(1, 114) = 41.37, p < .001; \eta^2p = .27; 95\% \text{ CI } [6.07, 11.48]$) with participants' rate of recall poorer in the high CL condition ($M = 76.02\%, SD = 16.38$) compared to the low CL condition ($M = 85.06\%, SD = 16.56$). In line with our prediction, a significant interaction emerged between group and CL ($F(1,114) = 5.11, p < .05; \eta^2p = .04$) such that the improvement at low CL was smaller for post-stroke patients compared to controls. Put it differently, groups differed only in the low CL condition ($p < .01; 95\% \text{ CI } [2.69, 18.63]$), with better performance for controls ($M = 89.93\%, SD = 11.39$) compared to patients ($M = 79.23\%, SD = 19.71$) (see Figure 1.). No significant differences in recall performance emerged between controls ($M = 78.08\%, SD = 16.57$) and patients ($M = 73.58\%, SD = 15.97$) in the high CL condition ($p=.44, 95\% \text{ CI } [-3.48, 12.47]$). Regarding the parity task within the complex span task, no significant effect of the group was observed on accuracy ($t(115)=-.97, p=.33$. Control: $M=93.48, SD=8.56$; Patient: $M=94.93, SD=7.30$), nor on processing speed ($t(115)=-1.57, p=.11$. Control: $M=717.64\text{ms}, SD=132.94$; Patient: $M=766.44\text{ms}, SD=197.10$)

Insert Figure 1 about here

In order to take into account the lesion side, we also performed an analysis of variance on the percentage of images recalled in correct order with the group (control, left hemisphere stroke patients, right hemisphere stroke patients) as between-subjects variable and the CL (low or high) as within-subjects variable. The main effect of group was significant ($F(1, 112) = 4.77$, $p < .01$), such that left hemisphere stroke patients ($M = 74.73\%$, $SD = 21.88$) showed lower memory performance compared to controls ($M = 84.33\%$, $SD = 13.54$) ($p < .01$), and right hemisphere stroke patients ($M = 75.88\%$, $SD = 15.91$) obtained lower performance compared to controls ($p < .05$). The main effect of CL also proved significant ($F(1, 112) = 19.53$, $p < .001$) with participants' rate of recall was poorer in the high CL condition ($M = 74.71\%$, $SD = 16.72$) compared to the low CL condition ($M = 81.70\%$, $SD = 17.79$). A significant interaction also emerged between groups and CL ($F(1,112) = 4.30$, $p < .05$). The improvement of memory performance at low CL compared to high CL was significant for controls (difference $_{low vs. high} = 11.86$; $p < .001$) and to a lesser extent for right hemisphere stroke patients (difference $_{low vs. high} = 8.52$; $p < .05$). However, left hemisphere stroke patients did show significant difference between high and low CL (difference $_{low vs. high} = .60$) (see Figure 2).

Insert Figure 2 about here

Discussion

The aim of the present study was to investigate how attentional maintenance in WM is impaired in post-stroke patients. We observed better WM performance in the low CL condition compared to the high CL condition and for controls compared to patients. However, as expected the improvement in recall at low CL was smaller for post-stroke patients compared to controls. According to the TBRS model (Barrouillet, et al., 2011), WM traces suffer from temporal decay and interference as soon as attention is switched away. Consequently, to avoid memory loss, attention has to be frequently redirected on memory traces, by refreshing process. The CL effect observed reflects the use of attentional refreshing. In the low CL condition, a longer “free” time is used to refresh WM traces, resulting in better WM performance. Our study showed that patients benefited less from refreshing opportunities than healthy controls suggesting a less efficient attentional refreshing. This is consistent with the fact that post-stroke patients usually presented a specific attentional deficit (Schaapsmeeders et al., 2013). Importantly, it seems

that patients did not behave differently on the concurrent processing. In consequence, the effects observed on the memory performance could be hardly explained by this task. It is worth noting that left hemisphere stroke patients did show difference between high and low CL, suggesting that these patients in particular cannot benefit from attentional refreshing.

In the literature few studies have compared WM performance between left and right hemisphere stroke patients. For those who have done so, Lugtmeijer et al. (2021) noted that 66.7% of these studies did not report a significant difference in performance between left and right hemisphere stroke patients. However, the 25% which reported a difference, showed a worse performance in left hemisphere stroke patients compared to right hemisphere stroke patients and controls (e.g. Ho, Kong, & Koon, 2018; Andrews, Halford, Shum, Maujean, Chappell, & Birney, 2014; Low, Crewther, Perre, Ong, Laycock, & Wijeratne, 2016). Because our results suggest that left hemisphere stroke patients did not benefit from refreshing opportunities compared to right hemisphere stroke patients, they support the idea of lower WM performance with a left lesion. A double dissociation has been proposed in the past, through the theory of hemispheric specialization, suggesting more severe impairments in verbal WM in patients with a left hemisphere stroke and more spatial WM impairments in patients with right hemisphere stroke (e.g. Habib, Nyberg, & Tulving, 2003). Accordingly, Geva et al. (2021) observed that verbal short-term memory impairments are most consistently associated with damage to left temporo-parietal structures. Our task was rather verbal than visuospatial as participants had to recall names of images. This might explain in part why we observed no CL effect for our left-stroke patients. However, we need to remain cautious in our interpretation as a recent study indicates that visual and verbal memory deficits are better predicted by measures of functional connectivity rather than lesion characteristics (Siegel et al., 2016). The meta-analyse of Lugtmeijer et al. (2021) supports indeed the view of a bilateral fronto-parietal network involved in WM, explaining notably the high frequency of WM deficits after stroke. More research in the future on the question of the laterality of the lesion will allow to better understand its impact on WM performance. In particular, because our patient sample size was relatively small, although this is common in clinical studies.

Our study also provides interesting insights into the methods used to measure WM. Classical neuropsychological assessment (e.g. digit span, PASAT) does not necessarily allow to determine the specific cognitive mechanisms impaired in WM. The complex span paradigm with a varying CL is particularly relevant because it allows to investigate WM in interaction with attention, and thus to reveal a potential deficit of attentional refreshing in post-stroke patients. In terms of contribution for WM theory, the fact that the CL effect arose even when

processing speed and memory span are controlled is interesting and makes an original contribution. As a matter of fact, it suggests that the CL effect generally reflects a genuine attentional phenomenon. Overall, our study highlighted the importance of controlling confounding factors such as processing speed and memory span when investigating WM. This might be particularly important for post-stroke patients given that such factors are known to affect their performance in many classical cognitive tests (Su et al., 2015). Based on this approach, future WM training program should be adapted to individual cognitive profile in order to (i) target pure WM processes, and (ii) increase the efficiency of the training. Indeed, WM research in healthy young adults showed that adjusting task difficulty to performance generally lead to larger training gains (Brehmer, Westerberg, & Bäckman, 2012), in part because it increases participant's motivation (Jaeggi, Buschkiuehl, Shah, & Jonides, 2014).

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Table 1. Means and Standard Deviations for Stroke patients and Healthy controls at Demographics and Neuropsychological Measures

	Post-stroke patients (Mean ± SD)	Healthy controls (Mean ± SD)	Student T test
Age (Years)	47.84 ± 11.90	48.83 ± 10.83	<i>p</i> <.63
Education Level (years of school)	13.09 ± 3.81	13.39 ± 3.20	<i>p</i> <.64
IQ logic reason	101.94 ± 13.88 (N=51)	108.13 ± 13.46 (N=46)	<i>p</i> =.03
Direct Span	6.09 ± 1.24 (N =52)	6.73 ± 1.12 (N=60)	<i>p</i> <.01
Indirect Span	4.64 ± 1.19 (N=53)	5.41 ± 1.08 (N=60)	<i>p</i> <.001
Stroop Colors of words - Stroop colors (ms)	55.73 ± 29.90 (N=52)	37.37 ± 17.95 (N=58)	<i>p</i> <.001
TMT B - TMT A (ms)	42.98 ± 25.81 (N=51)	34.80 ± 20.64 (N=60)	<i>p</i> =.06
PASAT (/60)	50.07 ± 9.68 (N=44)	54.88 ± 5.21 (N=41)	<i>p</i> <.01

Figure 1. Proportion of images recalled in correct order (means and standard errors) by post-stroke patients and healthy controls according to the CL of the concurrent task.

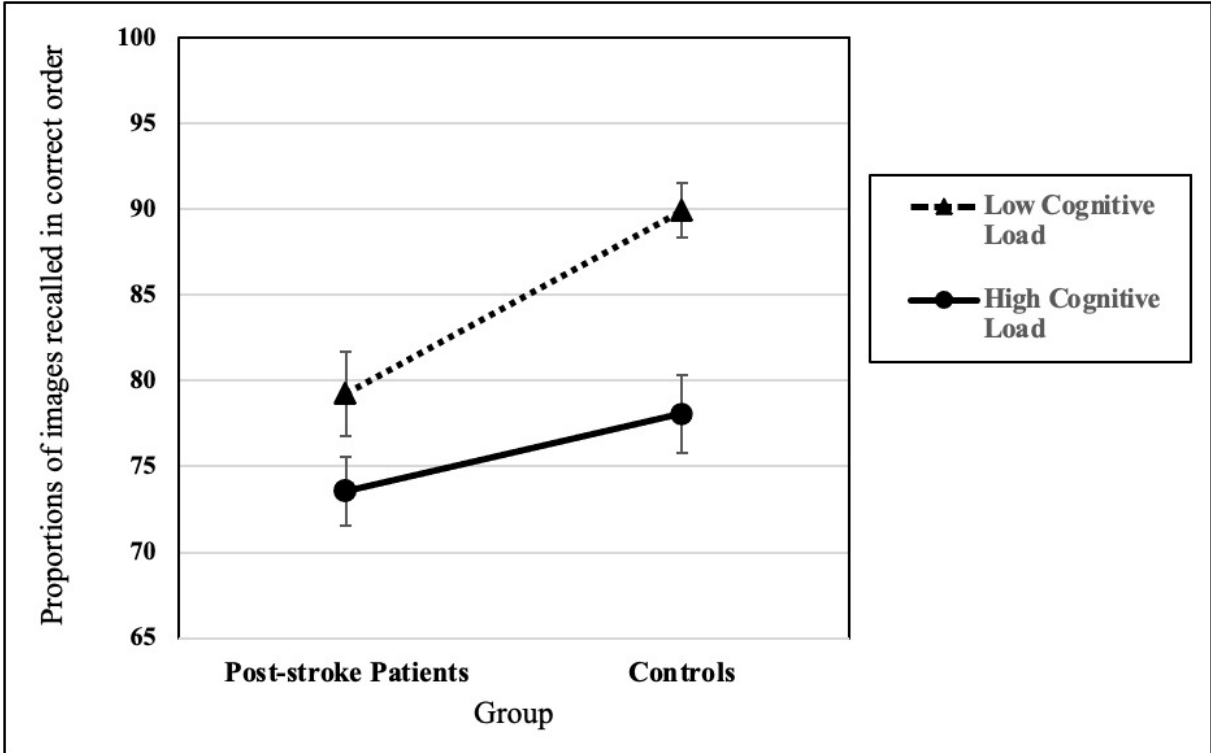


Figure 2. Proportion of images recalled in correct order (means and standard errors) for left hemisphere stroke patients, right hemisphere stroke patients and healthy controls according to the CL of the concurrent task.

