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Integration of representations is key to the enactment benefit: Insights from individuals with stroke lesions

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ABSTRACT

Previous research has suggested that performing an action during encoding, related to the meaning of a target word (known as 'enactment'), benefits later memory retrieval relative to when the word is simply read. It has been suggested that enactment confers this memory benefit by promoting the formation of a multimodal memory trace through the integration of verbal and motoric representations, facilitated by the parietal lobe. More recent work has proposed that cognitive planning preceding the execution of enactment, via engagement of frontal lobe-based processes, is most critical for the memory benefit. Here, evidence for these two accounts was assessed by comparing memory in healthy controls relative to individuals with lesions to parietal or frontal brain areas. Frontal stroke participants and controls both showed significant enactment effects: Recall was better for words enacted at encoding relative to those that were silently read. In contrast, participants with parietal lesions did not show the effect. Results suggest that the integration of multimodal representations by parietal lobe-based processes is a critical step necessary to evoke the benefit of enactment on memory performance.

1. Introduction

1.1. Enactment as an effective encoding strategy

The enactment effect refers to the finding that performing an action related to a target word or phrase (also known as Subject-Performed Task, or SPT) during encoding enhances memory for that word or phrase, relative to simply reading or listening to it (also known as a Verbal Task, or VT; Cohen, 1981; Engelkamp and Krumnacker, 1980; Saltz and Donnenwerth-Nolan, 1981). This benefit from enactment has been demonstrated with various types of to-be-remembered information [e.g., action verbs and phrases, actions performed with imaginary objects or real objects] (Cohen, 1983, 1989), across the lifespan [children, younger, and older adults] (Backman et al., 1986; Nyberg et al., 2002), with different test formats [free recall, cued recall, and recognition] (Engelkamp,1997; Kormi-Nouri et al., 1994), and during incidental or intentional memory encoding contexts (Engelkamp and Zimmer, 1985, 1989). Further, the beneficial impact of enactment on memory (relative to a verbal task) has also been reported in diverse neurological patient groups, such as those with Alzheimer's disease (Dick et al., 1989), Korsakoff syndrome (Mimura et al., 2005), patients with severe anterograde amnesia (Hainselin et al., 2014), and those with Autistic spectrum disorder (Durban, 2014; Yamamoto and Masumoto, 2018). Given the robustness of this mnemonic technique and its utility in various age groups and patient populations, understanding the underlying neural substrate and the implicated mechanism of action could offer insights into developing new memory strategies for overcoming memory deficits in neurological patients.

1.2. The role of action planning in the enactment effect

Despite the robustness of the enactment effect and the rich history of studies investigating its mnemonic benefits, the neural mechanism(s) responsible for the boost to memory from enactment are still debated. Prior research has demonstrated that cognitive planning preceding the execution of an action (requiring frontal lobe-based resources) performed at encoding is a critical mechanism underlying the memory boost (Knopf et al., 2005; Macedonia et al., 2011; see Roberts et al., 2022 for a systematic review on enactment). In the review by Roberts and colleagues (2022), evidence for the role of planning in enactment was revealed in behavioural, neurological patient, and neuroimaging studies. For example, Eschen and colleagues (2007) showed that

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planning to perform an action at a later time led to activation in the same brain areas (i.e., premotor and inferior parietal sites, including the supramarginal gyrus) implicated in the actual performance of actions. Indeed, Nyberg and colleagues (2001) also found activation in premotor areas of the brain during encoding trials of both enacted items and motor-imagery tasks. These findings are further supported by behavioural evidence from studies showing memory benefits for verbal items that were simply planned to be performed but were never executed (Engelkamp, 1997; Koriat et al., 1991).

The work of Ratner and Foley (1994, 2020) highlight the importance of intentional planning when enacting action phrases. In their 'Activity Memory Framework', Ratner and Foley (2020) suggest that the enactor is a goal-directed agent. That is, enactment of items does not consist of performing simple unrelated actions but rather goal directed ones that must be produced in response to targets. If one were to break down the sequential steps involved in enactment, Ratner and Foley (2020) would suggest that they include appropriate appraisal of the verbal material to infer its meaning, selection of the correct action to represent the word, and finally planning and execution of the correct action (Ratner and Foley, 1994, 2020; Zimmer et al., 2001). Given this, one might predict enactment to be a futile strategy in participants with frontal lobe damage, as action planning is typically compromised in such individuals (Roberts et al., 2022).

Relatedly, in a study from Knopf and colleagues (2005), an experimental condition called "Director's Task (DT)" was included (in addition to an enactment and verbal task condition at encoding) to assess whether memory for performed actions is linked to movement execution or achieved through the process of action planning. Specifically, in the DT condition, participants with Frontal Lobe Syndrome (FLS) and Parkinson's Disease (PD) were asked to instruct the experimenter to perform two action steps in response to a verbal command (e.g., the participant read "opening a book" and named two acts such as "take a book in one's hand", and "open the book cover"). It was hypothesized that PD participants, whose deficit predominately affects action execution (but not planning), would still show an enactment benefit (SPT $>$ VT). In contrast, it was predicted that FLS participants whose deficits include impaired action planning (DT), but intact action execution, would fail to show an enactment effect. As predicted, Knopf and colleagues (2005) found an enactment benefit in PD participants, but not in FLS individuals. Interestingly, in the DT condition, FLS participants struggled to understand how to precisely break up each action into two acts, and to then communicate these instructions to the experimenter within the time limit of 15 s. However, a limitation of the work by Knopf and colleagues (2005) is that they did not measure working memory performance of the FLS participants in their study. Thus, it is unclear whether potential deficits in working memory in FLS participants led to their poorer performance in the enactment and DT conditions (i.e., a failure to hold verbal commands in mind to be able to communicate an action plan to the experimenter, or to perform an action) as opposed to the predicted action planning processes (Roussel et al., 2012). On the other hand, some studies have shown that when participants with frontal lobe lesions act out a word relative to simply naming it, they gain a significant enactment benefit for serial-order memory (Butters et al., 1994; McAndrews and Milner, 1991). Therefore, in light of these results, further research is warranted to delineate the contribution of action planning to the enactment effect.

1.3. The role of multimodal integration in the enactment effect

Another alternative explanation for the enactment benefit to memory is one that emphasizes the integration of information encoded in multiple sensory modalities. In Engelkamp's view (1984, 1985), the critical benefit elicited by overtly carrying out a representative action during encoding is from the motor components of the action becoming part of the episodic memory trace. In a sense, this account is a dual-coding one. Enactment boosts memory because the encoding strategy establishes a motor trace in addition to the verbal representation of the item; thus, creating two (verbal and motor) rather one (verbal) memory representations of the to-be-remembered information (Backman et al., 1986; Masumoto et al., 2006; Mohr et al., 1989). Further, Bäckman and colleagues (1986) suggest that when participants are given an object to enact object-noun phrases (e.g., pick up the ball), they obtain visual and tactile information as well as feedback on physical body movement (kinesthetics), in addition to the verbal information from the target word. By this account, motor encoding leads to better memory performance than verbal encoding by evoking representations of information across different sensory modalities (i.e., verbal, visual, motor, tactile, kinesthetic, etc.). Complementing this behavioural evidence, the posterior parietal lobe, precisely the Supramarginal Gyrus (SMG; Brodmann Area 40) has been documented as an important area in the enactment literature that enables the integration of information represented in multiple sensory modalities (Masumoto et al., 2006; Nyberg et al., 2001; Russ et al., 2003). In line with this, an fMRI study by Russ and colleagues (2003) reported activity in the bilateral parietal cortices, especially in the inferior parietal cortex/supramarginal gyrus (SMG), during recognition of target items that were previously enacted relative to those that were only read at encoding. Researchers have suggested that this region aids in the creation of integrated movement representations that takes into account both semantic information, as well as motor imagery (i.e., imagining performing an action; Masumoto et al., 2006, 2015; Russ et al., 2003). For example, neural findings in Masumoto et al.'s (2006) study suggests that it is the reactivation of movement representation that is linked with semantic information about the action—as opposed to just physical motor information alone (speed and form of actions)—that drives the enactment benefit. As well, reactivation at retrieval of the sensory experiences that represent particular actions performed at encoding, has been suggested to contribute to the mnemonic benefits of the enactment task (Hostetter and Alibali, 2019; Ianì, 2019).

Of particular importance to the current study is the research conduced by Masumoto and colleagues (2015) on patients with different symptoms of apraxia. In apraxia, the patient has all the sensory–motor capabilities required for proper execution of the movement, and in fact succeeds in many circumstances, but fails when the act must be performed in response to the examiner's request (Kareken et al., 1998). In the patient work by Masumoto and colleagues (2015), patient K.T. had sustained a left hemispheric lesion resulting in ideational and ideomotor apraxia, leading to an inability to process multiple movement representations and integrate functional knowledge of an action with an object. In contrast, patient O.T. showed symptoms of mostly ideomotor apraxia, along with corticobasal syndrome which meant they could not experience sensory feedback (e.g., tactile, motor) from the accuracy of their movements during enactment (i.e., a process implicated during action planning). Therefore, while patient K.T. and O.T. both struggled to complete actions, patient K.T. had trouble with action-conceptual integration while patient O.T. had a lack of sensory feedback. If the enactment benefit were to be driven by the process of integrating semantic or conceptual information about the target item with the physical action, then K.T. should perform poorly following enactment of words. If, however, it is the reactivation of the sensory experience created at encoding that confers a memory boost, more so than the integration of information represented in different sensory modalities, then patient O.T. should perform poorly following enactment of words. These participants enacted or verbally read aloud action sentences, and later their recall and recognition of these items were tested. Findings revealed that patient K.T.—who had expressed trouble with action-conceptual integration into a proper action sequence—did not show an enactment benefit to memory in recognition, whereas patient O.T. did show it. Further, imaging results revealed that patient K.T. had substantive lesions in the posterior parietal lobule and inferior temporal lobe, while patient O.T. had sustained lesions to the bilateral parietal cortex, basal ganglia, and thalamus. Simply put, the behavioural findings from patient K.T. revealed that integration of conceptual knowledge of the verbal command and functional knowledge of actions is required to gain a memory boost from enactment, while findings from patient O.T. downplay the potential contribution of sensory feedback from kinesthetics and tactile senses. This claim is corroborated by their imaging results that highlight the posterior parietal lobe as a critical substrate for this effect. Thus, the ability to integrate information represented in multiple modalities (i.e., conceptual and motor) is an important factor underlying enactment's memory benefit.

1.4. Current study

Given these prior mixed findings on the brain basis of the enactment effect, the current study sought to examine and compare the magnitude of the enactment effect in individuals who sustained a focal stroke to either the frontal or parietal region of the brain. Our work is novel in that it is the first to directly compare the relative contribution of the two most prominent brains areas thought to be implicated in the enactment effect. To this end, our study aims to answer two critical questions pertinent to the field of action memory research: (1) Does motor-based encoding (enactment) confer a memory benefit relative to silent reading in individuals who have suffered a stroke, and is the magnitude of the effect comparable to that in healthy controls? More importantly, (2) are there differential impacts to memory performance for enacted items relative to items silently read, depending on the location of the stroke-related brain lesion (i.e., frontal lobe or parietal lobe)? In answering the latter question, we hope to elucidate the relative roles of action planning and multimodal integration in the enactment benefit to memory.

Based on past work from our own lab (see Roberts et al., 2022 for a meta-analytic review; Sivashankar and Fernandes, 2022; Sivashankar et al., 2023), we predict enactment of target words will enhance memory performance compared to silent reading. Specifically, we hypothesize this pattern of findings to manifest in individuals who have had a stroke affecting frontal or parietal regions, as well as in healthy controls. However, we anticipate finding a greater magnitude of the enactment benefit (SPT > VT) in healthy controls, relative to the stroke groups. As prior findings are mixed and have not examined samples who have had focal lesions, we do not have a-priori predictions regarding the differential impact on memory from stroke (Knopf et al., 2005; Willms et al., 2021).

If memory for enacted items is higher in the Frontal group relative to the Parietal group, then this would suggest that enactment benefits memory only when integration capabilities, mediated by the parietal lobe, are intact. The parietal lobe is linked to processing of mental images using movement (Buxbaum et al., 2005; Sirigu et al., 1996; Wolpert et al., 1998), sensorimotor knowledge of tool use (Buxbaum, 2001), and execution of goal oriented purposeful movement (Fogassi et al., 2005). If, however, we find diminished memory performance for enacted items in the Frontal group in comparison to the Parietal group, then this would suggest that frontal lobe-based processing like action planning are likely critical factors in the enactment effect.

Given that enactment has been found to significantly improve memory in a wide range of clinical groups (Roberts et al., 2022), the findings of our work may also support the therapeutic benefit of enactment as a memory enhancement technique for stroke survivors (Hasan, 2006). That is, it could serve as an alternative to more invasive and expensive neurorehabilitation procedures, such as neuroprosthetics, surgical neurorehabilitation, and deep brain stimulation. Another advantage of our study design is that we administered several neuropsychological measures to assess participants' working memory (Digit Span; Schroeder et al., 2012), strategic planning (Tower of London; Krikorian et al., 1994), verbal fluency (Category Fluency; Acevedo et al., 2000), and degree of apraxia (The Apraxia Screen of TULIA [AST]; Vanbellingen et al., 2010; 2011). This allowed us to evaluate how cognitive functions indexed by these neuropsychological metrics influence memory performance; a critical piece of analysis missing in the highly related research study by Knopf and colleagues (2005).

2. Methods

2.1. Participants

According to our meta-analysis of the enactment effect (Roberts et al., 2022), the overall effect size of the within-subject enactment benefit is Hedges' $g = 1.23$. Using G*Power software (V. 3.1.9.6; Faul et al., 2007), our target sample size to achieve 95% power to detect this effect size would be 11 participants per group (or 8 participants to achieve 80% power; both with alpha set at 0.05 and assuming two-tailed paired-sample tests). Accordingly, in our pre-registration of the study hypothesis and sample size, we had aimed to collect a minimum of 11 participants per group to achieve 95% power. We were able to achieve our target sample for the Frontal Group ($n = 11$; *M*age = 58, *SD*age = 13.04; Females = 9; Males = 2), but not the Parietal Group ($n = 6$; *M*age = 65, *SD*age = 9.17; Females = 3; Males = 3)[1,2].

Individuals with stroke lesions were recruited from several sources: 1) an existing Neurological Patient Database (NPD)[3] affiliated with the University of Waterloo, and 2) stroke patient communities and foundations such as the Heart and Stroke Foundation, and March of Dimes.[4] When recruiting from the Neurological Patient Database (NPD), we specifically filtered to only include participants who were (1) diagnosed by medical doctors (via CT or MRI scan) at the time of the stroke as having focal damage to frontal or parietal lobes, (2) had history of only a single brain lesion, and (3) showed no signs of visual neglect following the stroke. Eligible individuals (both males and females) who had documented focal damage to either frontal or parietal lobes were included to participate in this study. Participants were excluded if they had experienced more than a single stroke, if they were using medication for neurological or psychological illnesses, and/or if they had a psychological or a secondary neurological disorder/symptoms (other than the stroke), as these factors could influence memory performance. Tables in Appendix A show demographic information of participants in our Parietal and Frontal Groups.

We employed a multi-step verification process to confirm that participants recruited through our Neurological Patient Database and from Stroke organizations (March of Dimes and Heart and Stroke Foundation) had localized damage to the frontal or parietal lobes: First, all participants were required to provide medical documentation via a Qualtrics survey to help us confirm their diagnosis of brain injury. These reports specifically indicated the location of the damage, either in the frontal or parietal lobes. Most ($n = 12$) of our participants were recruited from our Neurological Patient Database (see Tables 1 and 2 for information on lesion localization for both stroke groups). Here we were already able to confirm lesion localization based on previous medical reports (CT or MR scan) and details recorded in the database. Below are additional questions asked of this group:

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[1] Data collection was stopped after exhausting all possible platforms for recruiting stroke participants.

[2] Male and Female classifications in our paper refers to sex assigned at birth.

[3] The Neurological Patient Database is affiliated with the Department of Psychology at the University of Waterloo. Participants from the local community were approached and invited to join the NPD on the basis of having had a recent physician-documented stroke.

[4] Heart and Stroke Foundation and March of Dimes are organizations in Canada that provide education, workshops, and other rehabilitative resources to stroke survivors and caregivers. A recruitment letter was posted to the website for these organizations and interested participants contacted the researchers to participate.

Table 1
Lesion localization of individuals with stroke lesions affecting the frontal lobes.

Participant number	Lesion and behavioural details	Scan type for lesion localization
PID6 (NPD)	Stroke in the left frontal lobe causing speech difficulties (aphasia), reduced verbal fluency, and weakness in the right arm and leg	MRI
PID8 (NPD)	Stroke in the left frontal lobe causing motor weakness on the right side of the body, impaired concentration.	CT
PID10 (MOD)	Left-sided frontal stroke with some difficulty in speaking, muscle weakness, and difficulty maintaining attention during tasks.	CT
PID11 (HSF)	Left-sided frontal stroke, weakness on the right side (hand and legs), still not able to run or bike.	CT
PID12 (NPD)	Stroke in the left frontal lobe resulting in difficulty organizing thoughts, reduced attention span, and right-sided hemiparesis.	CT/MRI
PID13 (NPD)	Frontal stroke in the left hemisphere, motor deficits on the right side, and trouble with concentration.	CT
PID15 (NPD)	Right frontal stroke, left side weaker (hand).	CT
PID16 (NPD)	Intracerebral bleed affecting frontal lobe decreased motor control on the right side.	CT
PID17 (NPD)	Right frontal stroke, left side weaker, walking sometimes using walker, wears glasses for reading.	CT
PID3 (MOD)	At the time of the frontal stroke right sided paralysis, aphasia. Currently, muscle weakness.	CT
PID5 (NPD)	Right frontal stroke, can walk with cane or walker, speech impairments initially.	CT

Note. NPD = Neurological Patient Database; MOD = March of Dimes; HSF = Heart and.
Stroke Foundation. Descriptions for participants from NPD were taken directly from the medical notes supplied by the consulting physician. For participants recruited from MOD and HSF, the information was obtained from our medical questionnaire and screening interview included in this study.

Table 2
Lesion localization of individuals with stroke lesions affecting the parietal lobes.

Participant number	Lesion and behavioural details	Scan type for lesion localization
PID1 (NPD)	Stroke sustained to right parietal region. Poor circulation on the left side, deep purple in colour. Loss of feeling on the left side. Reason: cerebral bleed due to viral infection.	CT
PID2 (NPD)	Stroke sustained to left parietal region. Has some difficulty with speech production and reading. Numbness and weakness on the right side of the body (fingers and legs).	CT
PID4 (NPD)	Right parietal stroke resulting in challenges with reading and writing, and sensory deficits (e.g., numbness) on the left side of the body.	CT
PID7 (NPD)	Stroke in the left parietal lobe, resulting in difficulty with spatial awareness, and mild right-sided numbness.	CT and MRI
PID9 (MOD)	Right parietal stroke. Left-sided weakness (initially left hemiparesis)	CT
PID14 (HSF)	Stroke in the left parietal lobe. Right-sided weakness.	CT

Note. NPD = Neurological Patient Database; MOD = March of Dimes; HSF = Heart and.
Stroke Foundation. Descriptions for participants from NPD were taken directly from the medical notes supplied by the consulting physician. For participants recruited from MOD and HSF, the information was obtained from our medical questionnaire and screening interview included in the study.

1. To the best of your memory, please specify the date (YYYY-MM-DD, e.g.: 2018-07-22) of the stroke that was recorded when you joined the Neurological Patient Database (NPD).
2. Are you currently taking any medication(s)? If so, please list the name(s) of the medication(s) used.
3. Have you incurred any other neurological impairments (including a secondary stroke)?
4. Are you currently experiencing feelings of depression, anxiety, and/ or post-traumatic stress disorder (PTSD)?
5. Have you ever been diagnosed with a neurological disorder (other than the stroke recorded when you joined the NPD), such as, a traumatic brain injury (TBI), acute spinal cord injury, epilepsy or seizures, amnesia, or Alzheimer's disease?

For participants recruited through Stroke organizations ($n = 5$), we asked these same questions as noted above, along with an additional one to verify the localization of the lesion.

1 Please indicate the exact location of your stroke, providing as much detail as you can based on medical reports (CT or MRI scans).

After assessing eligibility based on responses from the Qualtrics survey as part of the screening process, participants recruited through the Stroke organizations were interviewed briefly (via phone call) to verify missing information or clarify details (e.g., medications used for ongoing symptoms, presence of any secondary neurological deficits). Examples of interview questions asked of this group:

1. Can you describe where the stroke occurred (e.g., left side, right side, or specific region such as frontal or temporal lobe)?
2. When did your stroke occur (exact date as possible), and what were the immediate symptoms you experienced?
3. What neurological symptoms are you currently experiencing (e.g., weakness, numbness, speech difficulties, vision changes)?
4. Did your doctors perform any scans (such as an MRI or CT scan) to determine the location and extent of your stroke?
5. Did the medical team mention any specific areas of your brain that were impacted by the stroke?

Finally, additional neuropsychological assessments were conducted to assess cognitive impairment associated with the lesion. These assessments included tasks specifically designed to evaluate executive functions, visuospatial and motor tasks mediated by the frontal and parietal cortices. These measures include assessments of planning, working memory, verbal fluency, and test of Apraxia.

We also recruited a sample of 24 community-dwelling older adults from the local community of Kitchener-Waterloo in Canada, consisting of participants aged 60 and above, to serve as healthy controls. Data from neurotypical controls, whose MoCA (Montreal Cognitive Assessment; Nasreddine et al., 2005) and Mill Hill Vocabulary Scale (MHVS; Raven, 1958) score fell below our cut-off were excluded from data analysis; A MoCA score below 26 was interpreted as indicating potential atypical cognitive aging (Nasreddine et al., 2005), and a score below 30% on the MHVS (a score of 10 out of a total of 33 items) was indicative of poor English language competency (Raven, 1958).[5] Two participants were removed due to failure to follow experiment instructions, and two were removed for scoring below a clinical threshold (score <26) on the MoCA. The final sample consisted of 20 participants (*M*age = 74, *SD*age = 4.35; Females = 15; Males = 5) who served as control participants, achieving at least 95% power to detect an enactment effect in this group. All healthy older adults were retired at the time of testing and had

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[5] Data from all stroke participants were included in data analyses, even if they scored below the cut-off on the MoCA, as such individuals often have cognitive impairments (Tatemichi et al., 1994).

attained at least high school education (e.g., Bachelors, Masters, Trade school).

Participants were compensated $15 in the form of an electronic gift card. The University of Waterloo Research Ethics Board approved all study procedures. All study procedures were carried out in accordance with the World Medical Association Declaration of Helsinki. Written informed consent was obtained from all participants prior to the experiment. Data collection took place between September 2022 to June of 2023.

2.2. Materials

2.2.1. Stimulus list

Forty action verbs were selected from the Max Planck Institute for Psycholinguistics WebCelex (see Appendix B for the list of target words). Action verbs ranged in frequency from 1 to 464 ($M = 70.04$, $SD = 99.69$) based on the Frequency Analysis of English Usage (Francis et al., 1985), varied in length from 3 to 7 letters ($M = 4.60$, $SD = 0.96$), and had either one or two syllables ($M = 1.13$, $SD = 0.34$). Examples of target words include: “Throw”, “Chop”, “Knit”, “Salute”, “Comb”, “Stir”.

While some words were tool-based, many were not (e.g., applaud, salute, flick, wave, etc.). For all enacted words, participants were instructed to encode words by performing a related physical action depicting the to-be-remembered word. If actions required tool use, participants simply performed the actions without physical objects.

2.3. Neuropsychological battery

2.3.1. Measure of apraxia

To determine patient characteristics, we administered a set of neuropsychological test measures. We first administered the Apraxia Screen of TULIA (AST; Vanbellingen et al., 2010, 2011). This is a 12-item neuropsychological assessment of apraxia symptoms to screen for both severity and presence of motor deficits in individuals with stroke lesions and took roughly 3 min to administer. Responses were tabulated to yield a maximum score of 12 for each hand (right and left). The Apraxia Screen of TULIA is a valuable tool for evaluating motor planning and execution, and it also provides insight into the capacity one has for integration of sensory and motor information, particularly in relation to action-related tasks.

2.3.2. Measures of cognitive planning

Participants also completed a series of neuropsychological tests of cognitive planning to assess frontal-lobe-based cognitive competencies: Category Fluency Test, Tower of London, and the Digit Span Test.

2.3.2.1. Category Fluency. On the Category Fluency Test (Acevedo et al., 2000), participants were asked to generate words belonging to the categories Animals, then Vegetables, and then finally Fruits for 60 s per category. Table 3 shows the average number of words retrieved by participants in each Group for each sub-category. This test took 3 min to administer.

2.3.2.2. Tower of London. We then administered the Tower of London (ToL; Unterrainer and Owen, 2006), which is an assessment of executive functioning, specifically to detect deficits in cognitive planning. Participants were asked to solve a custom online version of the original Tower of London task (Berg and Byrd, 2002; Krikorian et al., 1994).[6] This test took 20 min to administer. We collected data on four metrics as indices for cognitive planning measured by the Tower of London (Michalec et al., 2017). One of the measures was the time (in seconds) taken to solve each problem. Participants were given a maximum of 2 min to complete each of the 12 problems. We tabulated the total time to complete all 12 problems as our measure of time taken to complete problems on the Tower of London. We also calculated the number of moves made by a participant to correctly solve each problem, above and beyond the minimum moves required to complete the problem. We defined a “move” as every instance a participant clicked on a ball and moved it to a peg of their choice. For example, if a problem required a total of 4 moves, and a participant made 9 moves to solve, then their score for that trial would be 5. We then derived the average and sum scores across trials using these raw “accuracy” values.

Table 3
Neuropsychological test performance by Group.

Cognitive Test	Parietal ($n = 6$)	Frontal ($n = 11$)	Control ($n = 20$)
	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
AST (Right hand)	11.33 (1.63)	11.55 (0.82)	11.75 (0.72)
AST (Left hand)	7.67 (4.68)**	10.64 (3.30)	11.75(0.64)**
Digit Span (Forward)	4.50 (1.87)	3.27 (1.62)**	5.30 (1.22)**
Digit Span (Reverse)	4.17 (1.72)	2.73 (1.27)*	4.52 (1.89)*
ToL (pKR)	22.67 (2.73)	21.30 (2.67)	24.80 (5.21)
ToL (SH2)	13.00 (3.74)	16.10 (3.78)	17.30 (4.61)
ToL (Sum moves)	24.50 (4.76)	29.30 (3.56)	22.20 (3.60)
ToL (Mean moves)	2.04 (0.88)	2.44 (1.72)	1.86 (1.12)
ToL (Mean seconds)	48.80 (3.67)	44.56 (4.56)	41.48 (1.45)
Category Fluency: Animals	18.5 (5.82)	16.91(5.59)	21.35 (5.22)
Category Fluency: Vegetables	12.50 (4.42)	10.09 (1.12)***	16.60 (4.36)***
Category Fluency: Fruits	12.00 (5.93)	9.64 (3.30) ***	15.85 (3.87)***
Mill Hill Vocabulary Scale	18.33 (3.45)	15.55 (4.76) ***	21.75 (3.21)***
MoCA	25.83 (3.19)	22.82 (4.33)	27.90 (1.07)

Note. ToL = Tower of London; MoCA = Montreal Cognitive Assessment. Asterisks (*) indicate group differences relative to the other two groups for each metric (*$p < .05$; **$p < .01$; ***$p < .001$) based on Bonferroni-adjusted pairwise comparisons. For example, in the Digit Span (Forward) task, only the frontal and control groups show a significant difference, with the frontal group scoring notably lower than the control participants. The parietal group’s score on this measure does not significantly differ from those of either the frontal or control groups.

We then scored time-based and move-based activity using the ‘SH2’ and ‘KR’ scoring systems recommended by Michalec et al. (2017). The SH2 assigns points based on the amount of time a participant needed to complete a problem (>60s = 0, <60s = 1, <30s = 2, and <15s = 3). The KR method is scored based on the number of attempts a participant takes to solve a problem, but since we did not offer repeat attempts and instead automatically moved to the next problem after 2 min, we formed a pseudo-KR score (‘pKR’) which followed the same method but differentially defined failures as moves required to complete the problem over and above the required number: 3 moves = 0 points, 2 moves = 1 point, 1 move = 2 points, and 0 moves = 3 points.

2.3.2.3. Digit Span. The Digit Span assessment is a subtest of both the Wechsler Adult Intelligence Scale (WAIS) and the Wechsler Memory Scales (WMS; Wechsler, 1945). During the task, the experimenter reads a sequence of numbers to participants, and participants are instructed to repeat the same sequence back in the same order (Forward span) or in reverse order (Backward span). During scoring, we recorded the list length for which participants were last able to correctly repeat all of the numbers (in either Forward or Backward order) during at least one of the 2 attempts at that level of difficulty. This test took 8 min to administer.

2.3.3. Screening measures

Following these test measures, we administered the Mill Hill Vocabulary Scale (MHVS; Raven, 1958) as a measure of English language competency. Following the MHVS, participants completed the Montréal

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[6] We used a modified version of the online ToL task provided by the Experiment Factory (Sochat et al., 2016).

Cognitive Assessment (MoCA; Nasreddine et al., 2005); a test designed to screen for general cognitive impairment. Data from control participants were removed from our main reported analyses if their MOCA score was less than 26, or if their MHVS score was less than 30% (a score of 10 out of a total of 33 items). In our sample, all Mill Hill scores from controls and patient groups were above 30%. Please see Table 3 for all mean scores (and standard deviations) obtained by each group across the neuropsychological assessments.

2.4. *Experiment procedure*

Prior to the date of experimentation, participants completed a medical screening questionnaire consisting of general health history and demographics questions to determine eligibility for the study. Only those who were deemed eligible (please see Section 2.1 "Participants" for inclusion and exclusion criteria) were then invited to participate in the experiment via video call. Participants were required to have not reported a prior history or current diagnosis of a secondary stroke, epilepsy or seizures, active vestibular disorders, acute psychiatric disorders, or diagnosis of dementia.

Due to COVID-19, the study was conducted remotely using a combination of video calling on Zoom, as well as an experiment administered using Qualtrics and jsPsych (v. 5.0.3; de Leeuw et al., 2023). Participants received an email from the researcher detailing the date and time of the study and were given a Zoom meeting link to join on the day of the experiment. When the participants joined the call, video recording started to ensure that we could later check whether participants complied with instructions for each encoding task, and to aid scoring of words recalled aloud at retrieval. Once the researcher explained the study procedure and received informed consent from participants, the study began.

Each participant was tested individually and viewed their own randomly ordered set of target words (40 action verbs), paired randomly with each encoding trial type. During enactment trials, participants were instructed to encode the words by performing a physical action related to each word. In silent reading trials, participants encoded the words by reading them without any physical movement or lip movement. Participants were instructed to continue repeating the action or reading the word until a fixation cross appeared on the screen. After the study phase, participants were given 60 s to recall as many words as they could, aloud and in any order (recall performance was the primary memory measure).

For each trial, a blank white screen was displayed for 250 ms (milliseconds), then a fixation cross was centrally presented for 500 ms, followed by another blank white screen for 250 ms, then the task prompt word ('enact' or 'read'; all in lowercase, centered on the screen) was presented for 1s (font size: 36, colour: black, font style: Times New Roman), indicating to participants to either enact or silently read the target word that followed. The to-be-remembered target word was then centrally presented on the screen for 4.5 s (font size: 16, colour: Black, font style: Courier New). In total, the duration of the encoding phase was 4 min. After this phase, participants were immediately given 60 s to verbally recall as many words as they could, aloud and in any order.

Following the study and test phases, participants completed the series of neuropsychological assessments to evaluate cognitive planning (targeting frontal lobe function), the ability to process semantics/meaning during action execution (test of apraxia, targeting parietal lobe function), as well as the MHVS and MoCA (to assess general cognitive and language abilities).

3. Results

3.1. *Main analysis of encoding strategy in each group for number of words recalled*

We conducted a 2 × 3 repeated-measures ANOVA with Encoding Strategy (Enact or Read) as a within-subject factor, and Group (frontal lesion, parietal lesion, healthy controls) as a between-subject factor.[7] The dependent variable was the number of words correctly recalled following each Encoding Strategy. As predicted, we found a main effect of Encoding Strategy, $F(1, 34) = 8.77$, $MSE = 3.95$, $p = .006$, $BF_{10} = 69.12$,[8] $\eta^2p = .205$ (see Table 4), such that enacted words were overall recalled more than read words.[9] There was also a significant main effect of Group, $F(2, 34) = 6.94$, $MSE = 5.16$, $p = .003$, $BF_{10} = 7.82$, $\eta^2p = .29$, suggesting that overall recall differed amongst stroke groups and controls (see Fig. 1). The two-way interaction was non-significant, $F(2, 34) = 0.21$, $MSE = 3.95$, $p = .814$, $\eta^2p = .012$.

Following our pre-registered analysis plan, we broke down the interaction. We computed Wilcoxon Signed Rank Tests to address our pre-registered *a priori* predictions related to mean differences in recall performance for Enacted and Read items within each Group[10]. A significant difference ($Z = 2.45, p = .015$) between enact and read scores in the Frontal group was revealed (see Fig. 2), such that 10 out of the 11 (91%) participants yielded greater recall for enact relative to read items. We found the same result for the healthy controls ($Z = 2.48$, $p = .013$), such that 15 out of the 20 (75%) participants showed higher recall for enacted words compared to read words. In the Parietal group, however, we did not find a significant difference in recall performance for enact and read items ($Z = 0.54, p = .684$), as only 3 of the 6 (50%) participants produced a higher recall for enacted words relative to read.

3.2. *Assessing the relationship between recall of enacted items and cognitive assessments*

To examine whether there are relations between the neuropsychological test measures of cognitive planning (as indexed by the Category Fluency, Tower of London, and Digit Span tasks) or apraxia (as indexed by the AST) with recall performance of Enacted items, we conducted a series of Pearson correlations collapsed across Groups to increase power. We observed significant positive correlations between recall of words enacted at encoding and performance on the Category Fluency test, *r*

Table 4
Number of Enact and read words recalled in each Group.

Encoding Strategy	Parietal	Frontal	Control
	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
Enactment	4.33 (1.2)	3.36 (1.5)	5.6 (2.09)
Read	3.33 (1.5)	1.55 (0.22)	3.80 (1.70)

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[7] To ensure that uneven sample sizes or violations of homogeneity of variance were not influencing the main effect of Group, we replicated the analysis using a Welch-corrected One-Way ANOVA, demonstrating this main effect remained significant: $F(2, 25.99) = 9.98$, $p < .001$.

[8] Bayes factors were calculated using the Bayes-Factor package in *JASP*, enlisting a default Jeffreys–Zellner–Siow (JZS) prior with a Cauchy distribution (center = 0, $r = 0.707$). This package compares the fit of various linear models. Bayes factor interpretations follow the conventions of Lee and Wagenmakers (2014). Bayes factors in favour of the alternative (BF_{10}) or null (BF_{01}) models are presented in accordance with each preceding report of null hypothesis significance testing analyses (i.e., based on a $p < .05$ criterion). A $BF_{10} > 1$ is interpreted as evidence in favour of the alternative hypothesis, while $BF_{01} > 1$ is interpreted as evidence in favour of the null.

[9] We chose to report Bayes Factors alongside traditional *p*-values for two main reasons. First, we wanted to provide the reader with both results so that they could better interpret the evidence being reported. Second, reporting Bayes Factors allows for the evaluation of evidence that is consistent with the null hypothesis, lending to more meaningful interpretation of null results.

[10] The Wilcoxon Signed Rank Test is useful to detect significant median differences in a dependent sample when sample sizes are small (Laureysens et al., 2004).

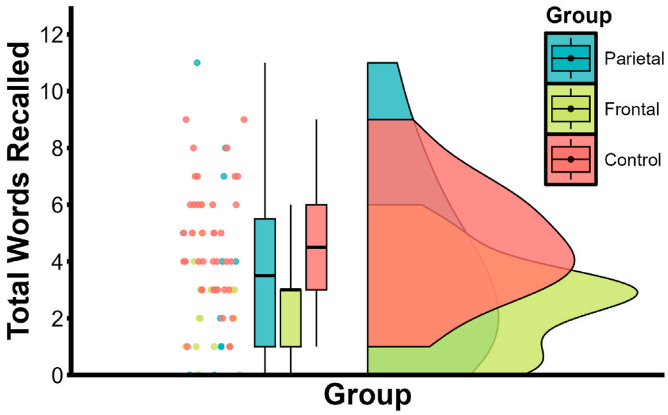

Fig. 1. Total words recalled by each Group.

(35) = 0.52, $p = .001$. All other correlations were nonsignificant ($rs \leq |0.22|$, $ps \geq 0.194$).

4. Discussion

The enactment effect refers to the phenomenon where performing an action related to a target word or phrase during encoding enhances memory for that word compared to simply reading it. This benefit has been demonstrated with various types of to-be-remembered information such as action verbs, phrases, and actions performed with both imaginary and real objects (Cohen, 1983, 1989). It has been observed across different age groups, including children, younger adults, and older adults (Backman et al., 1986; Nyberg et al., 2002), and in various test formats, including free recall, cued recall, and recognition (Engelkamp, 1997; Kormi-Nouri et al., 1994). The memory benefit of enactment has also been reported in neurological patient groups, such as individuals with Alzheimer's disease (Dick et al., 1989), Korsakoff syndrome (Mimura et al., 2005), severe anterograde amnesia (Hainselin et al., 2014), and autism spectrum disorder (Durban, 2014; Yamamoto and Masumoto, 2018). Despite the robustness of this mnemonic technique across various populations, the precise neural mechanisms underlying how enactment aids recall remain unclear. The primary aim of our current research was to investigate the brain areas responsible for the memory benefit conferred by enactment and to explore the cognitive and neural mechanisms driving the effect. In our study, both individuals with frontal stroke lesions and healthy controls showed greater recall of words enacted during encoding compared to those silently read, while participants in our parietal lesion group did not.

It has been hypothesized that the enactment benefit derives from the creation of a motoric-based representation of the target (Ianì et al., 2018; Masumoto et al., 2006, 2015), in addition to the verbal representation created when reading the target word. Specifically, Knopf and colleagues (2005) suggest that it is precisely the planning of the motoric action executed during enactment of words that is responsible for the memory performance. Further, Ratner and Foley (1994, 2020) pinpoint that actions performed during enactment are goal-directed related actions that one must plan in response to verbal commands. In contrast, Masumoto and colleagues (2015) proposed that the memory benefit following subject-performed actions (i.e., enactment) is not simply due to action planning mediated by the pre-motor areas of the frontal lobe. Instead, they suggest it results from integration of conceptual knowledge of the verbal command and functional knowledge of actions, mediated by the posterior parietal lobe (Masumoto et al., 2006, 2015; Russ et al., 2003).

The advantage of the current study is that we directly assessed the relative benefit gained from enactment at encoding compared to silent reading in focal stroke participants with frontal and parietal damage, in a single study. Previous work by Macedonia and colleagues (2011) and Knopf and colleagues (2005) have independently examined the neural mechanism of the enactment effect in participants with frontal and parietal lesions, but not concurrently within the same study design. Similarly, in the work by Knopf and colleagues (2005), baseline working memory performance of the FLS (Frontal Lobe Syndrome) group was not assessed. Thus, it is unclear whether potential deficits in working memory in FLS participants led to their poorer performance in the enactment condition (i.e., a failure to hold verbal commands in mind to be able to communicate an action plan to the experimenter, or to perform an action) as opposed to the predicted action planning processes. In the current study, both of our patient samples (Parietal and Frontal Groups) showed equivalent performance on measures of working memory, as indexed by scores on the Digit Span test (see Table 3), therefore allowing us to control for this critical factor when examining planning processes mediated in the enactment effect. We found the typical enactment benefit relative to silent reading in healthy controls and in those with lesions to the frontal lobe, but not in participants with stroke lesions to the parietal lobe. Specifically, our findings reveal the constraints of the enactment benefit to memory when integration of multimodal information is impaired. Of note, the superior temporal sulcus (STS) is a region involved in integrating processes related to movement, such as the movement of people or objects, as well as combining auditory and visual cues for speech and language processing (Beauchamp, 2005). While crucial for multisensory integration, the STS would remain unaffected by damage in our current participants, as it is located in the temporal lobe, while our participants have damage limited to the frontal and parietal lobes. Given that the Parietal group did not show an enactment benefit, it suggests that the integration occurring in the STS is likely not sufficient to drive this effect. Overall, our study suggest that the posterior parietal lobe plays a central role in linking verbal and motoric representations that are semantically related

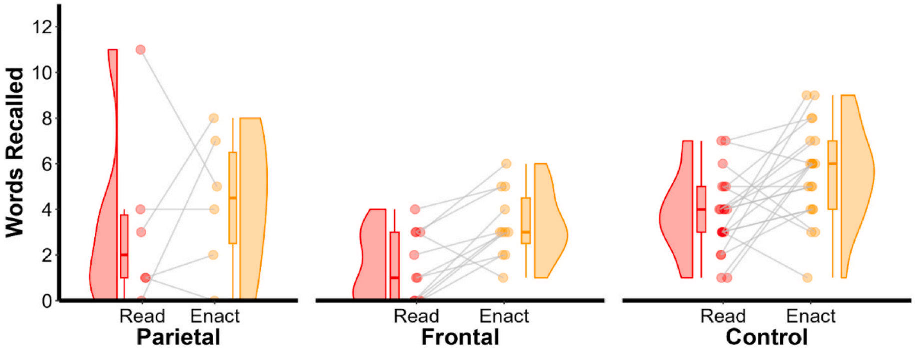

Fig. 2. Depiction of the distribution of recall data following enactment and silent reading of target words in each Group.
Note. Individual data points are presented for each participant, along with gray lines connecting their data between conditions, as well as smoothed distributions and box-plots for each condition.

(Masumoto et al., 2006; Nyberg et al., 2001; Russ et al., 2003). Damage to this region may limit multimodal integration of enacted words, and the subsequent memory benefit that this process is thought to confer (Pulvermüller, 2005). These findings inform models of the neural basis of the enactment benefit to memory.

In our previous work (Sivashankar and Fernandes, 2022; Sivashankar et al., 2023) and in others' (Zimmer and Engelkamp, 2003), findings show that meaningless actions/gestures fail to produce an enactment effect. More broadly, the beneficial role of semantic relatedness to encoding strategies has been found in other types of memory techniques, such as in drawing and production (MacLeod et al., 2010; Meade et al., 2019). Specifically in the study by Meade and colleagues (2019), participants were asked to either draw a picture related to the target word or engage in free form doodling at encoding. At retrieval, they found greater memory performance for words drawn relative to words encoded using free form doodling (the latter of which is conceptually unrelated to target items). Moreover, research examining the underlying mechanisms of the drawing effect suggest that it is precisely the multimodal encoding context created by drawing (requires elaborative, pictorial, and motoric components) that makes this encoding strategy potent (Wammes et al., 2019). Based on these findings in similar mnemonic techniques, we infer that the semantic relatedness of the encoding strategy to the target item is a critical requirement for multimodal encoding to benefit memory, binding conceptual knowledge through actions.

While our findings pinpoint the parietal lobe to be a central region of interest to the enactment effect, planning is presumably still required for one to execute meaningful actions (Knopf et al., 2005). This is also supported by neural findings, where many researchers have found activation of the pre-motor areas of the frontal lobe during both enactment of actions and retrieval of enacted targets (Masumoto et al., 2006; Nyberg et al., 2001). For example, research by Macedonia and colleagues (2011) aimed to map out brain areas recruited during recognition of words learned with iconic gestures (similar to enactment). In addition to the core language network (Friederici, 2011), these researchers found activation in brains areas such as premotor, motor, and sensorimotor areas during recognition of target words. The language network is a set of interconnected brain regions primarily involved in processing and producing language. This network typically includes areas such as Broca's area (in the left inferior frontal gyrus), Wernicke's area (in the posterior part of the superior temporal gyrus), and other regions involved in auditory, semantic, and syntactic processing (Friederici, 2011). Notably, their fMRI analyses also revealed activity in large portions of the left premotor cortex (BA 6), which is uniquely engaged in movement preparation and simulation. However, we speculate that it is not necessarily the planning of action that yields the enactment effect, but rather the *integration* of action and conceptual representations for a given item that drives this benefit. That is, we endorse the view that planning of actions is a critical preparatory step for enactment to occur, but the integration of information processed in distinct sensory modalities is what might be beneficial for the subsequent memory performance.

4.1. Limitations and implications of the current study

One of the limitations of the current study is that we did not have direct access to MR (Magnetic Resonance) or CT scans to confirm the locus of the stroke ourselves. However, we consulted medical notes and imaging results provided by physicians to confirm lesion localization for participants from the Neurological Patient Database and gathered medical information via a detailed medical questionnaire to approximate lesion location in those patients recruited from other organizations. We also recognize that a larger sample size in each of the stroke groups could have provided greater power for the statistical analyses. Our sample sizes are, however, comparable to previous studies examining the enactment effect in individuals with stroke lesions and other clinical groups with neurological impairments (Butters et al., 1994; Willms et al., 2021). Finally, the online nature of our experiment due to COVID-19 restricted use of various in-person neuropsychological assessments. Future, in-person testing could assess cognitive planning using the Rey–Osterrieth complex figure (Lezak, 2005) or the Block design (Kohs, 1920) to measure cognitive planning more precisely in our sample. Nonetheless, the neuropsychological assessments used in the current study are validated measures of cognitive planning (Acevedo et al., 2000; Unterrainer and Owen, 2006; Wechsler, 1945).

Another factor to consider in future research on the mechanisms underlying the enactment effect is whether a verbal command in a sentence or a single action verb is used as the target item to be enacted. This distinction is important, as it could influence the complexity of the action performed during encoding, and the pre-task planning that occurs before it. In the current study, although the action words studied by participants were simpler than a string of commands in a sentence, they were still entirely self-generated. Only one word was provided, requiring participants to think about the word, imagine how a related action might be performed, and then carry out the action themselves. This still involved some level of 'planning,' as participants were not given specific instructions on how to move for each word. Moreover, research suggests that the enactment effect is not dependent on the complexity of the action itself, but on the participant's ability to understand and integrate meaningful information to motor functions (Engelkamp and Zimmer, 1989; Liu and Wang, 2018). That is, it is not just the complexity of the movement that matters, but rather the individuals' ability to understand the verbal command, and then to initiate and execute the correct action.

Nonetheless, it is reasonable to consider that the complexity of an action phrase presented at encoding could lead to differences in action planning, and therefore may be an important variable to consider for individuals with frontal lobe lesions. For instance, while participants with frontal stroke lesions in the current study were indeed able to benefit from enactment, it is possible that encoding of more complex action phrases would have illuminated action planning deficits that could in turn attenuate later memory performance. Future research should incorporate both single action verbs and commands to determine whether the memory benefit conferred by enactment in frontal stroke patients differs depending on the intensity of action planning required at encoding.

Finally, our current findings highlight the robustness of the enactment effect, especially its effectiveness across different age groups and patient populations. This suggests that active participation in subject-performed tasks—such as physically performing or "enacting" actions related to information—can consistently improve memory. This can be particularly useful for individuals with memory impairments following a stroke. For example, individuals with stroke lesions often experience challenges in memory and cognitive functions, particularly in tasks that require recall of verbal or abstract information (Carlsson et al., 2009). The enactment effect shows that physically performing an action related to the information being learned (e.g., demonstrating the use of an object, mimicking an action described in a story, or engaging in role-playing) can enhance memory (Liu and Wang, 2018). To this end, an individual with stroke lesions might benefit from physically engaging in activities related to daily routines (e.g., making a cup of tea, dressing, taking medication, or cooking a simple meal) as part of their rehabilitation, which can strengthen their memory for these tasks or the surrounding contexts.

Further, rehabilitation programs for stroke survivors could integrate the enactment effect by designing exercises that require patients to actively participate in the learning process. For example, rather than simply reading instructions or viewing a demonstration, individuals with stroke could be asked to perform the tasks themselves, thereby linking physical actions with verbal information (e.g., enacting a morning routine like brushing teeth). In summary, the enactment effect provides a practical tool for memory rehabilitation by incorporating physical activity with verbal information, enhancing memory through multisensory and motor involvement. This approach, when applied in the context of stroke rehabilitation, could improve memory retention and help individuals recover memory skills necessary for daily life.

4.2. Conclusions

The goal of the current research was to compare recall performance in participants who have sustained lesions to frontal or parietal areas of the brain in order to study the relative contribution of cognitive planning and multimodal integration, respectively, to the enactment benefit. Individuals with frontal stroke lesions and controls both showed greater recall of words enacted at encoding, relative to words that were read silently. In contrast, participants with parietal lesions did not gain such a memory benefit. Results suggest that enactment benefits memory only when integration capabilities, mediated by the parietal lobe, are intact. Such findings benefit the field by illuminating the various brain areas involved in the enactment benefit and the relative contribution of each region in facilitating memory formation and retrieval.

CRediT authorship contribution statement

Yadurshana Sivashankar: Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Brady R. Roberts:** Writing – review & editing, Visualization, Software, Project administration, Methodology, Investigation, Data curation. **Myra A. Fernandes:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition.

Data statement and pre-registration of predictions

The data necessary to reproduce the analyses presented here and pre-registered report of predictions are publicly accessible on the OSF website through this link: https://osf.io/p34rz/

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Declaration of competing interests

None.

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.

Glossary

Enactment Performing an action related to a target word or phrase (also known as a Subject-Performed Task, or SPT) during encoding enhances memory for that word or phrase, relative to simply reading or listening to it

Encoding refers to the acquisition of information from our senses into our memory system within the brain, through automatic or effortful processing

Multimodal integration Integration of information encoded in multiple sensory modalities (e.g., motor, visual, verbal)

Appendix A

Table 1
Characteristics of Participants in the Frontal Group

Participant Number	Date of Stroke	Age	Sex	Education	Occupation
PID6	July/2017	70	Female	Trade School	Retired
PID8	August/2019	69	Female	Professional Degree	Retired
PID10	August/2018	33	Female	Trade School	Bookkeeper
PID11	October/2019	53	Female	Bachelor's Degree	Retired
PID12	February/2020	64	Female	College Diploma	Disabled
PID13	November/2020	56	Female	Master's Degree	Retired
PID15	June/2018	82	Male	Trade School	Retired
PID16	November/2014	70	Male	Master's Degree	Retired
PID17	October/2022	53	Female	Associate Degree	Retired
PID3	November/2009	64	Female	High School Diploma	Lead Cook
PID5	October/2020	52	Female	Professional Degree	Unemployed

Table 2
Characteristics of Participants in the Parietal Group

Participant Number	Date of Stroke	Age	Sex	Education	Occupation
PID1	June/2016	83	Female	Professional Degree	Retired
PID2	December/2018	61	Male	Bachelor's Degree	Sales
PID4	August/2011	63	Female	Bachelor's Degree	Retired
PID7	July/2011	62	Male	Bachelor's Degree	Retired
PID9	November/2017	63	Male	Doctorate Degree	Retired
PID14	November/2021	57	Female	Master's Degree	Unemployed

Appendix B

List of target words used in the current study.

List A		List B	
ENACT	drive	READ	drive
ENACT	throw	READ	throw
ENACT	type	READ	type
ENACT	chop	READ	chop
ENACT	whisk	READ	whisk
ENACT	applaud	READ	applaud
ENACT	comb	READ	comb
ENACT	knock	READ	knock
ENACT	punch	READ	punch
ENACT	knit	READ	knit
ENACT	stir	READ	stir
ENACT	greet	READ	greet
ENACT	pour	READ	pour
ENACT	crawl	READ	crawl
ENACT	eat	READ	eat
ENACT	salute	READ	salute
ENACT	bend	READ	bend
ENACT	swim	READ	swim
ENACT	flick	READ	flick
ENACT	juggle	READ	juggle
READ	tap	ENACT	tap
READ	wave	ENACT	wave
READ	flex	ENACT	flex
READ	catch	ENACT	catch
READ	tear	ENACT	tear
READ	paint	ENACT	paint
READ	drink	ENACT	drink
READ	cut	ENACT	cut
READ	hug	ENACT	hug
READ	hammer	ENACT	hammer
READ	dig	ENACT	dig
READ	stop	ENACT	stop
READ	dive	ENACT	dive
READ	climb	ENACT	climb
READ	count	ENACT	count
READ	sweep	ENACT	sweep
READ	row	ENACT	row
READ	wipe	ENACT	wipe
READ	snap	ENACT	snap
READ	honk	ENACT	honk

Data availability

https://osf.io/p34rz/

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