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When does a strategy intervention overcome a failure of inhibition?

Evidence from two left frontal brain tumour cases

Gail A. Robinson¹*, David G. Walker², Vivien Biggs² and Tim Shallice³⁴

¹Neuropsychology Research Unit, School of Psychology, University of Queensland, St Lucia, Brisbane, Australia.

²BrizBrain & Spine, Wesley Hospital, Brisbane, Australia.

³Institute of Cognitive Neuroscience, University College, London, UK.

⁴International School for Advanced Studies (SISSA), Trieste, Italy.

*Correspondence to: Gail Robinson

School of Psychology,

The University of Queensland,

Brisbane QLD 4072

Australia

E-mail: g.robinson@psy.uq.edu.au

Word Count: 3000

Running page heading: Strategy use and inhibitory failures
Strategy use and inhibitory failures

Highlights

- Two patients exhibit profound suppression failures on the Hayling Test.
- Explicit strategy trial intervention aimed to facilitate suppression.
- One patient (PM) failed to generate and one patient (KI) failed to use a strategy.
- Suppression failures are due to motivational (PM) and inhibitory (KI) deficits.
Abstract

Introduction: Initiation and inhibition of responses is crucial for appropriate behaviour across different settings. Initiation and inhibition difficulties are well documented following frontal damage, although task differences have limited our understanding. The Hayling Sentence Completion Test was designed to assess verbal initiation and inhibition within the same task. This study investigates the ability of two patients with left frontal tumours (KI: high grade glioma; PM: meningioma) to use a strategy to overcome profound suppression failures on the Hayling Test.

Method: KI and PM completed the Hayling Test and two experimental tasks. The Selection Investigation assessed verbal initiation on a sentence completion task that varied selection demands (high/low). The Suppression and Strategy Investigation assessed ability to implement four strategies aimed to override a suppression failure and facilitate production of an unconnected word.

Results: On the Hayling Test, KI and PM initiated responses to complete high constraint sentences, in contrast to impaired suppression. KI benefitted minimally from strategies to overcome suppression failure although one strategy (object naming) was partially successful. KI’s errors revealed fast suppression errors, in contrast to slow no responses, and selection ability was also impaired for verbal initiation. PM, however, implemented each strategy 100% to overcome a suppression failure and had no difficulty completing sentences meaningfully, regardless of selection demands.

Conclusion: This first investigation of strategy implementation to overcome profound suppression impairments provides insights into verbal initiation, inhibition, selection and strategy mechanisms, which has implications for neurorehabilitation. Specifically, both patients had profound inhibition deficits but KI also presented with a selection deficit and was unable to implement a strategy. By contrast, PM’s selection ability was intact but she was unable to generate, rather than implement, a strategy. We suggest that KI has both fast, uncontrolled semantic output and response inhibition difficulty, whereas PM’s difficulty is underpinned by motivational factors.

Key Words: suppression, inhibition, initiation, strategy, Hayling Test, lesion, frontal cortex.
1. INTRODUCTION

Initiation and inhibition are crucial processes for adaptive, appropriate behaviour across contexts and disruption can affect long-term outcomes for individuals with frontal lobe damage (Cicerone, Levin, Malec, Stuss & Whyte, 2006; Stuss & Benson, 1984). Initiation deficits following frontal lesions are reported for single item generation (e.g., word fluency - Milner, 1964; word, ideational, design and gesture fluency – Robinson et al., 2012) and spontaneous speech production (e.g., dynamic aphasia – Robinson et al., 1998; 2005).

Similarly, inhibitory deficits in frontal patients occur on the Stroop Test (e.g., Perret, 1974; Stuss et al., 2011), stop signal task (e.g., Aron et al., 2011; 2014) and as suppression failures on the Hayling Sentence Completion Test (Burgess & Shallice, 1996; Robinson et al., 2015).

The Hayling Test is unique in that it assesses verbal initiation and inhibition in the same task (Burgess & Shallice, 1996). The Hayling involves completion of an orally presented sentence with the last word omitted (e.g., The captain stayed with the sinking ...) under two conditions; meaningfully in the ‘Initiation’ Section 1 (..ship) or instead with a semantically unrelated word in the ‘Suppression’ Section 2, (..banana). For the suppression section, patients with frontal lobe damage produce more suppression errors, compared to posterior patients and healthy controls (Burgess & Shallice, 1996), with a critical role for the right inferior lateral area (Volle et al., 2012). Specifically, when we recently analysed frontal patients’ suppression errors, all frontal patient groups (left/right lateral, superior medial) produced many more blatant suppression failures (e.g., ..ship) than controls, but there was only a right lateral frontal effect for producing semantically related ‘subtle’ errors (e.g., car in the example above; Robinson et al., 2015). Additionally, frontal patients are also impaired on the Hayling initiation section, compared to healthy controls. Verbal initiation in patients with left frontal damage is affected by selection demands on sentence generation/completion tasks (e.g., Robinson et al., 1998; 2005; 2010). Moreover, initiation of an unconnected word is necessary for a successful Hayling suppression performance.

Strategy generation/use has received little focus in lesion studies despite being crucial for successful and appropriate behaviour. Broadly, a strategy is a method or plan to achieve a desired future goal or to solve a problem efficiently and effectively. Successful strategy application requires plan formulation/modification, marker creation/triggering and goal evaluation/articulation (Burgess & Shallice, 1991). Poor use of strategies has been reported in frontal patients on numerous tasks including spatial working memory (Owen et
al., 1990), semantic word fluency (Reverberi et al., 2006), problem solving (e.g., Match Problems; Miller & Tippett, 1996) and planning (e.g., Tower of London; see Robertson 2001). In the original Hayling study, Burgess and Shallice (1996) attributed their frontal patients’ high rate of errors in part to a strategy-attainment failure. In our recent study, the right frontal patient difficulties were partially attributed to problems generating or implementing an appropriate strategy (Robinson et al., 2015). Thus, the response time difference (i.e., suppression-initiation) for right lateral patients was substantially greater than for healthy control (i.e., >400%) and nearly double that for non-right lateral patients. In addition, 4 out of 15 left frontal patients were >2SDs worse than healthy controls. This pattern is more consistent with a failure to generate and/or implement a strategy rather than faulty monitoring, use of a semantic strategy or inhibition per se, all giving rise to faster responding, if anything.

To date there are no detailed investigations of suppression failures or strategy generation/implementation on the Hayling Test. We report two patients with large left frontal tumours with profound suppression impairments on the Hayling Test. We investigate three aspects: 1. Verbal initiation under high and low selection conditions (Selection Investigation); 2. Verbal suppression; and 3. Strategy implementation, given four strategies aimed to facilitate suppression and retrieval of an unconnected word (Suppression and Strategy Investigation).

2. CASE SUMMARIES

KI is a 57 year-old, right-handed, technician with 16 years education. He presented with a few months history of fatigue and a 2-week progression of right arm/leg weakness. In the context of sudden expressive dysphasia, MRI brain scan revealed a large left frontal lobe high grade anaplastic oligodendroglioma (WHO Grade IV) tumour extending to the mesial region and left corpus callosum, involving the genu (for further detail see Fig. 1). Post-tumour resection, right-sided weakness improved but expressive language difficulties remained.

PM is a 61 year-old, right-handed, clerk/housewife with 12 years education. Following a 2-year history of increasing memory problems and apathy, then falls, MRI revealed a large left frontal meningioma, compressing the left frontal horn, with inferior
frontal gyrus preserved (see Fig. 1). PM and her husband reported no residual difficulties at two weeks and two years post-tumour resection.

KI and PM were recruited by the Brain Tumour Nurse (VB). The UnitingCare Human Research Ethics Committee approved the study and both patients provided written consent.

Insert Figure 1 about here

2.1 Cognitive Baseline Tests

KI completed the cognitive baseline and experimental investigations two weeks post-surgery. PM completed the cognitive baseline at two weeks and two years post-surgery. PM’s performance on baseline cognitive tests including the Hayling was almost identical at both time points; PM also completed the experimental investigations two years post-surgery. On cognitive tests, both patients obtained average scores on a non-verbal general intelligence test, consistent with premorbid estimates (for Cognitive Baseline see Table 1).

PM performed well on memory tests while KI performed poorly (impaired verbal, weak visual memory). Visual perception and attention were intact for both patients; however, KI’s visuomotor processing speed was slowed.

Language functions were intact for PM (spontaneous speech, repetition, naming, comprehension). By contrast, KI’s language abilities were poor apart from good sentence repetition. Thus, semantic errors were noted in repetition (chair – seat; brown – black) and picture naming (e.g. chopsticks – sushi), and word synonym test performance was impaired. KI’s spontaneous speech was hesitant, with semantic errors, but there were no phonological or syntax errors.

KI and PM both passed simple tests of executive function (Weigl, 1941; Luria, 1973). By contrast, KI was unable to switch on Trails B, PM performed poorly on the Stroop Test and both patients’ word fluency (‘S’) was severely reduced. The Hayling Test Overall scaled scores were ‘Abnormal’ (KI) and ‘Impaired’ (PM), which was the basis and motivation for the experimental investigations. The Hayling Sub-scale Scores, number of sentences completed and total response time (sum of all 15 sentences) are reported below in Experimental Investigation 3.1 (Initiation RTs) and 3.2 (Suppression RTs/Errors) (see Table 2). The Selection Investigation (3.1) addressed verbal initiation ability under high/low selection
conditions and the Suppression and Strategy Investigation (3.2) addressed inhibition of a prepotent word and ability to generate/use a strategy to produce an unconnected word.

*Insert Tables 1 and 2 about here*

3 Experimental Investigations

3.1 Verbal Initiation and Selection Investigation: Sentence Completion Task

In addition to the Hayling Test Initiation Section 1, KI and PM were given a similar sentence completion task that requires production of a meaningful word. However, sentence frames were either high or low in constraint, such that either a dominant or many competing responses are activated. By varying constraint levels, task selection demands, which can affect verbal initiation, are manipulated. For example, dynamic aphasia patient CH’s performance deteriorated as sentences became low in constraint, thus increasing selection demands (e.g., There was nothing wrong with the... table, beef, colour, shoe, etc; Robinson et al., 2005). By contrast, CH was unimpaired for high constraint sentences that activate a ‘prepotent’ word, which minimises selection (e.g., Water and sunshine help plants... grow). This differential performance was interpreted as due to an inability to select between competing words.

3.1.1 Method

Patients were orally presented with high (n = 15) and low (n = 15) constraint sentence frames (stimuli from Robinson et al., 2005) and asked to generate a word to complete each sentence meaningfully. Number correct and response time (RT: i.e., after stimulus presentation to beginning of word production) were recorded.

3.1.2 Results

On the standard Hayling Initiation Section 1, both patients promptly generated single words to complete all sentences meaningfully although RTs were mildly slowed (Table 2).

For the experimental sentence completion task, KI completed 100% of high but only 40% of low constraint sentences ($\chi^2(1) = 12.86, P<.05$; see Table 3). His errors involved no response (33%) or >1 word (27%) and his mean RTs for correct high/low constraint sentences were virtually identical. By contrast, PM had no difficulty generating a word to complete all sentences although her RTs appeared slightly longer for low than high constraint sentences, but this did not differ from controls (modified $t_{(34)} = 1.039$, n.s.).
3.1.3 Summary

Constraint level affected both patients although performance differed qualitatively. KI was severely impaired but only for low constraint sentences that require selection. By contrast, PM was able to complete 100% of high/low constraint sentences; however, for low constraint sentences, RT’s were somewhat prolonged presumably due to ‘thinking’ time, which suggests a more effortful process.

*Insert Table 3 about here*

3.2 Verbal Suppression and Strategy Investigation: Strategy Trials

3.2.1 Method

After profound suppression deficits were evident on the Hayling Test, the patients were given four strategies to facilitate suppression of a prepotent, and production of an unconnected, word. Each strategy was explicitly discussed and practiced, without time limits. The only criterion was that patients understood the task, which generally required ≤2 practices. In addition, patients were instructed to generate the unconnected word, using the relevant strategy, prior to sentence presentation. A novel set of high constraint sentence frames were selected from the set devised for patient CH (Robinson et al., 2005). Each sentence was presented after patients indicated they had an unconnected word, by a nod (Strategy 1 – Covert object naming) or by saying the word aloud (Strategy 2-4). Four Strategies were presented in the following order:

**Strategy 1 and 2: Object Naming (1 – Covert; 2 – Aloud):** ‘Stop, look around the room and think of (1)/ say aloud (2) the name of a visible object. Use the object name as your unconnected word when I present a sentence. Nod (1)/ Name the object (2) when you are ready’.

**Strategy 3 and 4: Reading Aloud (3- Arabic Numeral; 4 – Single Word):** ‘Read aloud an Arabic numeral (3)/ a word from this page (4) [Arabic Numerals 1-9, random order; Single words, Recognition Memory Test Answer card]. After I present the sentence repeat the number/word as your unconnected word.’
3.2.2 Results

On the Hayling Test Section 2, both patients were unable to generate unconnected words. All errors were blatant suppression failures and not semantically connected ‘subtle’ errors (Table 2). Suppression RTs were fast for KI, resulting in an ‘average’ RT score, suggesting the wrong connected word was produced quickly. By contrast, PM was slow to produce words, resulting in an ‘impaired’ RT score, consistent with ‘thinking time’ prior to production of the wrong connected word.

*Insert Table 4 about here*

For the Strategy Trials, PM benefitted 100% in contrast to KI who minimally benefitted (see Table 4). KI failed to implement Strategy 1 (Covert Object Naming), Strategy 3 (Arabic Numeral Reading Aloud) and Strategy 4 (Single Word Reading Aloud) was largely unsuccessful. By contrast, Strategy 2 (Overt Object Naming) was partially successful; KI suppressed a prepotent word and instead named a visible object for 50% of sentences. Notably, controls use the covert version of this strategy (Burgess & Shallice, 1996). Interestingly, following all but 1 suppression error for Strategy 2, KI produced a second correct word comprising a visible object, reflecting ‘secondary’ strategy implementation, post-suppression failure.

KI’s errors across all four strategies were predominantly blatant suppression failures (42.5%) or responding ‘No’ (40%). KI’s mean response time for suppression errors was fast (3.6 seconds) in contrast to slow ‘No’ responses, 3 times longer (10.8 seconds). The latter possibly reflects partial suppression.

3.2.3 Summary

On the Hayling Test, KI and PM were unable to suppress a connected word and produce an unrelated word. However, given a strategy to facilitate suppression, PM implemented each strategy (100%) to correctly generate an unconnected word. By contrast, KI failed to implement three strategies and only partially benefitted from the object naming strategy, which suggests that activation of semantics and phonological output was necessary. Analysis of KI’s errors suggests ‘partial suppression’ for about 50% of total errors, as evidenced by a slow ‘No’ response. By contrast, blatant suppression errors were fast and
for the object naming aloud strategy, KI produced a secondary ‘correct’ strategic-based response.

4 DISCUSSION

Our two patients (KI and PM) were profoundly impaired in the suppression of strongly connected words on the Hayling Test. For KI, the failure to suppress a prepotent word was so striking that, even when given four explicit strategies to aid this process, only one was partially successful. By contrast, PM implemented each strategy 100% and was thus able to suppress a connected word and generate an unconnected alternative. The similarities and differences between KI and PM provide important clues to verbal response inhibition and what strategy has the potential to successfully overcome suppression failures.

First, response inhibition on the Hayling occurs at output from the language system, implicating semantic processing, distinguishable from inhibition of automatic stimulus-response associations (e.g., Stroop Test - see Robinson, 2013). For KI, strategies that bypassed the semantic system, namely reading aloud words/numbers, were virtually completely unsuccessful, as was covert object naming. KI’s errors were primarily slow ‘No’ responses, which may indicate partial suppression. By contrast, KI could implement the overt object naming strategy 50% of the time. Unlike covert naming that may only activate semantics, overt naming also involves phonological output, and thus leaves a stronger trace in phonological buffers. Additionally, KI presented with language difficulties, including semantic errors in output (repetition, naming), which may also arise due to suppression failures. Notably, despite some executive difficulties, KI performed simple non-verbal switching and inhibition tasks satisfactorily. Thus, semantic-phonological processes may be important for inhibition of strongly associated verbal output.

Second, the performance of KI and PM highlights subtleties in the relationship between activation and inhibition. Specifically, a trade-off between response time and suppression was apparent, which was altered when a strategy was used. Thus, PM was initially unable to suppress prepotent responses, despite prolonged response times reflecting an effortful process. Given an explicit strategy, bypassing strategy generation, PM’s suppression became effortless as she promptly produced an unconnected word. In contrast, provision of a strategy did not affect KI’s ability to suppress prepotent responses. Moreover, KI’s suppression errors were fast, in contrast to his slow ‘no’ responses, which suggests an automatic rather than effortful process. In addition, KI’s ‘secondary’ strategy
implementation for the overt naming Strategy 2 condition is consistent with a first fast automatic response followed by a second correct but effortful response. This pattern suggests KI has abnormally ‘fast, uncontrollable’ semantic output that is hard to ‘stop’ and thus frequently results in speedy suppression failures (for a related account in jargon aphasia see Robinson, Butterworth and Cipolotti, 2015).

A further source of difference between KI and PM is in their verbal initiation ability with increasing selection demands. In the Selection Investigation, PM completed 100% of high and low constraint sentences. However, KI was impaired for weakly constrained sentences, only completing 40%. The differential pattern for sentences observed in KI has previously been interpreted as a selection failure (e.g., Robinson et al. 1998; 2005; see also Badre et al. 2005; Thompson-Schill et al. 1998). A selection mechanism failure could contribute to a Hayling Suppression failure as this condition, in particular, must also recruit a selection mechanism in order to produce an unconnected word. A selection failure can therefore possibly explain KI’s failure for low constraint sentences and is the complement of his failure to suppress a strongly associated word in the Hayling Suppression condition.

What is the basis for our patients’ differential ability to implement a strategy to overcome a suppression failure? Our results show that KI has at least two difficulties: one, a suppression failure when a prepotent word is activated, and possibly complementarily, a selection failure for initiation when multiple competing words are available. Whether he also has a strategy implementation failure is unclear. Moreover, KIs fast suppression errors are consistent with both quick, uncontrolled semantic output and impaired response inhibition. By contrast, in the context of preserved selection for initiation, PM could implement strategies to overcome her suppression failures, which suggests a strategy generation failure. This is likely due to motivational factors and not general cognitive decline as her memory, intelligence and attention are preserved. Additionally, PM and her husband report a lack of initiation, suggestive of behavioural apathy or amotivation. The latter resembles reduced “energization”, associated with the superior medial prefrontal region (Stuss et al, 2007; Robinson et al. 2012) or frontostriatal connections (Robinson, Spooner and Harrison, 2015). Thus, PM may not be capable of generating an alternative strategy for novel tasks like the Hayling.

Our two patients had large left frontal brain tumours. They made blatant suppression errors, not subtle errors (i.e., semantically connected), where right frontal
Strategy use and inhibitory failures

lesions appear critical. Moreover, Ki’s malignant high grade glioma impinged on inferior frontal regions bilaterally, which may give rise to his suppression and selection (and possibly strategy implementation) difficulties. By contrast, in the context of a benign meningioma, PM’s selection ability and left inferior frontal region were preserved. We note that malignant and benign tumours are associated with different evolution, damage and/or plasticity, which may have also impact our results. Thus far lesion studies have implicated particularly the right lateral frontal and orbitofrontal regions in response suppression on the Hayling (Burgess and Shallice, 1996; Cipolotti et al. 2015; Robinson et al. 2015; Volle et al., 2012, but all frontal groups have difficulty. A variety of frontal processes are involved in the Hayling task, which will need to be investigated in future studies.

In summary, these cases shed light on the nature of initiation, inhibition, selection and strategy processes and show that the Hayling Test can be failed in at least two or possibly three ways. For individuals following brain damage, difficulty with response inhibition poses safety risks (e.g., falls) or impacts the quality of social relations if behaving inappropriately. Ability to override automatic responses is crucial in neurorehabilitation when learning compensatory behaviours.
5. REFERENCES


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6. ACKNOWLEDGEMENTS

This study was not possible without the willingness of KI and PM to participate. We also thank Prof Peter Nestor for providing the second analyses of the MRI images. GR is the recipient of an Australian Research Council DECRA fellowship (DE1211119) and this research was supported by a small grant from the NEWRO Foundation (Australia).
Table 1. Cognitive Baseline Scores for patients KI and PM.

<table>
<thead>
<tr>
<th>Time of Assessment Post-surgery</th>
<th>KI</th>
<th>PM</th>
<th>Score/Age Scaled Score (Percentile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOMAINS/TEST</td>
<td>KI</td>
<td>PM</td>
<td></td>
</tr>
<tr>
<td>INTELLECTUAL FUNCTIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ravens Advanced Progressive Matrices&lt;sup&gt;1&lt;/sup&gt;</td>
<td>7/12</td>
<td>7/12</td>
<td>6/12 (50-75&lt;sup&gt;th&lt;/sup&gt;%ile)</td>
</tr>
<tr>
<td>MEMORY FUNCTIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recognition Memory Test Words&lt;sup&gt;2&lt;/sup&gt;</td>
<td>31/50</td>
<td>47/50</td>
<td>44/50 (&lt;5&lt;sup&gt;th&lt;/sup&gt;%ile)</td>
</tr>
<tr>
<td>Recognition Memory Test Topography&lt;sup&gt;3&lt;/sup&gt;</td>
<td>19/30</td>
<td>27/30</td>
<td>25/30 (10-25&lt;sup&gt;th&lt;/sup&gt;%ile)</td>
</tr>
<tr>
<td>VISUAL PERCEPTION FUNCTIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOSP&lt;sup&gt;4&lt;/sup&gt; Incomplete letters</td>
<td>20/20 (Normal)</td>
<td>20/20 (Normal)</td>
<td>-</td>
</tr>
<tr>
<td>ATTENTION FUNCTIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEA&lt;sup&gt;5&lt;/sup&gt; Elevator Counting</td>
<td>7/7 (Normal)</td>
<td>7/7 (Normal)</td>
<td>7/7 (Normal)</td>
</tr>
<tr>
<td>LANGUAGE FUNCTIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repetition: High Frequency Words</td>
<td>8/10</td>
<td>10/10</td>
<td>-</td>
</tr>
<tr>
<td>Sentences</td>
<td>5/5</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Graded Naming Test&lt;sup&gt;6&lt;/sup&gt;</td>
<td>13/30</td>
<td>18/30</td>
<td>22/30 (5&lt;sup&gt;th&lt;/sup&gt;%ile)</td>
</tr>
<tr>
<td>Word Synonyms Test (Concrete Words)&lt;sup&gt;7&lt;/sup&gt;</td>
<td>13/25</td>
<td>22/25</td>
<td>-</td>
</tr>
<tr>
<td>National Adult Reading Test&lt;sup&gt;8&lt;/sup&gt;</td>
<td>10/50</td>
<td>27/50</td>
<td>28/50 (10-25&lt;sup&gt;th&lt;/sup&gt;%ile)</td>
</tr>
</tbody>
</table>
## EXECUTIVE FUNCTIONS

<table>
<thead>
<tr>
<th>Test</th>
<th>SS = 2 (Abnormal)</th>
<th>SS = 1 (Impaired)</th>
<th>SS = 1 (Impaired)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hayling Test Overall Scaled Score⁹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phonemic Word Fluency¹⁰ (S)</td>
<td>1 (&lt;1⁰ %ile)</td>
<td>3 (&lt;5⁰ %ile)</td>
<td>6 (&lt;5⁰ %ile)</td>
</tr>
<tr>
<td>Stroop Test¹¹</td>
<td></td>
<td>2-4⁰ %ile, 16 err</td>
<td>14-16⁰ %ile, 6 err</td>
</tr>
<tr>
<td>Weigl Sorting Test¹²</td>
<td>2/2 (Pass)</td>
<td>2/2 (Pass)</td>
<td>-</td>
</tr>
<tr>
<td>Luria’s Bimanual Hand Sequence</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>Luria’s Go-No Go Rhythm Tapping Task</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>Trail Making Test (seconds)¹³ A</td>
<td>92 (&lt;10⁰ %ile)</td>
<td>30 (50-75⁰ %ile)</td>
<td>31 (50-75⁰ %ile)</td>
</tr>
<tr>
<td>B</td>
<td>Fail (unable to do)</td>
<td>84 (25-50⁰ %ile)</td>
<td>57 (&gt;90⁰ %ile)</td>
</tr>
</tbody>
</table>


Table 2. Standard Hayling Test for Patients KI and PM.

<table>
<thead>
<tr>
<th></th>
<th>KI</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hayling Test Overall Scaled Score</strong></td>
<td>SS = 2 (Abnormal)</td>
<td>SS = 1 (Impaired)</td>
</tr>
<tr>
<td><strong>Section 1 Initiation RT Sub-scale Score</strong></td>
<td>SS = 3 (Poor)</td>
<td>SS = 5 (Mod. Average)</td>
</tr>
<tr>
<td>Total Number of Items answered (/15)</td>
<td>14/15</td>
<td>15/15</td>
</tr>
<tr>
<td>Total Response Time (seconds)</td>
<td>77.4^</td>
<td>21.8</td>
</tr>
</tbody>
</table>

| **Section 2 Suppression RT Sub-scale Score** | SS = 6 (Average) | SS = 1 (Impaired) |
| Total Number of Items completed (/15) | 15/15 | 10/15 |
| Total Response Time (seconds) | 21.0 | 527.5~ |

| **Suppression Errors Sub-scale Score** | SS = 1 (Impaired) | SS = 2 (Abnormal) |

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a SS = Scaled Score is 1-10, 6 is average. ^ = Total includes 60 seconds for one ‘no response’; ~ = Total includes 300 seconds for five ‘no response’ items.
### Table 3. Selection Investigation. Sentence Completion and Level of Constraint: Number Correct and Mean Response Time (Standard Deviation) for patients KI and PM.

<table>
<thead>
<tr>
<th>Selection Demands</th>
<th>KI</th>
<th>PM</th>
<th>Healthy Controls (N=35) a</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low (High Constraint)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number Correct (/15)</td>
<td>15</td>
<td>15</td>
<td>14.91 (0.3)</td>
</tr>
<tr>
<td>Mean RT (seconds)</td>
<td>1.40 (0.9)</td>
<td>0.86 (0.5)</td>
<td>0.71 (0.4)</td>
</tr>
<tr>
<td><strong>High (Low Constraint)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number Correct (/15)</td>
<td>6*</td>
<td>15</td>
<td>14.60 (0.9)</td>
</tr>
<tr>
<td>Mean RT (seconds)</td>
<td>1.41 (0.9)</td>
<td>3.69 (4.2)</td>
<td>2.32 (1.3)</td>
</tr>
</tbody>
</table>

RT = Response Time; * = P<0.05, compared to High constraint, using the Chi-square test of independence. a= Robinson, 2006.
### Table 4. Suppression and Strategy Investigation. Strategy trials: Percentage correct and Mean Response Time (standard deviation) for Patients KI and PM.

<table>
<thead>
<tr>
<th></th>
<th>KI</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Correct</td>
<td>RTs</td>
</tr>
<tr>
<td>1. Covert Object Naming</td>
<td>0</td>
<td>9.9±5.1</td>
</tr>
<tr>
<td>2. Object Naming (Aloud)</td>
<td>50~</td>
<td>3.6±4.9</td>
</tr>
<tr>
<td>3. Arabic Numeral Reading (Aloud)</td>
<td>0</td>
<td>6.5±4.7</td>
</tr>
<tr>
<td>4. Single Word Reading (Aloud)</td>
<td>10</td>
<td>6.9±5.3</td>
</tr>
</tbody>
</table>

~ All but 1 suppression error (Category A) was followed by a 2\textsuperscript{nd} word that indicated correct use of the strategy i.e., a visible object.
A. KI: MRI is showing a large left frontal anaplastic oligodendroglioma extending to the mesial region and left corpus callosum, with the genu involved. Perilesional oedema caused localised mass effect with sulcal effacement, distortion, left frontal horn compression and right deviation of the cingulate gyrus, thus, impinging on inferior frontal regions (left/right).

B. PM: MRI is showing a large left frontal meningioma compressing the left frontal horn, sparing the left inferior frontal region.

*Figure 1.* Axial MR Images for KI (A) and PM (B) with the left cortex displayed on the right.