

## Congenital blindness improves semantic and episodic memory

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## Abstract

Previous studies reported that congenitally blind people possess superior verb-generation skills. Here we tested the impact of blindness on capacity and the fidelity of semantic memory by using a false memory paradigm. In the Deese-Roediger-McDermott paradigm, participants study lists of words that are all semantically related to a lure that is not presented. Subsequently, participants frequently recall the missing lure. We found that congenitally blind participants have enhanced memory performance for recalling the presented words and reduced false memories for the lure. The dissociation of memory capacity and fidelity provides further evidence for enhanced verbal ability in the blind, supported by their broader structural and functional brain reorganisation.

**Keywords:** semantic memory; false memories; visual experience; brain plasticity; blindness.

**Abbreviations:** CB, congenitally blind; LB, late blind; S, sighted.

## 1. Introduction

Distortions and illusions within human memory are well documented in the scientific literature and forensic work [1-2], and appear to be a basic feature of memory functioning. A well-studied case is the emergence of false memories from the free recall of lists of words as discovered by Roediger and colleagues [3-4]. For example, hearing ‘cigarette’, ‘cigar’, and ‘tobacco’ is likely to produce a false memory of the word ‘smoke’ during free recall. Thus, the fact that human memory is prone to be distorted should be a relatively robust phenomenon, which would be unaffected by changes in the quality and magnitude of environmental stimulation during development as would occur for false memories from auditory input in the visually impaired.

Yet several studies suggested that blind individuals, especially those without visual experience (i.e. congenitally blind, or ‘CB’), possess superior verbal and memory skills [5-6]. Superior verbal skills seem to be supported by plastic recruitment of visual areas that otherwise would be unused [7-8], and which may be recruited to provide ‘extra neural capacity’. Because people without visual experience undergo a particularly intense neural reorganisation [9-10], it is conceivable that neural plasticity supports these ‘new abilities’. As a matter of fact, a recent study [11] suggested that visual areas may store semantic knowledge and, therefore, involved in semantic processing also in sighted individuals. Thus, new abilities in congenitally blind individuals may be supported by a basic brain feature that is normally masked by the visual input.

However there are two aspects of the mechanisms of memory in the visually impaired that are unknown. First, prior tests have only assessed the capacity of memory, but not the fidelity or accuracy of memory. Second, it is unclear whether the memory performance improvement derived from an enhanced storage of the information, or from enhanced

retrieval of such information. We thus examined the impact of visual experience on memory by employing a false memory paradigm that would allow the investigation, for the first time, of not only memory capacity, but also the fidelity of memory and the importance of retrieval for the superior performance in the blind. Here we investigated the impact of visual experience on semantic memory by using the Deese-Roediger-McDermott false memory paradigm [3]. We found that participants without visual experience possess superior memory capacity and fidelity. In other words, they reported more words from the original list, and were less affected by the formation of false memories than both late blind and sighted participants (i.e. those who experienced vision).

## 2. Method

### 2.1. Participants

Blind participants were recruited through the Royal National Institute for the Blind, Royal London Society for the Blind, and via word-of-mouth. Sighted participants were recruited at the Queen Mary University of London (QMUL). We tested: ten CB participants, three males and seven females with a mean age of 40.6 years (range 26-62), ten late blind (LB) participants, three males and seven females with a mean age of 44 years (range 23-58), and ten sighted (S) participants three males and seven females with a mean age of 41.6 years (range 23-58), see Table 1 for further details. This study was approved by the QMUL Ethics Committee. Accordingly, all participants gave informed consent prior to the experiment.

**Table 1:** The details of the participants. 'Educ.' indicates the level of education (University or Secondary). 'Y' means 'yes' and 'N' means 'no', while 'L/D' means 'light/darkness' sensitivity and, if relevant, in which eye (left of right). Aetiology abbreviations: 'RoP', retinopathy of prematurity; 'Cong', congenital; 'Retinobl', retinoblastoma; 'Gla', glaucoma; 'Cat', cataracts; 'RP', retinitis pigmentosa; 'Ret deg' retinal degeneration.

|      | Sex | Age | Hand | Educ. | Onset | Aetiology               | Braille reading | Visual imagery | Residual vision |
|------|-----|-----|------|-------|-------|-------------------------|-----------------|----------------|-----------------|
| CB1  | M   | 59  | Rx   | Uni.  | Birth | RoP                     | Y               | N              | N               |
| CB2  | M   | 58  | Rx   | Sec.  | Birth | Cong Retinobl           | Y               | N              | N               |
| CB3  | F   | 26  | Rx   | Sec.  | Birth | Cong retinal dysplasia  | Y               | N              | N               |
| CB4  | F   | 27  | Rx   | Sec.  | Birth | Undeveloped optic nerve | Y               | N              | L/D             |
| CB5  | F   | 27  | Rx   | Sec.  | Birth | Gla + Cat               | Y               | N              | L/D             |
| CB6  | F   | 26  | Rx   | Uni.  | Birth | Cong RP                 | N               | N              | N               |
| CB7  | F   | 27  | Lx   | Uni.  | Birth | Cong gla + Cat          | Y               | N              | N               |
| CB8  | F   | 35  | Rx   | Uni.  | Birth | Cong gla                | Y               | N              | L/D             |
| CB9  | F   | 59  | Rx   | Uni.  | Birth | RoP                     | Y               | N              | N               |
| CB10 | M   | 62  | Rx   | Uni.  | Birth | RoP                     | Y               | N              | N               |
| LB1  | F   | 23  | Rx   | Uni.  | 11    | Gla                     | Y               | Y              | N               |
| LB2  | F   | 43  | Rx   | Sec.  | 5     | Retinobl                | Y               | Y              | N               |
| LB3  | M   | 58  | Rx   | Uni.  | 12    | Gla                     | Y               | Y              | N               |
| LB4  | F   | 25  | Rx   | Uni.  | 4     | Retinobl                | Y               | Y              | N               |
| LB5  | M   | 58  | Rx   | Sec.  | 50    | RP                      | N               | Y              | N               |
| LB6  | M   | 44  | Rx   | Sec.  | 32    | Ret deg                 | Y               | Y              | L/D             |
| LB7  | F   | 44  | Lx   | Sec.  | 21    | Diabetic retinopathy    | N               | Y              | N               |
| LB8  | F   | 54  | Lx   | Uni.  | 2     | Retinobl                | Y               | Y              | N               |
| LB9  | F   | 44  | Rx   | Sec.  | 25    | RP + Retinal dystrophy  | Y               | Y              | L/D (Lx)        |
| LB10 | F   | 47  | Rx   | Sec.  | 11    | Ret deg                 | Y               | Y              | N               |

## 2.2. Material methods

The 28 lists with the highest Backward Associative Strength (BAS) from the study by Roediger and colleagues [4] were selected for our study. Within each list we chose the 12 words with the highest BAS. The lists were (named after their more frequent critical lure): anger, black, bread, car, chair, city, cold, doctor, foot, fruit, king, lion, man, mountain, music, needle, pen, river, rough, rubbish, shirt, sleep, slow, smell, smoke, soft, sweet, and window. Lists were then recorded using Audacity 1.3 by a native-English female voice. One-second interval was placed after each word of the list. The stimuli were presented to participants over the telephone using by using a Dell™ laptop running Windows Media Player™. In order to minimise interference, we used a landline telephone and called all participants on their landline telephones, which offered neater and more continuous transmission of the voice than mobile telephones. Thus, participants were tested while they were comfortably inside their home with dedicated time for the study (i.e. we called when participants were free from ‘family matters’), which virtually eliminated noise and distractions during the experiment. Each phone call was recorded for future transcription by using a microphone connected to the laptop. Participants were asked to refrain from recording (e.g., writing by the sighted) the words.

Participants knew that the experiment was about memory and that they were going to hear lists that they had to recall. Four seconds after the end of each list the participants were asked to begin the recollection [4]. The lists order was randomised across participants. The entire experimental session took approximately 30 minutes.

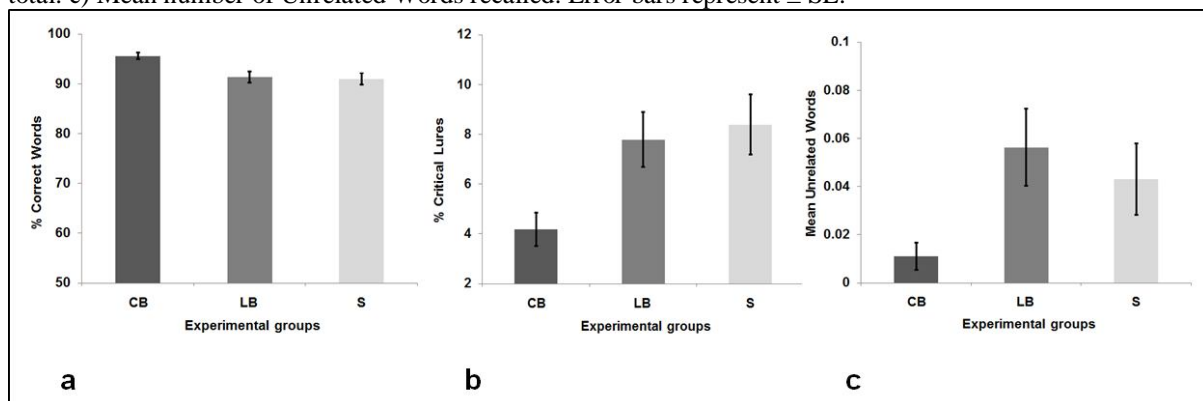
### 3. Results

On average during free recall CB reported 6.48 words (total number of words), LB 6.02 words, and S reported 6.05 words without any significant difference across groups [ $F(2,27) < 1$ ]. We classified the total number of words as mean percentage of Correct Words (i.e. words that were actually in the list), mean percentage of Critical Lures (or false memories, i.e. words related to those of the list), and mean number of Unrelated Words (i.e. words unrelated to those of the list) and for each dataset we performed a one-way ANOVA with the Visual Condition (CB, LB, or S) as between-subjects variable. For Correct Words we found a significant effect of the Visual Status [ $F(2,27) = 5.69$ ,  $p < .01$ ]. As seen in Figure 1a, the group without visual experience (CB) recalled more correct words than the groups with visual experience (LB and S). This observation was supported by a post-hoc Fisher test that showed that CB reported more Correct Words than both LB and S [ $p < .05$ ], while LB and S performed alike [ $p > 0.05$ ]. For Critical Lures we also found a significant effect of the Visual Status [ $F(2,27) = 4.96$ ,  $p < 0.05$ ]. Figure 1b and post-hoc Fisher comparisons revealed that CB reported fewer Critical Lures than both LB and S [ $p < 0.05$ ], while LB and S reported equivalent levels of Critical Lures [ $p > 0.05$ ]. For Unrelated Words (which were quite rarely reported, as seen in Figure 1c) the Visual Status significantly influenced the results [ $F(2,27) = 3.84$ ,  $p < 0.05$ ]. Post-hoc Fisher test showed that CB reported fewer Unrelated Words than LB [ $p < 0.05$ ], while S participants reported equivalent levels of Unrelated Words as both CB and LB [ $p > 0.05$ ].

In sum, we found that CB participants reported significantly more Correct Words than both LB and S (see Figure 1a). Moreover CB reported significantly fewer Critical Lures than both LB and S (see Figure 1b). Most of the CB participants avoided Unrelated Words (see Figure 1c). Thus CB participants can store more items and with a higher fidelity.

To provide additional statistical comparisons to corroborate our results, we further analysed the results relative to the Correct Words and Critical Lures by using pairwise t-tests. The results fully confirmed that CB participants have both a bigger ‘memory storage’ and higher memory fidelity. For the Correct Words the difference CB vs. LB was significant [ $t(1,18)=3.13, p<.01$ ], as it was significant the comparison CB vs. S [ $t(1,18)=3.18, p<.01$ ] –in both cases CB were better. The difference LB vs. S was not significant [ $t(1,18)=0.19, p>.05$ ]. For Critical Lures both CB vs. LB, and CB vs. S were significant [ $t(1,18)=-2.78, p<0.05$ ] and [ $t(1,18)=-3.04, p<0.01$ ] respectively –again in both cases CB were better. Finally, LB vs. S was not significant [ $t(1,18)=-0.37, p>.05$ ].

Figure 1: a) Mean percentage ‘recall’ of Correct Words. b) Mean percentage recall of Critical Lures over the total. c) Mean number of Unrelated Words recalled. Error bars represent  $\pm$  SE.



## 4. Discussion

Current theories of false memory propose that intrusions arise naturally from normal memory mechanisms [4]; in fact, superior semantic memory performance is often accompanied by higher false memory rates [12]. Here we employed the false memory Deese-Roediger-McDermott paradigm to simultaneously assess the impact of visual experience on memory capacity and fidelity. Unlike prior research with sighted participants, here we discovered a dissociation dictated by visual experience: the congenitally blind participants can recall more words with fewer false memories. We did not find any significant difference



between sighted and late blind participants, suggesting that visual input during the experiment did not play a main role; for practical reasons sighted participants were not blindfolded. Finally, we did not find any strong evidence that visual imagery plays a major role; in fact, we used more lists (18 out of 28) of concrete words (bread, car, etc.), which could advantage the participants able to use visual imagery (i.e. sighted and late blind). Yet, the results do not support this hypothesis.

Not only did the present study reveal greater memory accuracy in the absence of visual experience, but the importance of retrieval was also assessed. One primary contribution of Roediger and colleagues [3-4] was the use of a recall test to clearly demonstrate the fundamental role of retrieval for memory. Recognition tasks alone do not demonstrate this. For example, prior research on sound recognition research in the blind supports our results, though does not provide a crucial test of retrieval mechanisms. For example, Röder and colleagues [13] reported that congenitally blind participants were less likely to recognize false sounds as old than did the sighted participants. Crucially, they did not investigate semantic material and their task was a recognition paradigm (i.e. not a free recollection). Here we also found a difference between congenitally and late blind participants in a task requiring active memory retrieval. False memory formation has been viewed as an adaptive side effect of efficient memory retrieval processes that depend on spreading-activation [14-15]. Semantic memory is organized as a network where semantically related contents are closer to each other. Therefore, when a given content is activated during retrieval, part of the activation spreads to the neighbouring contents.

The reduced false memory effects in the congenitally blind suggest two mechanisms that potentially work in concert: superior retrieval processes and superior encoding to support accurate reality monitoring [16]. If congenitally blind participants encode more surface

information about each word in the original list, then they can use additional resources in monitoring and rejecting intrusions. Thus if they think of "smoke" during recall in the absence of supporting evidence, then they can reject it [4]. Follow-up studies should try to disentangle the contributions of semantic activation of concepts (encoding) and the episodic monitoring (retrieval) in blind individuals. Finally, our results confirm those from studies reporting that congenitally blind are less susceptible to perceptual illusions than sighted and late blind individuals [17-18].

Alternative explanations of the results may involve greater auditory [19] and working memory [20] processing for congenitally blind participants. Although better verbal auditory processing may lead to better memory performance, that is more correct words are recalled, it does not explain why fewer false memories are produced. In other words, finer auditory perception should increase the number of correct words, but also the number of false memories. Finally, there is little evidence that congenitally blind individuals possess a more efficient working memory [21].

Congenitally blind participants' performance may be supported by deeper structural and functional brain reorganization [22-23], where former visual areas are recruited for carrying out semantic tasks [6-8], or for better monitoring of inputs [24]. Previous studies suggested that remembering a past event requires the retrieval of incomplete fragments [25], and that this process is prone to interferences from related memory fragments. Thus, it is likely that congenitally blind participants were better at minimising the interference from related but irrelevant memory fragments. This may be supported by the indication that congenitally blind individuals have less multisensory integration [17-18] that may represent a source of interference across memory fragments. Nevertheless, our results show that visual experience has a significant negative impact on both the capacity and fidelity of semantic

memory, and also demonstrate the importance of enhanced retrieval mechanisms by the congenitally blind brain.

## 6. Conclusion

We found an effect of visual experience on both size and reliability of semantic memory and, possibly, the monitoring of episodic memory, which may be the result of the stronger recruitment of the unused visual areas of the brain. In a minor extent, these areas may be dealing with semantic memory also in sighted individuals, but in this case visual input may mask their involvement in semantic processing. Future research should investigate whether congenitally blind individuals actually show a stronger recruitment of the former visual areas during a false memory task.

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