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"I know your name, but not your number" – Patients with verbal short-term memory deficits are impaired in learning sequences of digits

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A B S T R A C T

Studies on verbal learning in patients with impaired verbal short-term memory (vSTM) have revealed dissociations among types of verbal information. Patients with impaired vSTM are able to learn lists of known words but fail to acquire new word forms. This suggests that vSTM is involved in new word learning. The present study assessed both new word learning and the learning of digit sequences in two patients with impaired vSTM. In two experiments, participants were required to learn people's names, ages and professions, or their four digit 'phone numbers'. The STM patients were impaired on learning unknown family names and phone numbers, but managed to acquire other verbal information. In contrast, a patient with a severe verbal episodic memory impairment was impaired across information types. These results indicate verbal STM involvement in the learning of digit sequences.

1. Introduction

Meeting new people can be exciting, stressful, or simply routine; regardless of which, it poses considerable challenges to our episodic memory. By introducing ourselves with name, age and profession etc., we force others to encode and consolidate information in episodic memory, and later recall this information. When uncommon last names (e.g. "Mr. Bob Dobalina") are encountered for the first time they are comparable to pseudowords, and thus pose a particular challenge for memory. What if we are also told a phone number? Or an office or apartment number? Whilst the memorization of verbal information, including learning new phonological word forms, has received considerable attention in neuropsychology, there are relatively few studies on the memorization of digit sequences, even though this task is frequently practiced in everyday life.

Previous research has revealed that the ability to learn new word forms depends on both preserved learning and intact verbal short-term memory (STM). Evidence for this comes from patients with a selective impairment of short-term memory, who exhibit a reduced capacity to immediately recall lists of digits, words, and letters. They are also impaired in sentence repetition, a task in which they would have difficulties with longer sentences of which, however, they would sometimes retain the gist (e.g., Baldo et al., 2008; Saffran, 1990; Saffran and Marin, 1975).

Although these individuals are severely impaired in immediate serial recall, it has been demonstrated that STM patients may have preserved learning as long as the information involves known words, such as in word list learning tasks (e.g., Vallar and Baddeley, 1984; Warrington and Shallice, 1969). In contrast, these patients are observed to fail at nonword learning. Baddeley et al. (1988) assessed patient PV's ability to learn pairings of known words and pairings of known words and nonwords. PV suffered from impaired verbal short-term memory yet performed in the normal range in known word pair learning. In contrast, he failed to acquire nonwords. This pattern has been replicated repeatedly (Dittmann and Abel, 2010; Freedman and Martin, 2001; Trojano and Grossi, 1995; Trojano et al., 1992). Q4

The neural correlates of verbal short-term memory have been discussed in both single case and group studies. Vallar et al. (1997) suggested that rehearsal was associated with Brodmann Areas 44 and 6 while the phonological store was located in inferior parietal areas of the left hemisphere, broadly consistent with functional imaging studies (e.g., Paulesu et al., 1993; Petrides et al., 1993;

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Smith and Jonides, 1998; Smith et al., 1998). Recently, two studies with a large group of patients have identified comparable neural correlates of impaired verbal short-term memory: Leff et al. (2009) carried out voxel-based lesion symptom mapping in 210 patients with left hemisphere damage. They identified the left posterior superior temporal gyrus as the neural substrate of digit span. These findings were largely confirmed by Baldo et al. (2012).

Comparable correlations between STM span and word learning have been reported in the field of developmental language deficits and vocabulary acquisition in normally developing children. Baddeley (1993) described the severe impairment of vocabulary acquisition in a student (SR) with a short-term memory developmental deficit. SR had failed to learn foreign languages in school and performed poorly on several tasks involving word learning. In children, significant correlations have been reported between the ability to repeat nonwords and the size of vocabulary later in life (e.g., Gathercole, 1999, 2006, 2007). Finally, there is also evidence that phonological variables shown to affect immediate serial recall (e.g., length, similarity, concurrent articulation) also affect new word learning in unimpaired individuals (e.g., Papagno et al., 1991; Papagno and Vallar, 1992).

To our knowledge, the present study is the first of its kind to investigate the ability of STM patients to learn digit sequences. This kind of learning is practiced in everyday life for the memorization of personal identification codes, passwords and phone numbers etc., and is therefore an important skill in contemporary society. Digit sequences consist of known elements combined in an unpredictable order, and as such may be comparable to novel word forms, which consist of the known inventory of phonemes and syllables combined in a previously unencountered sequence.

This study assessed the acquisition of four-digit sequences in two patients with impaired short-term memory. We employed a paired-associate learning paradigm in which participants had to learn the digit sequences (‘phone numbers’) when faced with photographs of unknown people accompanied by their names. The material was presented visually to enable the participants to immediately recall the sequences. This method was also chosen due to Baddeley et al.'s (1988) observation that their participant PV was slightly better (although still severely impaired) with visual as opposed to verbal presentation of novel words.

2. Methods

2.1. Participants with memory impairment

Two patients with impaired verbal short-term memory and one control patient with a verbal learning deficit participated in this study. IS (born 1954) suffered from a ruptured aneurysm in the right frontal cortex and a subsequent ischemia in the left parietal cortex (Fig. 1a), several years before the onset of the present study. Her spontaneous speech was fluent with very occasional paragrammatic errors. Over the course of several years, no phonemic errors were noted and comprehension in informal conversation was preserved. IS had participated in a previous study on sentence repetition (Schweppe et al., 2011). IS's digit span of four digits forward corresponds to severely impaired performance in the Wechsler Memory Scale (percentile rank 2). A span of four digits is below the normal short-term memory capacity; other STM patients in the literature have been reported with comparable limitations (e.g., Best and Howard, 2005; Newhart et al., 2012; cf. Lezak, 1995, p. 359). In sentence repetition, she would be able to repeat correctly sentences of five words but would fail on longer sentences (e.g., “The man ordered some soda”, recalled as “The man … well, the man got himself some lemonade.”). She performed normally on verbal fluency tasks, the Wisconsin Card Sorting Test, and a planning test.

BB (born 1965) suffered from bilateral strokes in temporo-parietal areas in 2009 (Fig. 1b). She presented with a severely reduced digit span (limited to single digits), deep dysphasia, and word-meaning deafness that had been previously investigated (Bormann and Weiller, 2012). Her lexical and semantic processing of written words remained unimpaired. For the present study, language tests were re-administered due to the intervening three-year period since last assessment. BB could repeat some, though not all sentences of three words length but failed completely on sentences of four or more words (0% correct).

HT (born 1951) suffered from ischemia six months prior to the administration of our experiments. The ischemic stroke affected the left anterior thalamus and, as was suspected by in-house radiologists, the left fornix. There were no lesions in left temporal or parietal areas that are supposed to be the correlate of verbal STM (Fig. 1). HT had undergone detailed neuropsychological assessment of verbal and nonverbal episodic memory, attention, and other cognitive functions revealing a selective impairment of verbal episodic memory in the face of spared attention, short-term memory, and episodic memory for nonverbal contents. His performance on the Rey Auditory Verbal Learning test (Lezak, 1995) was grossly impaired, including recognition memory (percentile rank below 2), whereas performance on the Doors-Test (Baddeley et al., 1994) was in the upper normal range. HT was unimpaired in the repetition of sentences. This pattern has remained stable over time.

Table 1 shows the participants' performance on a number of episodic memory and language tests. On formal testing, all three participants showed preserved nonword reading and preserved access to digit names. The latter was assessed by having the patients provide the results of short arithmetic problems (e.g., “8 − 2 = ?”).

2.2. Lesion mapping and processing

Diffusion-weighted imaging is the method of choice for detecting early ischemic lesions in stroke patients (Van Everdingen et al., 1998) and was therefore used for lesion delineation for BB and HT. MRI examination of IS was conducted several years after her stroke which is why T1-images were used for lesion mapping. Lesion mapping was performed semi-automatically. First, the lesions were delineated roughly using a regions of interest (ROI)-tool implemented in SPM8 (http://www.fil.ion.ucl.ac.uk/spm/ext/).

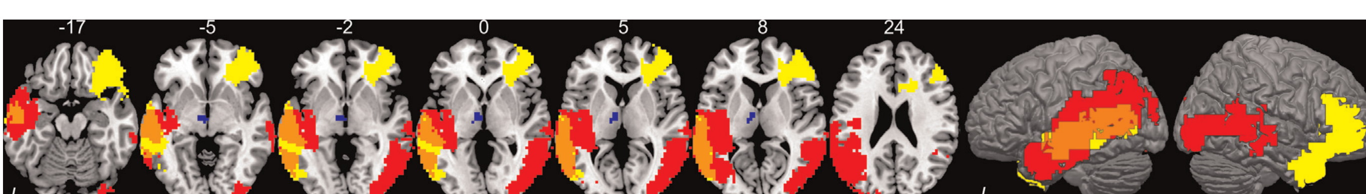

Fig. 1. Participants' lesions (yellow: IS; red: BB; blue: HT; orange: overlap IS and BB). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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