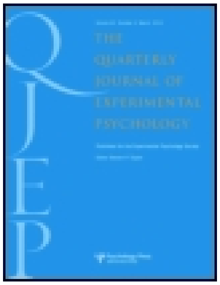

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Environmental context effects on episodic memory are dependent on retrieval mode and modulated by neuropsychological status

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Environmental context effects on episodic memory are dependent on retrieval mode and modulated by neuropsychological status

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Contextual change or constancy between occasions of memory formation and retrieval are commonly assumed to affect retrieval success, yet such effects may be inconsistent, and the processes leading to the pattern of effects are still not well understood. We conducted a systematic investigation of environmental context effects on memory, using a range of materials (common objects, pictures of familiar and unfamiliar faces, words, and sentences), and four types of retrieval (free recall, cued recall, recognition, and order memory), all assessed within participants. Additionally, we examined the influence of mnemonic challenge on context effects by examining both healthy participants and a group of patients in rehabilitation following traumatic brain injury (TBI). We found no effects of contextual factors on tests of recognition for either group of participants, but effects did emerge for cued and free recall, with the most prominent effects being on memory for objects. Furthermore, while patients' memory abilities in general were impaired relative to the comparison group, they exhibited greater influences of contextual reinstatement on several recall tasks. These results support suggestions that environmental context effects on memory are dependent on retrieval mode and on the extent to which retrieval is challenging because of neurocognitive status. Additionally, findings of environmental context effects in memory-impaired TBI patients suggest that by harnessing such preserved indirect memory (e.g., using reminder technologies), it may be possible to ameliorate TBI patients' difficulties in explicit remembering.

Keywords: Context; Memory; Recall; Recognition; Traumatic brain injury.

A common assumption of cognitive psychology is that memory is context dependent, in that context can activate or facilitate memories of previous events and items experienced in that context (Smith, 2007). There are several levels or aspects of a situation that can be understood as serving as the context in which a mnemonic representation is formed. The state of the person or animal undergoing an experience is the "state-dependent context" (e.g., emotional, alcohol, and drug

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state-dependent memory; Eich, 1980; Eich & Birnbaum, 1982). Stimulus parameters irrelevant to encoding tasks—for example, font colour, background colour, and location of words within a display (Macken, 2002), or speaker gender (Schacter & Church, 1992), which are not intentionally encoded or focally attended—may be described as "within-stimulus context". Yet another type of context is provided by discrete stimuli accompanying an encoding target, which form a "local context" (e.g., scene pictures as backgrounds for object pictures or object names, Craik & Schloerscheidt, 2011; hats accompanying faces, Vakil, Raz, & Levy, 2007). All these factors have been demonstrated to influence memory performance in a range of circumstances. However, arguably the most intuitive form of the context of a to-be-remembered experience is provided by the overall natural environment. Environmental context effects (for a review, see Smith & Vela, 2001) have been reported for contextual change versus constancy for exotic environment changes such as underwater/dry land (Godden & Baddeley, 1975), and flotation tank vs. lounge (Smith & Sinha, 1987, reported in Smith & Vela, 2001), as well as for more mundane changes, such as classroom changes on college campus (e.g., Fernández & Alonso, 2001; Fernández & Glenberg, 1985; Metzger, Boschee, Haugen, & Schnobrich, 1979; Smith, Glenberg, & Bjork, 1978) and room changes with variation in ambient odour and music (Parker & Gellatly, 1997). It should be noted that many studies use the term "environmental context" to denote local changes to the stimulus presentation framework, such as screen colour (Dougal & Rotello, 1999; Murnane & Phelps, 1993, 1994; Rutherford, 2004). That is a very different sense of environment than land-water or even different room conditions, and the current study focuses on the more intuitive sense of environmental context—that is, vicinity changes between acquisition and expression of memory.

Environmental context effects are notoriously inconsistent, as illustrated by Table 1. There have been several attempts to address this discrepancy. Smith and Vela (2001), who offer a comprehensive review and meta-analysis of the subject, have proposed two primary modulators of environmental context effects: *outshining* (at test) and *overshadowing* (at encoding). The outshining hypothesis states that if tests encourage or enable the use of extracontextual cues, such as interitem associations, the subject's use of ambient contextual cues diminishes, thereby decreasing the influence of environmental manipulations. Similarly, environmental suppression during encoding leads to overshadowing of contextual information by other information at the focus of attention during the encoding process. Thus, in some retrieval conditions, such as recognition tests, the repeated presentation of the target is such a strong cue that it overwhelms any aid to retrieval that might be rendered by contextual information (Smith, 1988; Smith & Vela, 2001). Smith and Vela (2001) accordingly predicted that there should be more environmental context effects in free recall than in cued recall and the least effect in recognition.

Other theoretical models of memory yield complementary accounts and predictions. The global activation approach, which views memory as reflecting the summation of activation of encoding event representations, claims that an old context presented in recognition tests along with a new foil may lead to false endorsement of foils as old. Therefore, context effect benefits would emerge only when totally new contexts are contrasted with old contexts, for both targets and foils (Murnane & Phelps, 1994). Another approach posits that context effects emerge in recognition only for totally novel stimuli, since for items that are very familiar from past experience, existing representations may be employed to construct a strong episodic trace at encoding, obviating the need for contextual information (Dalton, 1993; Russo, Ward, Guerts, & Scheres, 1999). Finally, building upon dual-process theories of recognition (e.g., Jacoby, 1991), Macken (2002) suggested that context effects obtain only for the recollective aspect of recognition but not for its familiarity aspect.

All these approaches have attractive features. However, none of them are in total accord with the empirical findings (see Macken, 2002). Aside

Table 1. *Representative findings of prior studies of environmental context effects*

Material type	*Free recall*		*Cued recall*		*Recognition*	
	Found	*Not found*	*Found*	*Not found*	*Found*	*Not found*
Words	Godden & Baddeley (1975); Parker & Gellatly (1997); Smith, Glenberg, & Bjork (1978)	Fernández & Alonso (2001) [younger participants]; Wilhite (1991) [+ prose passages; negative context effect]	Smith, Glenberg, & Bjork (1978)	Fernández & Glenberg (1985)	Russo et al. (1999) [nonwords] Smith (1986) [brief retention interval]	Fernández & Alonso (2001) [older participants]; Fernández & Glenberg (1985); Godden & Baddeley (1980); Russo et al. (1999); Smith, Glenberg, & Bjork (1978)
Performed actions	Phillips & Kausler (1992)					
Faces			Davies & Milne (1985) [eyewitness paradigm]		Dalton (1993); Russo et al. (1999) [unfamiliar]	Russo et al. (1999) [familiar]
Studied line drawings						Earles, Smith, & Park (1996)
College exams						Saufley, Otaka, & Bavaresco (1985)

from findings of individual studies, it is notable that in the meta-analysis conducted by Smith and Vela (2001) to test their prediction that environmental context effects should show a pattern of free recall > cued recall > recognition, the differences in effect sizes between studies of those three types of retrieval were not significant.

Furthermore, Fernández and Glenberg (1985), who in eight separate experiments failed to find reliable effects of context on memory for recall of word lists, raise doubts about the ability of laboratory-controlled models to capture the putative ecological phenomenon of content reinstatement enabling access to memories. They assert that environmental context effects are characterized by long retention intervals (i.e., years as opposed to days-, hours-, or even minutes-long delays used in experimental studies), rich and unique context nature, and repeated retrieval attempts, without which context effects do not emerge. We therefore were concerned to determine whether failures to demonstrate environmental context effects reflect a fundamental problem with the paradigm, or can be understood in terms of the necessity for certain boundary conditions. Accordingly, following the proposal of Smith and Vela (2001), we set out to compare measures of environmental context effects in tests of free and cued recall and recognition, using a variety of materials, and to do so within subjects, which has not be done in prior studies.

An additional factor that may influence the emergence of environmental context effects is individual differences in mnemonic competence, especially extreme differences resulting from pathologies. One such pathology with profound implications for memory abilities is traumatic brain injury (TBI). Such closed-head traumas frequently lead to widespread, diffuse axonal injury, in which the frontal and temporal lobes were found to be the most vulnerable cortical areas. In addition, head injury can lead to contusions, cerebral oedema, ischaemia, and haemorrhages (reviewed in Vakil, 2005). TBI may cause problem with a wide range of mnemonic abilities. However, the most common vulnerable memory processes following TBI very much resemble the memory deficits reported in patients following frontal lobe damage—for example, difficulties in applying active or effortful strategy in the learning or retrieval process (Vakil, 2005).

Prior studies show that explicit, direct memory for contextual information and temporal order requires frontal lobe integrity (e.g., Janowsky, Shimamura, & Squire, 1989). However, memory for such contextual information expressed implicitly, through context effects on retrieval, may be intact even in cases of frontal lobe damage (e.g., Vakil, Openheim, Falck, Aberbuch, & Groswasser, 1997). Patients affected by TBI have been shown to be quite consistently impaired relative to controls on all the explicit memory tests of target information (e.g., word recall and recognition) and of ancillary context information (e.g., modality and temporal order judgement). However, when contextual information was tested implicitly, the patient and control groups did not differ significantly—that is, the groups showed the same magnitude of environmental context effects. This has been shown for temporal order judgement (McDowall & Martin, 1996; Vakil, Blachstein, & Hoofien, 1991); frequency judgement (Vakil, Biederman, Liran, Groswasser, & Aberbuch (1994); perceptual context (Vakil, Golan, Grunbaum, Groswasser, & Aberbuch, 1996); and modality of presentation (Vakil et al., 1997).

While the abovementioned studies indicate that TBI patients do retain and benefit from *local* and *within-stimulus* contextual information (to use the terms introduced above), it remains to be determined whether they reliably retain and may benefit from reinstatement of *environmental* context. The phenomenon of preserved memory context effects in TBI patients is far from intuitive. Classic neuropsychological approaches to memory disorders posited that one of the foundations of amnesia is a deficit in the processing of contextual information at encoding, leaving patients without sufficient retrieval cues to access the desired information (Huppert & Piercy, 1976; Kinsbourne & Wood, 1975). It might therefore be expected that contextual information might be specifically vulnerable in TBI patients with general memory deficits. Accordingly, we conducted the current study of environmental context effects on free recall, cued recall, and recognition for a wide range of memoranda (faces, objects, narrative information, and individual words) in TBI patients and matched healthy persons in a comparison group, to determine under which of those circumstances context might benefit memory-impaired patients following TBI. In the appropriate conditions, we included a manipulation of generation versus presentation, a factor that has been linked with contextual memory (Mulligan, 2004). We also examined memory for temporal order, a measure of source memory (Milner, Corsi, & Leonard, 1991; Vakil et al., 1991), and memory for self-generated information (Slamecka & Graf, 1978), providing estimates of context effects on two higher order aspects of memory that are ecologically relevant. Furthermore, we examined context effects on memory for both familiar and unfamiliar faces, which have been shown to be differentially sensitive to context change in regard to recognition (Dalton, 1993; Russo et al., 1999). In those studies, face familiarity was manipulated by preexposure. In the present study, we used faces of well-known personalities as familiar faces, in order to be able to test recall as well as recognition. The goals of this complex design were (a) to enable simultaneous assessment of a range of factors that might modulate environmental context effects within subjects, (b) to achieve a certain degree of ecological validity, by modelling the range of memoranda and retrieval modes to which a person is generally exposed in real-life memory requirements, and (c) to explore the effect of mnemonic challenge on environmental context effects.

Method

Participants

The patient group comprised 20 participants with moderate-to-severe TBI: 16 male; age range

23–58 years, mean age 33.7 years; mean education 13.9 years (*SD* 2.6 years). All were attending a rehabilitation programme at a centre for the rehabilitation of brain injuries and received payment for their participation in this study. They were without other history of psychiatric illness, alcoholism, or drug abuse. All patient participants underwent extensive neuropsychological assessment focused on memory, attention, and executive functions (Table 2). We also collected information about severity of injury (Glasgow Coma Scale, duration of coma) and time after injury, as well as demographic information (age, sex, socioeconomic status, education). We further assessed orientation, spatial and visual perception, and visuomotor organization. Only patients whose intelligence and linguistic capacities were sufficient for the execution of the experimental tasks participated in the study. Approximately 20 patients in the catchment group were preexcluded based on those considerations, or did not participate due to unwillingness to travel to the experimental location.

We also tested a group of healthy participants, which comprised 20 persons: 10 male; age range 20–59 years, mean age 26.8 years; mean education 12.9 years (*SD* 1.1 years). They were recruited by poster advertisement and were admitted to the study on the basis of demographic matching with the participants with TBI. This comparison group was demographically matched to the patients from a general population sample, but we did not have the opportunity to conduct neuropsychological testing for them, which might have indicated whether any of those participants were cognitively challenged. Comparison group participants were paid for participation and were self-reportedly without neurological, psychiatric, or substance abuse disorders. The study was approved by the human subjects committees of the sponsoring institutions, and all participants provided written informed consent.

Table 2. *Neuropsychological characteristics of TBI patient participants*

Assessment	N *data available*	*Mean*	SD	*Mode*	*Median*
Glasgow Coma Scale	12	8.1	3.9	3	8
Length of coma (days)	10	6.8	5.3	0.01	7
Posttraumatic amnesia (days)	13	18.5	13.2	21	21
WAIS–III					
Full-Scale IQ	18	98.3	7.6	97	97.5
Verbal IQ	18	104.6	10.3	86	105
Performance IQ	18	89.5	7.5	85	87.5
Verbal Comprehension Index	17	107.1	10	105	105
Perceptual Organization Index	17	95.8	8.3	99	97
Working Memory Index	18	98.1	12	104	100.5
Processing Speed Index	18	82.4	10.3	81	82.5
WMS–III					
Auditory Immediate	15	99.5	7.9	105	99
Visual Immediate	15	83.7	14.9	78	81
Immediate Memory	15	90.5	10.6	89	89
Auditory Delayed	15	99.6	8.9	97	97
Visual Delayed	15	85	15.6	81	81
General Memory	16	93.4	11.2	79	94
Working Memory	14	94.9	11.4	96	94.5
Single trial learning	12	47.6	20.5	36	40
Learning curve	13	47.7	22.1	25	52
Retention	11	41.9	27.1	19	39
Retrieval	9	34.8	38.6	1	11

Note: TBI = traumatic brain injury. WAIS–III = Wechsler Adult Intelligence Scale–Third Edition. WMS–III = Wechsler Memory Scale–Third Edition.

Materials

Contexts. We created three distinct environmental contexts using three rooms in an on-campus location.

Context Room A. This was a room without windows, furnished as a domestic environment, containing two tables spread with coloured tablecloths, two lounge chairs, a side table with tablecloth, a black plastic bookcase, two upholstered armchairs, four pictures hanging on the walls, and two rugs. The acoustic environment (Balch, Bowman, & Mohler, 1992) was defined by soft instrumental jazz background music, and the olfactory environment character (Cann & Ross, 1989; Herz, 1997; Schab, 1990) was lavender scent. This room was used for study in all memory tasks and for testing in half of each of the tasks for each participant.

Context Room B. This was a room without windows, furnished as an office environment, containing one large table without tablecloth, two office chairs, an office closet, a small closet covered with a green cloth, a low side table, three small pictures, and a calendar. The floor covering was unpatterned wall-to-wall carpeting. The acoustic environment was defined by soft instrumental classical background music, and the olfactory environment character was apple–cinnamon scent. This room was used for testing in half of each of the tasks for each participant.

Context Room C (waiting room). This was a room without windows, containing a plain table, a nonupholstered chair, and travel magazines, which could be read during delay periods of the experiments. The walls were blank, and there was no music or scent in the room.

Memory tests. We employed five memory tests in the experiment. The materials for these tests were as follows:

Unfamiliar faces. This test used 30 colour photographs of unfamiliar faces on blank backgrounds, printed on A4-size paper, divided into two sets, counterbalanced as targets or distractors across participants (counterbalancing of sets/lists was also done for objects, famous faces, and words).

Common objects. This test used 40 common objects from five object categories, divided into two sets. Set A comprised the following: food—pasta, tea, brown sugar, cornflakes; tools—brush, screwdriver, hammer, scissors; toys—doll, deck of cards, ball, crayons; clothing—shoes, short pants, hat, tie; electronics—disk player, pocket calculator, extension cord, computer mouse. Set B comprised the following: food—white rice, chocolate bar, cola, canned vegetables; tools—tongs, wrench, drill, drain pump; toys—toy car, toy rifle, Rubik cube, toy noisemaker; clothing—socks, belt, undershirt, shirt; electronics—socket, light bulb, earphones, keyboard.

Famous faces. This test used 30 colour photographs of very well-known Israeli and international actors, actresses, and politicians, printed on A4-size paper, divided into two sets.

Stories. This test used a short story 45 words long, in Hebrew, similar to the first one found in the Logical Memory subtest of the Wechsler Memory Scale–Third Edition (WMS–III; Wechsler, 1997), consisting of 25 units of information. It was spoken by a female experimenter, recorded on a computer, and played using computer speakers, in order to achieve uniformity of verbal presentation to avoid experimenter effects. Additionally, we recorded six content questions to be answered expositorily (in the cued recall condition): who the main character of the story was, what her occupation was, what happened to her, what information was provided about her family, what the family's condition was, and what the police response was. We also recorded 15 yes/no questions regarding the story, which provided a recognition test of logical memory.

Words. Two lists of 15 Hebrew words each, matched for frequency (Drori & Henik, 2005), spoken by a female experimenter, were recorded on a computer and played using computer speakers. For each word, we also recorded a clue/definition to serve as a cue for recall. For example, for the word "smell", the cue was "one of the five senses", and for the word "pillow", the clue was "may be found in a bed".

Procedure

The procedure employed is outlined in Table 3. We employed a modified between-subject design, with two between-subject factors: patient/comparison participant, and same/different study–test contexts. The same/different condition was distributed among participants—that is, each participant executed some of his/her tasks in the same-context condition and the others in the different-context condition. Each participant took part in two sessions, each lasting 1–1.5 hours, spaced approximately one week apart. The session structure was the same for each participant, as follows:

First meeting. Part I: Unfamiliar faces. (a) *Unfamiliar faces study* (in Room A): Participants viewed 15 photographs of unfamiliar faces and were asked to guess the occupation of the person in the photograph and to remember the faces for a future memory test. The occupation guesses were recorded by the experimenter. This part of the task took 8 min on average. (b) *Delay period* (in Room C): Participants worked computerized Raven Matrices for 10 min. (c) *Unfamiliar faces*

Table 3. *Experimental structure*

Session	*Tests*
Session 1	**Unfamiliar faces** encoding
	Delay: Raven Matrices
	Unfamiliar faces recognition test
	Cued recall of self-generated occupations for unfamiliar faces
	Serial order recall test for unfamiliar faces
	Common objects encoding
	Delay: Raven Matrices
	Object free recall test
	Object cued recall test
	Object recognition test
	Serial order recall test for objects
	Famous faces encoding
Session 2 (after one week delay)	*Famous faces free recall test*
	Famous faces cued recall test
	Famous faces recognition test
	Serial order recall test for famous faces
	Story encoding
	Delay: demographic information
	Story free recall test
	Story cued recall test
	Story recognition test
	Word encoding
	Delay: magazine reading
	Word free recall test
	Word cued recall test
	Word recognition test
	Serial order recall test for words

recognition test (in Room A or B): Participants viewed 30 photographs of unfamiliar faces in a binder and were asked to identify the 15 that had been viewed previously. (d) *Generation test* (in same room as prior stage): The 15 studied photographs were randomly spread on the table, and participants were asked to recall the occupation they had guessed for each person. (e) *Unfamiliar faces serial order recall test* (in same room as prior stage): The 15 studied photographs were once again randomly spread on the table, and participants were asked to arrange them in the order in which they had been viewed in the study stage.

Part II: Objects. (a) *Common objects study* (in Room A): Participants viewed 20 objects scattered randomly throughout the room (but with the distribution clockwise-order consistent for all participants), for 8 min, and they were asked to identify the objects and to remember their identity and position for a later memory test. (b) *Delay period* (in Room C): Participants worked computerized Raven Matrices for 10 min. (c) *Object free recall test* (in Room A or B): Participants were asked to recall the names of the objects that they had viewed previously. (d) *Object cued recall test* (in same room as prior stage): Participants were cued with the names of the five categories of the viewed objects and were asked to recall the members of each category. (e) *Object recognition test* (in same room as prior stage): Participants were asked to step out of the room for 1–2 min, during which time the experimenter arranged 40 objects (the 20 viewed earlier and 20 distractors) randomly on the table. The experimenter read out the names of the 40 objects, and the participant indicated with a yes/no answer whether that object had been viewed earlier. (f) *Object serial order recall test* (in same room as prior stage): Participants were once again asked to step out of the room for 1–2 min, during which time the experimenter arranged the 20 objects viewed during the encoding stage randomly on the table. Participants were asked to distribute the objects throughout the room in the same clockwise order as that in which they had originally been viewed. When the participant indicated completion, the experimenter recorded a map of the object distribution, and the correlation between viewed and reconstructed orders was calculated for each participant.

Part III: Famous faces. (a) *Famous faces study* (in Room A): Participants viewed and named 15 photographs of famous faces in a fixed order and were asked to remember the faces for a future memory test. The names given were recorded by the experimenter. (b) Matrices (in Room C): If participants had not completed the computerized Raven Matrices task in the two prior delay sessions, they were requested to complete it at this point.

Second meeting. Part III: Famous faces. (a) We separated the study and test sessions of the famous faces test by a week in light of a pilot study that demonstrated that any shorter retention interval (e.g., beginning and end of session) caused strong ceiling effects for any practical number of face pictures. (b) *Famous faces recall test* (in Room A or B): Participants were asked to recall the names of the famous faces that they had viewed the previous week. (c) *Famous faces cued recall test* (in same room as prior stage): Participants were cued with the names of the three categories of the viewed faces (actors, actresses, politicians) and were asked to recall the members of each category. (d) *Famous faces recognition test* (in same room as prior stage): Participants viewed 30 photographs of famous faces in a binder and were asked to identify the 15 that had been viewed the previous week. (e) *Famous faces serial order recall test* (in same room as prior stage): The 15 studied photographs were randomly spread on the table, and participants were asked to arrange them in the order in which they had been viewed the previous week.

Part IV: Story memory. (a) *Story study* (in Room A): Participants listened to a recorded story and were asked to remember the details of the story for a subsequent memory test. (b) *Delay period* (in Room C): Participants provided demographic information and then could read magazines, for 10 min. (c) *Story free recall test* (in Room A or B): Participants were asked to recall as many details as possible of the story that they had heard previously, regardless of reference to story order. (d) *Story cued recall test* (in same room as prior stage): Participants were requested to answer recorded specific questions about the story. (e) *Story recognition test* (in same room as prior stage): Participants answered 15 yes/no recorded questions about the story.

Part V: Word memory. (a) *Word study* (in Room A): Participants listened to a recorded list of 15 words and were asked to remember them for a subsequent memory test. (b) *Delay period* (in Room C): Participants could read magazines for 10 min. (c) *Word free recall test* (in Room A or B): Participants were asked to recall as many words as possible, regardless of word list order. (d) *Word cued recall test* (in same room as prior stage): Participants listened to recorded clues for each word and were asked to recall the cued word from the studied list. (e) *Word recognition test* (in same room as prior stage): Participants listened to 30 recorded words, of which 15 were studied, and 15 were matched distractors, and indicated by a yes/no answer for each word whether it had appeared in the study list. (f) *Word serial order recall test* (in same room as prior stage): Participants were given a page on which the 15 original words were printed in alphabetical order and were asked to write the words in the order in which they had originally been presented.

Results

Our initial analysis aimed at an overall view of the effect of contextual reinstatement on the factors of free recall, cued recall, recognition, and order memory. The first three measures could be directly compared through the examination of the proportion of correct responses, while order memory, operationalized as correlations between the order of presentation and the order of reconstruction, was examined separately. Additionally, we performed a between-group comparison to determine the effects of memory challenge on retrieval success (Figure 1). Accordingly, we first conducted a mixed-model analysis of variance (ANOVA), in which the dependent variables were the mean

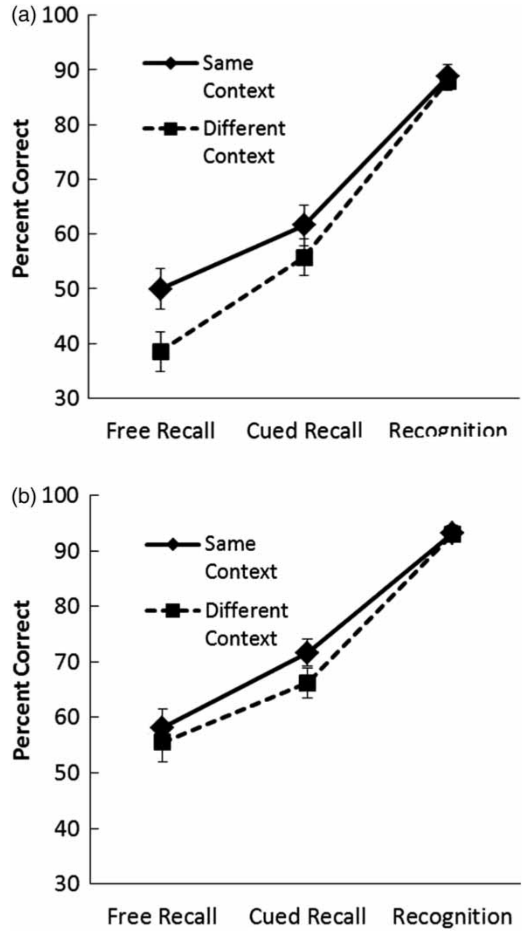

Figure 1. *Mean percentage correct scores across four material types (sentences, words, objects, famous faces) for traumatic brain injury (TBI) patients (A) and healthy comparison group participants (B), in same or different context condition groups; for each group, each condition* $n = 10$.

percentage correct scores for the free recall, cued recall, and recognition tests over the five types of memoranda (aggregating 13 tests in all; for unfamiliar faces, there were no free or cued recall tests). The between-subject factors were group (patient, comparison) and context condition (same, different). There were significant main effects of test type, $F(2,\ 72) = 491.86$, $p < .01$, $\eta = .932$, of group, $F(1, 36) = 18.61$, $p < .01$, $\eta = .341$, and of context, $F(1,\ 36) = 4.20$, $p < .05$, $\eta = .104$. Additionally, the Test × Context interaction was significant, $F(2,\ 72) = 3.44$, $p < .05$, $\eta = .087$, as was the Test × Group interaction, $F(2, 72) = 4.86$, $p = .01$, $\eta = .119$. However, the Test × Group × Context interaction was not significant, $F < 1.0$. Thus, although the TBI patients were indeed memory impaired relative to the healthy comparison group, we found no difference in the environmental context effects exhibited by the groups.

To determine whether these results support our hypothesis that environmental context effects apply differentially to free recall, cued recall, and recognition, we examined the Test × Context interaction by conducting separate ANOVAs for each type of retrieval (collapsing across groups, since the Test × Group × Context interaction was not significant), comparing same and different environmental context conditions. These test revealed trends towards differences between same and different context conditions for free and cued recall; for free recall, $F(1, 38) = 3.33$, $p = .076$, $\eta = .080$, and for cued recall, $F(1, 38) = 3.14$, $p = .084$, $\eta = .076$. In contrast, environmental context effects on recognition did not at all approach significance, $F(1, 38) < 1.0$.

We examined the Test × Group interaction by conducting a separate repeated measures ANOVA with factors of test and group. As expected, this yielded a significant main effect of test, $F(2, 76) = 454.41$, $p < .01$, $\eta = .923$, a significant main effect of group, $F(1, 38) = 17.32$, $p < .01$, $\eta = .313$, and a significant interaction, $F(2, 76) = 4.48$, $p < .05$, $\eta = .106$. The mean differences in percentage correct scores between patients and healthy participants were 12.6% for free recall, 10.3% for cued recall, and 4.7% for recognition. Within-subjects contrasts revealed that the percentage correct scores did not differ between groups for free and cued recall, $F(1, 38) = 1.45$, $p > .1$, $\eta = .037$, but those group score differences were significantly larger than the group score differences for recognition, $F(1, 38) = 5.56$, $p < .05$.

We also analysed scores of the four tests of memory for order of presentation (for familiar and unfamiliar faces, objects, and words) by calculating the rank order correlations (Spearman ρ) between presented and reconstructed order for each test for each participant. Mean order scores for each participant were then analysed for context condition and group effects. There was a significant effect of group, $F(1, 36) = 5.39$, $p < .05$, $\eta = .130$, but no effect of context condition, $F(1, 36) = 1.70$, $p > .05$, and no Group × Context interaction, $F < 1.0$.

Finally, to identify types of material for which environmental context effects might be most prominent, we conducted follow-up *t* tests for each of the individual tests (free recall, cued recall, and recognition) performed on the various material types (objects, faces, stories, and words, separately for patients and comparison group participants (see Appendix). One-tailed *t* tests indicated significant environmental context effect benefits ($p < .05$) for object free recall, object cued recall, and word recall for patients, but not for the healthy comparison group. These results should be treated with some caution, as they would not survive correction for multiple comparisons. Nevertheless, they may provide some indication of the relative strength of context effects in different test and material types.

Discussion

We report an extensive study of the effects of environmental context reinstatement on a range of retrieval methods and types of memoranda, with reference to the effects of memory challenge as expressed in differences between healthy participants and persons with memory impairment following traumatic brain injury. In this study, we found notable differences between tests of free and cued recall, for which environmental context effects were evident (greater for free recall than for cued recall), and tests of recognition, for which environmental context effects seem to be absent. Furthermore, there was some evidence that more prominent effects were found for memory for objects. The findings of differences between test types are in line with the predictions of Smith and Vela (2001) regarding the impact of outshining on environmental context effects. The current study, conducted using a modified within-subject design (i.e., the same participants performed half the tests in the same-context condition and half the tests in a different context condition) might have been able to capture the distinction between test types that was not revealed in the meta-analysis of earlier studies conducted by Smith and Vela.

Another goal of this study was the examination of memory challenge caused by neuropsychological impairment on the emergence of environmental context effects. As expected, the persons with TBI were impaired in almost all memory demands relative to the matched comparison group, notably so in the tests conducted over longer delays (i.e., the tests of memory for famous persons' faces, conducted after a one-week delay vs. 10 min in other tests; see Appendix). Despite this memory deficit, and perhaps because of it, patients especially benefited from contextual constancy in the case of memory for real physical objects. The findings reported here confirm those of earlier studies (McDowall & Martin, 1996; Vakil et al., 1991, 1994, 1996, 1997) that although direct memory for contextual information is impaired following TBI and in other illnesses, its effect may be seen in indirect expressions of its influence on remembering. Although the test-type environmental context effect differences were observed for the healthy as well as the memory-impaired participants, we found some evidence that they were stronger and more significantly widespread (across material types) for the TBI patients. This trend may be understood as being generally in line with the outshining and overshadowing principles espoused by Smith and colleagues. The upshot of these explanations is that context reinstatement may benefit memory performance when it is otherwise weak—as in the case of the persons with TBI, who may have cognitive deficits caused by frontal-lobe damage that impair both encoding and retrieval processes. Such a relationship has been found in the comparison of environmental context effects in ageing and younger adults (Fernández & Alonso, 2001, who report that environmental context effects were found for older but not for younger participants). In ageing as well, part of the decline in mnemonic abilities may be attributed to decline in frontal-lobe function (Moscovitch & Winocur, 1992), leaving older adults more dependent on contextual cues for the retrieval of episodic information. It is also notable that across context conditions, patients were differentially less impaired on tests of recognition than on tests of recall, with the greatest impairment being found in free recall. This finding is in line with prior research (reviewed by Davidson, Troyer, & Moscovitch, 2006).

To return to the distinction between environmental context effect test type differences, in the present study, there was no difference in the absence of recognition environmental context effects between famous and unfamiliar faces. Similarly, Dalton (1993), who experimentally manipulated face familiarity and used a retention interval of one week, reported that changing environmental context affected the recognition of unfamiliar faces but not of familiar faces, while changes in local context (occupational labels) affected both types of faces equally. In contrast, environmental context effects for unfamiliar faces, at a short retention interval similar to the current study, were reported by Russo et al. (1999). The hit rates for unfamiliar faces for the healthy comparison group in our study were slightly higher (88%) than the 56% in the study of Russo and colleagues; the environmental context effects reported there might reflect release from outshining.

The indication that stronger environmental context effects might be found for objects than for other materials may be related to the proposal of Bjork and Richardson-Klavehn (1988) that only integral environmental contexts—those associated with a person's prior knowledge, or that are needed to present the stimuli—reliably affect memory. It may be argued that physical objects are the type of stimuli for which the physical environment is most salient and therefore most likely to affect remembering by reinstatement. This account is in consonance with the suggestion of Baddeley and Woodhead (1982) that a distinction should be made between "interactive" context, which facilitates context effects, and "independent" context, in which context effects may not emerge.

The stronger presence of context effects in recall than in recognition tests could reflect either qualitative differences in mnemonic demands between those forms of retrieval, or merely quantitative differences in test difficulty, with a stronger role of context emerging in harder tests. One interesting aspect of our data might speak to this question. The five recognition tests (famous faces, nonfamous faces, objects, story details, words) employed in this study had differing degrees of challenge (as indicated by mean performance across all participants, as can be seen in the Appendix). If the relative absence of context effects in recognition reflects quantitative factors, we would expect a negative correlation between task performance and the strength of context effects: The harder the recognition task, the more context should modulate performance. However, within the context-effect-prone patient group, we found a strongly opposite correlation: The *easier* the recognition test, the more closely the context effect approached significance. This suggests that the difference between the nature of context effects in recognition and recall is categorical rather than strength driven. It accords with the observation of Smith and Vela (2001) that recognition tests provide strong noncontextual retrieval cues not offered by recall paradigms, which can yield outshining effects. While a graded comparison of nonsignificant effects must be treated with extreme caution, it does suggest a possible approach for further research to examine this issue.

Several limitations of this study must be noted. The manipulation of using two adjacent rooms as variable context, furnished differently though they were, is clearly a weaker change than classic situations such as underwater versus on land (Godden & Baddeley, 1975, 1980). Accordingly, the lack of emergence of recognition context effects cannot be asserted to unqualifiedly apply to any environmental manipulation (Canas & Nelson, 1986). Similarly, the short delay period employed in most of the tests, and the fact that free recall, cued recall, recognition, and order memory were tested repeatedly for the same memoranda, probably suppressed the emergence of more environmental context effects. These factors of the design were dictated by the desire to examine a wide range of mnemonic abilities within each group. However, it may be surmised that under more demanding retrieval circumstances, stronger environmental context effects may be found for TBI patients and perhaps for healthy individuals as well. It should be mentioned that several analyses were conducted to examine the data from different perspectives, such that experimental alpha was not fully controlled across the entire study.

Finally, these findings of prominent environmental context effects in memory-impaired TBI patients suggest that by harnessing such preserved indirect memory it may be possible to ameliorate TBI patients' difficulties in explicit remembering. Context effects might aid memory-impaired patients recall important information when their direct episodic recollection fails, even in new locations. This possibility is suggested by the finding that using mental visualization techniques to reinstate encoding context benefits recall (Chu, 2003; Fernández & Alonso, 2001; Smith, 1979; but see Fisher & McCauley, 1995). If patients are given reminders about the context of an event (using smartphones or SenseCam technologies; Berry et al., 2007), they might gain considerable leverage on retrieving important target information acquired during that event, much as free and cued recall was aided by context in the present study. Such strategies might overcome real-life memory problems, such as remembering the placement of objects, car-parking location, or instructions received from medical caregivers or employers. Patients with frontal-lobe damage are likely to be impaired in effortful or planned learning of new information. However, the fact that environmental context effects were found for persons with diffuse brain injuries not instructed to attend to contextual information indicates that acquisition of contextual information is a relatively automatic part of our encoding of experiences and information.

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APPENDIX

Percentage of correct responses (for free recall, cued recall, and recognition tests) for TBI patients and healthy comparison group

Test	*Group*	*Context*	*Mean* (%)	SD (%)	*Test*	*Group*	*Context*	*Mean* (%)	SD (%)
Unfamiliar faces recognition	Patients	Same	82	13.4	Story recognition	Patients	Same	82.7	11.0
		Different	83.3	12.3			Different	82.7	10.0
	Controls	Same	87.3	14.2		Controls	Same	83.3	9.0
		Different	88.7	10.4			Different	85.3	10.3
Unfamiliar faces generated occupations	Patients	Same	50	27.3	Word recall*	Patients	Same	35.3	17.2
		Different	34.7	14.7			Different	23.3	10.5
	Controls	Same	58.7	16.9		Controls	Same	43.3	24.2
		Different	48.7	17.2			Different	31.3	13.7
Famous face recall	Patients	Same	31.3	16.6	Word cued recall	Patients	Same	52.7	18.4
		Different	21.3	14			Different	60.7	17.3
	Controls	Same	55.3	14.1		Controls	Same	70.7	15.1
		Different	51.3	18.9			Different	60.7	13.1
Famous face cued recall	Patients	Same	36.7	20.2	Word recognition	Patients	Same	86	14.9
		Different	31.3	13.4			Different	90.7	7.8
	Controls	Same	60	14.7		Controls	Same	96.7	4.7
		Different	54.7	14.7			Different	93.3	8.3
Famous face recognition	Patients	Same	88	16	Object recall*	Patients	Same	73.5	13.3
		Different	82	13.4			Different	56.5	21.2
	Controls	Same	94.7	10.3		Controls	Same	73.5	15.8
		Different	95.3	4.5			Different	78	10.6
Story recall	Patients	Same	59.6	18.7	Object cued recall*	Patients	Same	77	11.4
		Different	52.8	16.4			Different	61	18.7
	Controls	Same	60.4	21.6		Controls	Same	75	12.7
		Different	61.6	17.1			Different	75.5	14.8
	Patients	Same	80	12.5	Object recognition	Patients	Same	98.5	3.4
		Different	70	13.7			Different	96.5	4.7
Story cued recall	Controls	Same	80.8	12.5		Controls	Same	98	2.6
		Different	74.2	17.8			Different	98	2.6

Note: TBI = traumatic brain injury. Significant individual tests (t tests, one-tailed, $p < .05$) are indicated by asterisks.