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Factor analysis of three standardized tests of memory in a clinical population

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Objectives. The aim of this study was to determine the factor structure of three standardized memory tests: Wechsler Memory Scale–Revised (WMS–R), Warrington Recognition Memory Test (WRMT), Doors and People Test (D&P). We investigated whether these different standardized tests of memory are consistent in their evaluation of memory function, and the extent to which these tests discriminate between different memory functions (e.g. recall/recognition and verbal/non-verbal memory).

Design. Fifty patients with selective memory impairment were tested on the WMS–R, WRMT and D&P.

Methods. Age-scaled scores from selective measures of these tests (WMS–R-verbal, WMS–R-visual, WMS–R-delay, WRMT-words, WRMT-faces, D&P-people, D&P-doors, D&P-shapes, D&P-names) were used as input to a factor analysis.

Results. Maximum likelihood factor analysis yielded a three-factor solution consistent with a theoretically motivated fractionation of memory function into recall and recognition components. Recognition performance, but not recall performance, showed dissociation into visual and verbal components.

Conclusions. The WMS–R, WRMT and D&P are highly consistent in their assessment of memory function. The results of the factor analysis are consistent with a theoretically motivated fractionation of recall and recognition memory. They are also partially consistent with a dissociation between visual and verbal memory function.

The development of research into disorders of memory has been accompanied by the introduction of standardized tools to assess memory dysfunction. The revised version of the Wechsler Memory Scale (WMS–R; Wechsler, 1987) was introduced in the 1980s to replace the original (WMS; Wechsler, 1945), which lacked measures of recognition or delayed recall. The Warrington Recognition Memory Test (WRMT; Warrington, 1984) was also published at this time, and provides comparable measures of recognition memory for verbal and non-verbal stimuli. In the early 1990s, Baddeley and colleagues introduced the Doors and People Test (D&P; Baddeley, Emslie, & Nimmo-Smith, 1994) following a request from the Scientific

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Committee of the Amnesia Association to provide a more sensitive measure of visual long-term memory. In addition to measures of visual recall and recognition, the D&P provides measures of both verbal recall and verbal recognition.

It is largely unknown, however, to what extent these different tests are consistent in their assessment of memory function, and whether they are equally sensitive to overlapping and distinct memory functions. Furthermore, the extent to which different types of memory (recall/recognition, verbal/visual) dissociate is unclear. Recent research has provided a theoretical basis for the fractionation of memory function into recall and recognition components (Aggleton & Brown, 1999), although this dissociation is disputed (Squire & Knowlton, 1994). Aggleton and Brown suggest that damage limited to the hippocampal system (hippocampus, fornix, mammillary bodies, anterior thalamus) leaves recognition intact despite causing a severe recall deficit. In contrast, Squire and colleagues repudiate the existence of such a dissociation, and argue that discrete hippocampal damage is sufficient to impair both recall and recognition (see Rempel-Clower, Zola, Squire, & Amaral, 1996).

Lateralization of verbal and visual abilities predicts a fractionation of memory performance which should be detectable with tests of visual and verbal memory. However, studies of patients with temporal lobe epilepsy (TLE) have not convincingly demonstrated a dissociation between visual and verbal memory function. Although some studies have shown material-specific deficits in patients with right and left temporal lobe damage (Glosser, Deutsch, Cole, Corwin, & Saykin, 1998; Morris, Abrahams, & Polkey, 1995), others have failed to show material-specific deficits (Grabowska, Luczywek, Fersten, Herman, & Szatkowska, 1994; Loiseau *et al*., 1983; Mayeux, Brandt, Rosen, & Benson, 1980) or show only partial dissociation (Baxendale, 1997). A further recent study involving stroke patients, which investigated the effect of unilateral lesions restricted to the hippocampus, also failed to find material-specific memory deficits (Dobbins, Kroll, Tulving, Knight, & Gazzaniga, 1998).

The aim of this study was to determine the factor structure of the three standardized memory tests referred to above. Accordingly, we examined whether these different standardized tests of memory are consistent in their evaluation of memory function. In view of the equivocal nature of the current evidence for a dissociation between visual and verbal memory, and between recall and recognition, we chose to use an exploratory factor-analytical procedure. We particularly wanted to examine the factor structure of measures commonly utilized in a clinical setting. We therefore examined both single measures (WRMT, D&P) and composite measures (WMS–R). Although this has limitations in terms of theoretical interpretation, our main objective was to examine clinical measures which, in practice, constitute both single and composite measures. To our knowledge, no comparative factor-analytic study of all these memory tests has been carried out before.

Method

Participants

The sample comprised 50 patients recruited to a study of memory dysfunction.[1] The inclusion criterion was evidence of memory impairment on at least one of three standardized measures of memory (WMS–R, WRMT, D&P). Specifically, participants were included if their performance was at, or greater than, one standard deviation below the mean on any subtest of the WRMT or D&P, or if their WMS–R General Memory Index was 15 points or more below their WAIS–R FSIQ. Exclusion criteria were evidence of additional major cognitive impairment (e.g. language or perceptual deficit) or evidence of a degenerative disorder. The sample included 35 males and 15 females with a mean age of 48.44 (SD = 13.00; range = 16–72). Mean estimated pre-morbid FSIQ (NART; Nelson, 1991) was 104.22 (SD = 11.12; range = 80–120; 4 missing scores). Mean current FSIQ (WAIS–R; Wechsler, 1981) was 99.63 (SD = 12.85; range = 75–135; 2 missing scores). The sample comprised a mixed aetiology: encephalitis ($N = 13$); Wernicke–Korsakoff syndrome ($N = 7$); anterior communicating artery aneurysm ($N = 3$); colloid cyst ($N = 4$); thalamic infarct/stroke ($N = 5$); other stroke ($N = 5$); head injury ($N = 4$); miscellaneous ($N = 9$). Participants' mean performance on each of the three standardized tests (WMS–R, WRMT, D&P) is given in Table 1.

Procedure

Patients were assessed using three standardized memory tests: WMS–R, WRMT and D&P. The WMS–R provides measures of verbal memory, visual memory, general memory, attention/concentration and delayed recall. Since the general memory measure is a composite of the verbal and visual memory measures, this was omitted from the analysis. The attention/concentration measure was also omitted, so that the analysis was restricted to measures of long-term memory. The WRMT provides measures of verbal (words) and non-verbal (faces) recognition. The D&P test provides measures of verbal recall (people), non-verbal recall (shapes), verbal recognition (names) and non-verbal recognition (doors). Control subjects were not included in this study because many would have been at ceiling on some of the measures used (WRMT-words and WMRT-faces).

Exploratory factor analysis was carried out using SPSS (version 6.1.1). The variables used as input to the factor analysis were nine measures derived from three standardized tests of memory function: WMS–R (verbal, visual, delay); WRMT (words, faces); D&P (people, doors, shapes, names). The input data were age-scaled scores from each of these measures. In order to test for outliers, scores on each test were expressed as z scores. Only one z score greater than 3.0 was observed across all tests, and this was on the D&P-people test ($z = 3.24$). (Removal of this outlier had a negligible effect on the pattern of results. The results presented here are therefore from the analysis in which the participant was included.) Maximum likelihood factor analysis was carried out, and a sequential procedure was used to determine the number of factors (k). (See Appendix II.) Starting with a one-factor solution, the number of factors was increased until a chi-square goodness-of-fit test indicated that the k-factor model accounted for the covariances of the observed variables. For the given solution, an orthogonal varimax transformation was applied in order to set the loading of each variable with respect to every factor to be either high or low.

Results

The correlations between the raw scores for the nine memory measures are given in Table 2. Overall, there is a tendency for each measure to correlate positively with most other measures. The only four correlations which failed to reach significance are as follows: (1) between WMS–R-verbal and WRMT-faces ($p > .1$); (2) between D&P-people and D&P-doors ($p < .07$); (3) between D&P-shapes and WRMT-faces ($p < .08$) and (4) between D&P-shapes and D&P-doors ($p < .06$). Although three

[1] Some of these patients have been included in other recent studies carried out by our group. A list of these studies is given in Appendix I.

Table 1. Mean performance of participants on the three standardized tests of memory

	WMS–R					WRMT		D&P			
	Verbal	Visual	General	Attention	Delay	Words	Faces	People	Doors	Shapes	Names
Mean scaled score	83.74	93.62	84.28	98.06	77.24	8.22	7.02	5.12	6.02	5.84	7.48
SD	16.37	18.62	17.97	19.00	22.15	4.11	3.74	2.97	3.40	3.92	3.68

Note. All scores are age-scaled scores.

Table 2. Pearson product moment correlations among the raw scores of the nine memory measures

	WMS–R-visual	WMS–R-delay	WRMT-words	WRMT-faces	D&P-people	D&P-doors	D&P-shapes	D&P-names
WMS–R-verbal	.497***	.754***	.548***	.162	.502***	.301*	.291*	.274*
WMS–R-visual		.692***	.377**	.423**	.345**	.564***	.367**	.392**
WMS–R-delay			.623***	.394**	.576***	.491***	.561***	.318*
WRMT-words				.507***	.549***	.334**	.333**	.628***
WRMT-faces					.268*	.741***	.208	.504***
D&P-people						.220	.281*	.354**
D&P-doors							.231	.437**
D&P-shapes								.255*

*$p < .05$; **$p < .01$; ***$p < .0005$, one-tailed.

of these four correlations approach significance, all four involve between which we may expect no significant correlation: both (1) and (2) involve correlations between verbal recall and visual recognition measures, and both (3) and (4) involve correlations between visual recall and visual recognition measures.

Maximum likelihood factor analysis, followed by orthogonal varimax rotation was applied, as described above. The chi-square goodness-of-fit test indicated that the minimum number of factors required to account for the covariance of the data was three ($\chi^2 = 12.68$, $p > .39$). The proportion of variance accounted for by these factors was 0.66. Factor loadings for the three-factor solution are given in Table 3.

Table 3. Rotated factor loadings corresponding to the three-factor solution for scaled scores

	Orthogonal solution			Oblique solution (pattern matrix)		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
WMS–R-verbal	**.728**	.071	.249	**.760**	−.091	.102
WMS–R-visual	**.588**	.468	.059	**.571**	.382	−.125
WMS–R-delay	**.943**	.269	.196	**.975**	.085	−.027
WRMT-words	.435	.147	**.888**	.329	−.020	**.836**
WRMT-faces	.123	**.755**	.386	−.037	**.746**	.282
D&P-people	**.517**	.073	.353	**.510**	−.059	.258
D&P-doors	.247	**.883**	.109	.121	**.888**	−.057
D&P-shapes	**.540**	.128	.090	**.566**	.023	−.036
D&P-names	.104	.388	**.592**	−.032	.334	**.557**

Note. The oblique solution factor loadings have a different scaling from the orthogonal factor loadings and can extend beyond ± 1. High loadings ($> .5$) are in bold.

For the orthogonal solution, a factor loading is the correlation between a given variable and a given factor. We refer to any factor loading above 0.5 as being high. Factor 1 appeared to be a recall factor with high loading from WMS–R-verbal, WMS–R-visual, WMS-delay, D&P-people and D&P-shapes. Factor 2 was a visual recognition factor, with a high loading from WRMT-faces and D&P-doors. Factor 3 was a verbal recognition factor, with a high loading from WRMT-words and D&P-names.

Given the large intercorrelations between individual subtests, an oblique solution was obtained using the oblimin factor rotation method. The three-factor oblique solution can also be seen in Table 3. The oblique solution shows a pattern of factor loadings very similar to that of the orthogonal solution. This suggests that the factors found using orthogonal varimax rotation were not an artefact of orthogonality imposed by the varimax method of rotation.

The factor analysis of the age-scaled scores from the WMS–R, WRMT and D&P tests indicated a dissociation between recall and recognition measures, and between verbal recognition and visual recognition measures. The analysis, however, provided no indication of a dissociation between verbal and visual recall. It is possible that the failure to identify this dissociation is a reflection of the composite nature of some of the measures used. Specifically, the WMS–R-delay score comprises delayed measures of both visual and verbal free recall, and visual and verbal cued recall; the WMS–R-visual comprises measures of visual recognition, visual free recall and visual cued recall; and the WMS–R-verbal scores comprises measures of verbal free recall and verbal cued recall. In order to determine whether a more coherent factor structure would be observed using single memory measures, the factor analysis was repeated using the WMS–R subtest scores (Figural Memory, Visual Paired Associates I, Visual Paired Associates II, Visual Reproduction I, Visual Reproduction II, Logical Memory I, Logical Memory II, Verbal Paired Associates I, Verbal Paired Associates II) together with the corresponding raw scores from the two WRMT subtests and the four D&P subtests. Since these measures are not age-corrected, age was entered into the factor analysis as a separate variable. No outliers were observed (all $z < 3.00$). The 16 variables were subjected to maximum likelihood factor analysis plus varimax rotation, using the procedure described above. This yielded a four-factor solution ($\chi^2 = 78.41, p > .07$) which can be seen in Table 4. Since this solution gave a p-value greater than our threshold of .05, H_k was accepted. It should be noted, however, that this solution is only marginally significant and the results should be viewed tentatively. An attempt to derive a five-factor solution failed since no local minimum was found during the maximum likelihood iterative process.

In the four-factor solution of the individual scores, the proportion of the variance accounted for by the four factors was .62. As in the three-factor solution of the age-scaled scores, a verbal recognition factor (Factor 4) emerged, with a high loading from WMRT-words and D&P-names. The remaining three factors were less clear-cut. Factor 1 appeared to be a recall factor with a high loading from subtests addressing visual and verbal recall, particularly when tested after a delay (Visual Reproduction II, Logical Memory II, Verbal Paired Associates II, D&P-people and D&P-shapes). Factor 2 appeared to be a visual recognition factor with a high loading from Figural Memory and D&P-doors. However, the loading of WRMT-faces on this factor (.472) was below .5, and there was a tendency for tests of visual recall to have a high loading on this factor (Visual Reproduction II .532). Factor 3 appeared to be a verbal recall factor with high loadings from Logical Memory I, Logical Memory II and Verbal Paired Associates I, but only low loadings from the two remaining verbal recall measures (Verbal Paired Associates II and D&P-people). An oblique solution was obtained by applying the oblimin rotation method, which yielded a similar pattern of factor loadings. The main difference between the orthogonal and oblique solutions was that Visual Reproduction II had a high loading on both the visual recognition factor and the delayed recall factor in the orthogonal solution, whereas it had a high loading only on the delayed recall factor in the oblique solution. In addition, Factor 3 appeared to be a cleaner indication of immediate verbal memory with high loadings restricted to WMS–R Logical Memory I and Verbal Paired Associates I in the oblique solution.

Table 4. Rotated factor loadings corresponding to the four-factor orthogonal solution for subtest scores

	Orthogonal solution				Oblique solution (pattern matrix)			
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 1	Factor 2	Factor 3	Factor 4
WMS–R Figural Memory	.138	**.645**	.124	.036	.106	**.599**	.111	−.011
WMS–R Visual Paired Associates I	.248	.409	.453	.248	.127	.279	.420	.156
WMS–R Visual Paired Associates II	.356	.497	.227	.466	.303	.263	.085	.424
WMS–R Visual Reproduction I	.423	.472	.086	.151	.472	.280	−.050	.084
WMS–R Visual Reproduction II	**.761**	**.532**	.200	.114	**.869**	.222	−.018	−.030
WMS–R Logical Memory I	.344	.231	**.905**	.088	.136	.121	**.943**	−.116
WMS–R Logical Memory II	**.673**	.314	**.553**	.013	**.669**	.077	.437	−.190
WMS–R Verbal Paired Associates I	.245	.181	**.545**	.299	.097	.041	**.515**	.201
WMS–R Verbal Paired Associates II	**.649**	.226	.362	.330	**.662**	−.089	.164	.206
WRMT-words	.442	.132	.369	**.768**	.346	−.209	.165	**.730**
WRMT-faces	.147	.472	.003	.445	.110	.314	−.106	.471
D&P-people	**.728**	−.005	.376	.285	**.772**	−.344	.157	.145
D&P-doors	.127	**.613**	.124	.292	.061	**.509**	.072	.279
D&P-shapes	**.554**	.422	.128	.093	**.635**	.194	−.034	−.008
D&P-names	.043	.216	.217	**.765**	−.118	.027	.119	**.813**
Age	−.048	.000	−.302	−.075	.042	.023	−.327	−.023

Note. The oblique solution factor loadings have a different scaling from the orthogonal factor loadings and can extend beyond ±1. High loadings (> .5) are in bold.

Discussion

Factor analysis of the age-scaled scores from the WMS–R, WRMT and D&P, yielded a three-factor solution with the three factors corresponding to recall, visual recognition and verbal recognition. The orthogonal and oblique solutions gave very similar results. Factor analysis of the individual subtest scores yielded a four-factor solution which was only marginally significant in accounting for the covariance of the data. This four-factor solution appeared to indicate the same visual recognition and verbal recognition factors, together with two recall factors: a delayed visual/verbal recall factor and a further verbal recall factor.

In terms of recognition memory, there was a clear partitioning of the age-scaled scores between verbal and visual memory factors. WRMT-words and D&P-names showed a high loading on the verbal recognition factor, and WRMT-faces and D&P-doors showed a high loading on the visual recognition factor. WMS–R-visual, which is a composite score comprising both visual recall and visual recognition measures, also showed a relatively high loading on this factor (.468).

In terms of recall, the age-scaled scores showed no evidence of partitioning between verbal and visual memory factors. One possible explanation for this is that some of the measures used in the factor analysis of the age-scaled scores were composite measures. However, a second factor analysis using the individual subtest scores yielded a four-factor solution which again provided no evidence for a dissociation between verbal and visual recall.

In summary, there is evidence for a dissociation between recall and recognition when applied to both the age-scaled scores and the individual subtest scores. Furthermore, there is evidence for a dissociation between visual and verbal recognition, but not between visual and verbal recall. The dissociation between recall and recognition is consistent with the views of Aggleton and Brown (1999) who proposed a distinction between recall processes which depend upon the hippocampal system, and recognition processes which are independent of the hippocampus. The dissociation between verbal recognition and visual recognition is consistent with the hemispheric lateralization of verbal and visual function. There is much evidence to indicate that, in most people, verbal processes are dealt with preferentially by the left hemisphere, and non-verbal processes are dealt with preferentially by the right hemisphere. More specifically, there is evidence that left temporal lobe damage disrupts verbal recognition whereas right temporal lobe damage disrupts visual recognition (Glosser *et al*., 1998; Morris *et al*., 1995; Warrington, 1984).

We consider four explanations as to why no distinct visual and verbal *recall* factors were identified. First, the data sample is too small. This explanation can only be assessed by further factor analysis employing a larger data set. It should be noted, however, there was no trend for a dissociation between verbal and visual recall in our sample.

Secondly, some of the measures used in the factor analysis (WMS–R immediate and delayed measures) are based on tests involving identical materials. Immediate and delayed performance levels based on identical materials are likely to be highly correlated, and may produce spurious results which mask a dissociation between verbal and visual factors. Two further factor analyses were therefore carried out, one using the immediate WMS–R measures and the other using the delayed WMS–R measures. In both cases, the WMS–R measures were used together with age, and the raw WRMT and D&P measures included in the analysis of individual subtest scores. These two analyses produced essentially the same factor structure as the overall scaled-score analysis. Both analyses yielded a three-factor solution (immediate: $\chi^2 = 32.84$, $p > .47$; delayed: $\chi^2 = 38.90$, $p > .22$) indicating distinct visual and verbal recognition factors, together with a general recall factor. Thus, the failure to identify separate visual and verbal recall factors cannot be accounted for by the inclusion of tests involving identical materials.

Thirdly, visual and verbal recall factors are not distinct. Since the four-factor solution of the individual scores gave no suggestion of a dissociation between verbal and visual recall factors, it is logically possible that these two factors do not dissociate. This view is consistent with other factor analytical studies which failed to show a verbal/visual dissociation (Roth, Conboy, Reeder, & Boll, 1990; Smith, Malec, & Ivnik, 1992), although there are studies which have suggested a dissociation (Moore & Baker, 1997).

Fourthly, visual and verbal recall tests are impure measures of visual and verbal memory processing. One criticism levelled at many visual recall tests, including WMS–R Visual Reproduction, is that they may allow verbalization, and consequently verbal encoding. Conversely, it seems plausible that performance on verbal tasks (e.g. WMS–R Logical Memory) may be facilitated by the use of imagery and visual encoding. It seems likely that this dual coding is of particular relevance to recall because dual encoding provides additional contextual information critical to recollection upon which recall is thought to depend (Mandler, 1980). In contrast, recognition responses are thought to rely to a greater extent on familiarity judgments. It seems likely that dual encoding provides less benefit to recognition performance because familiarity judgments allow less scope for influence by dually encoded information. Visual and verbal recognition factors are consequently easily dissociable, whereas the dissociation of visual and verbal recall factors depends much more strongly on the extent to which the test materials have been dually encoded. Visual and verbal recall factors may be distinct but test measures typically employed, including those in the current study, fail to allow these factors to be separated because verbal and visual materials are so often subject to dual encoding.

Although the current study did not identify separate visual and verbal recall factors, it did provide preliminary evidence of a dissociation between immediate and delayed recall. The four-factor solution of the individual subtest scores identified a visual and verbal delayed recall factor and a further verbal recall factor. The visual and verbal delayed recall factor had high loadings from three of the four WMS–R delayed measures (Visual Reproduction II, Logical Memory II, Verbal Paired Associates II) together with D&P-people and D&P-shapes. Although these two D&P tests are not really 'delayed' measures, they require participants to recall information after presentation of several stimuli, in contrast to WMS–R Visual Reproduction I in which participants are tested immediately after presentation of each item. The additional verbal recall factor identified by the four-factor solution had high loadings from Logical Memory I and Verbal Paired Associates I, suggesting that this factor may reflect immediate verbal memory. Although there is independent evidence that the WMS–R factor structure indicates separable immediate memory and delayed recall components (Bowden *et al*., 1997; Roth *et al*., 1990; Woodard, 1993), the present four-factor results should be viewed tentatively because this four-factor solution (the only valid solution obtainable) was only marginally significant, and needs replication.

No control participants were included in the current study because they are likely to have performed at ceiling on at least some of the memory measures (e.g. WRMT), making factor analysis impractical. If these ceiling effects could be avoided, then each factor identified by factor analysis should be an independent Gaussian source of variability in performance on memory tasks across participants. These factors presumably correspond to the efficiency with which specific brain systems function. In control participants, this functional efficiency is presumably determined only by intrinsic genetic and environmental influences, whereas functional efficiency of brain systems in patients is also subject to the extrinsic influence of brain lesions. It is possible that lesions provide an influence that affects the efficiency of different brain systems independently, in a way that intrinsic influences related to genes and the environment do not. If this is so, then factor analysis of patients may identify more factors than factor analysis of normal participants. A similar argument is made by Millis and colleagues (Millis, Malina, Bowers, & Ricker, 1999). In considering the factor structure of the Wechsler Memory Scale–Third Edition (WMS–III; Wechsler, 1997), they suggest that 'components of memory may vary as a function of cerebral compromise and, thus, changing a test's factor structure from one group to another' (Millis *et al*., 1999, p. 91). There is, therefore, a need to check whether factor analysis of normal participants identifies the same factors as those found in the present study of brain damaged patients.

Conclusion

Factor analysis of the WMS–R (verbal, visual, delay), the WRMT (words, faces) and the D&P (people, doors, shapes, names) scaled scores can be interpreted in terms of a three-factor solution allowing memory performance to be fractionated into a combined visual/verbal recall component and separate visual and verbal recognition components. Factor analysis of the individual subtest scores provides a marginally significant four-factor solution. In addition to the separable visual and verbal recognition factors, this solution suggests that there may be separate factors corresponding to verbal immediate recall and verbal/visual delayed recall. Neither factor analyses provided evidence for distinct visual and verbal recall components.

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Appendix I

Patients whose data have contributed to the current factor analysis have previously been reported in the following papers:

Broks, P., Young, A. W., Maratos, E. J., Coffey, P. J., Calder, A. J., Isaac, C. L., Mayes, A. R., Hodges, J. R., Montaldi, D., Cezayirli, E., Roberts, N., & Hadley, D. (1998). Face processing impairments after encephalitis: Amygdala damage and recognition of fear. *Neuropsychologia*, *36*, 59–70.

Downes, J. J., Holdstock, J. S., Symons, V., & Mayes, A. R. (1998). Do amnesics forget colours pathologically fast? *Cortex*, *34*, 337–355.

Holdstock, J. S., Mayes, A. R., Cezayirli, E., Aggleton, J. P., & Roberts, N. (in press). A comparison of egocentric and allocentric spatial memory in medial temporal lobe and Korsakoff amnesics. *Cortex*.

Holdstock, J. S., Mayes, A. R., Cezayirli, E., Isaac, C., Aggleton, J. P., & Roberts, N. (in press). A comparison of egocentric and allocentric spatial memory in a patient with selective hippocampal damage. *Neuopsychologia*.

Isaac, C. L., Holdstock, J. S., Cezayirli, E., Roberts, J. N., Holmes, C. J., & Mayes, A. R. (1998). Amnesia in a patient with lesions limited to the dorsomedial thalamic nucleus. *Neurocase*, *4*, 497–508.

Isaac, C. L., & Mayes, A. R. (in press). Rate of forgetting in amnesia I: Recall and recognition of prose. *Journal of Experimental Psychology: Learning, Memory and Cognition*.

Isaac, C. L., & Mayes, A. R. (in press). Rate of forgetting in amnesia II: Recall and recognition of word lists at different levels of organisation. *Journal of Experimental Psychology: Learning, Memory and Cognition*.

Mayes, A. R., van Eijk, R., & Isaac, C. L. (1995). Assessment of familiarity and recollection in the false fame paradigm using a modified process dissociation procedure. *Journal of the International Psychological Society*, *1*, 469–482.

Appendix II

Factor analysis: Choosing the number of factors

In order to test the hypothesis, H_k, that a k-factor model accounts for the covariance of the observed variables, we estimate the parameters of the model with $k = k_1$. If the chi-square test statistic is not significant at the chosen significance level (0.05) then H_k is accepted with $k = k_1$. If, however, the test statistic is significant, we repeat the fitting procedure with $k = k_1 + 1$. The procedure is continued, increasing k in steps of one, until H_k is accepted for some value of k (Everitt, 1984).