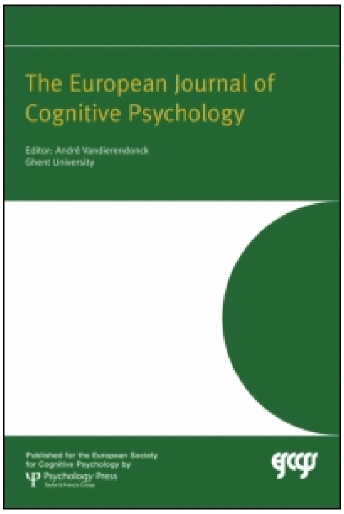

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Familiarity supports associative recognition memory for face stimuli that can be unitised: Evidence from receiver operating characteristics

Theodor Jäger [ab]; Axel Mecklinger [a]
[a] Department of Psychology, Experimental Neuropsychology Unit, Saarland University, Saarbruecken, Germany [b] Department of Neurology, Universitätsklinikum Mannheim, University of Heidelberg, Mannheim, Germany

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Familiarity supports associative recognition memory for face stimuli that can be unitised: Evidence from receiver operating characteristics

Theodor Jäger

Department of Psychology, Experimental Neuropsychology Unit, Saarland University, Saarbruecken, and Department of Neurology, Universitä tsklinikum Mannheim, University of Heidelberg, Mannheim, Germany

Axel Mecklinger

Department of Psychology, Experimental Neuropsychology Unit, Saarland University, Saarbruecken, Germany

According to dual-process models, associative recognition memory mainly relies on recollection without benefiting from familiarity. This study investigates the circumstances under which familiarity may support associative recognition judgements by comparing recognition memory for arbitrarily paired items (i.e., pairs of face stimuli depicting two *different* persons; interitem associations) with recognition memory for pairs of items that are highly overlapping and can be unitised into a coherent whole (i.e., pairs of physically different but very similar face stimuli depicting the *same* person; intraitem associations). Estimates of familiarity and recollection were derived from receiver operating characteristics. Consistent with the hypothesis that familiarity is able to support associative recognition memory, but only when the to-be-associated stimuli can be unitised, results from two experiments revealed higher familiarity estimates for intra- compared to interitem associations. By contrast, recollection for recombined pairs was higher for inter- compared to intraitem associations. We propose a hypothetical model on how intraitem associations may benefit from familiarity.

Recognition memory refers to experiences in which individuals become aware that a particular item or information has already been encountered in the

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Correspondence should be addressed to Theodor Jäger, Department of Psychology, Experimental Neuropsychology Unit, Building A 2.4, University Area, D-66123 Saarbrücken, Germany. E-mail: t.jaeger@gmx.ch

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past. A considerable body of evidence suggests that recognising is subserved by two (rather than one) qualitatively distinct and independently acting processes, which are termed *familiarity* and *recollection*, respectively (e.g., Aggleton & Brown, 1999, 2006; Diana, Reder, Arndt, & Park, 2006; Jacoby, 1991; Mandler, 1980; Norman & O'Reilly, 2003; Yonelinas, 2002). Familiarity is assumed to be a fast-acting memory process of continuously varying strength, whereby a previously encountered item is perceived as "reminding us of something" without retrieving further contextual information (e.g., "This woman looks very familiar to me but I can't remember where I met her!"; see Yovel & Paller, 2004). By contrast, recollection refers to a threshold-like process, which, once successful, leads to the conscious and effortful retrieval of an item plus further contextual details, such as the spatiotemporal context of an episode or other related information (e.g., "I have seen this man yesterday jogging through the park!").

Importantly, it is assumed that familiarity and recollection cannot contribute equally to all types of recognition memory tasks. Specifically, the dual-process view predicts differential contributions of familiarity and recollection to tests of *item* and *associative recognition memory*, respectively (e.g., Yonelinas, 2001a, 2002). Whereas item recognition memory involves judgements about the old/new status of single items, associative recognition memory typically requires participants to retrieve particular pairings of items in order to distinguish between *intact* pairs (i.e., pairs of test stimuli presented identically as in the study phase) and *recombined* pairs (i.e., pairs of test stimuli that were studied but not presented as pairs in the study phase). The dual-process account proposes that familiarity as well as recollection support item recognition, as stimuli can be judged "old" if participants recollect information about the study episode or if an item is experienced as sufficiently familiar. By contrast, only recollection but not familiarity is assumed to support associative recognition memory, as individual stimuli are equally familiar in both intact and recombined pairs and thus familiarity cannot be diagnostic to distinguish between them. Therefore, accepting intact or rejecting recombined pairs is thought to require recollection for the particular pairings of stimuli. A considerable body of literature supports this suggestion by revealing an important role of recollection in associative recognition memory tasks with little contributions of familiarity (e.g., Donaldson & Rugg, 1998, 1999; Hockley & Consoli, 1999; Rotello & Heit, 2000; Rotello, Macmillan, & van Tassel, 2000; Turriziani, Fadda, Caltagirone, & Carlesimo, 2004; Yonelinas, 1997, 1999).

However, since recently there is a growing interest into the role of familiarity for associative recognition memory (Aggleton & Brown, 2006). In fact, some findings challenge the view that familiarity cannot be supportive for associative recognition memory. These studies indicate that familiarity is diagnostic for associative recognition judgements given that the to-be-associated stimuli can be encoded as a coherent whole or as a "unitised" representation. *Unitisation* refers to a process by which two or more previously separate items become represented as a single unit (Graf & Schacter, 1989). Initial evidence for this suggestion is reported by Yonelinas, Kroll, Dobbins, and Soltani (1999). In this study, participants were required to memorise schematic faces and to discriminate repeated faces from faces that contained studied but rearranged features (e.g., hair, eyes, nose, head shape). The faces were either presented upright—by this allowing unitisation of facial features—or upside down. Estimates of familiarity derived from receiver operating characteristics (ROCs; see later) indicated that familiarity significantly contributed to recognition judgements for associations of facial features when the features could be unitised into a coherent whole, i.e., in the upright but not in the upside down condition.

ROCs examined by Quamme (2004) revealed greater contributions of familiarity for associative recognition memory for pre-experimentally existing compound words (e.g, sea-food) compared to unrelated word pairs (e.g., bullet-food). In addition, Quamme applied an encoding manipulation in which participants either encoded unrelated word pairs as if the two words referred to a single object (compound condition) or memorised word pairs while judging each word of the word pairs, separately (separate condition). Results revealed substantially higher contributions of familiarity (as well as recollection) in the compound condition relative to the separate condition even though the same stimuli were used in both conditions. However, it should be noted that there were substantial performance differences between conditions, which may have influenced the shape of the ROCs as well.

Similar findings were obtained by Giovanello, Keane, and Verfaellie (2006), who applied the remember/know procedure (Tulving, 1985) and found substantially higher contributions of familiarity to associative recognition memory for pre-experimentally existing compound words (e.g., land-scape) compared to unrelated word pairs (e.g., telephone-trumpet). Finally, Quamme, Yonelinas, and Norman (2007) applied a task in which unrelated word pairs were either encoded as separate units within sentences (sentences condition) or as if the two words of each word pair referred to a single object (compound condition). In this paradigm, three hypoxic patients previously determined to have impaired recollection together with intact familiarity showed a larger deficit in the sentences condition than in the compound condition compared to age-matched controls. This result indicates that intact familiarity processes supported associative recognition memory only given that the to-be-associated stimuli were unitised during encoding.

A few studies measuring event-related brain potentials (ERPs) have revealed further evidence that familiarity can support associative recognition memory in certain situations. Importantly, ERPs are thought to provide dissociable indices of familiarity and recollection: An early, frontally pronounced ERP old/new effect is suggested to be the putative neural correlate of familiarity, whereas a somewhat later, parietally pronounced ERP old/new effect is believed to reflect recollection (e.g., Curran, 2000; Mecklinger, 2006; Rugg & Yonelinas, 2003; Woodruff, Hayama, & Rugg, 2006).

Opitz and Cornell (2006) used an encoding manipulation that required participants to memorise words while judging which word out of four did not fit in the context of the other three words (associative condition) or while judging which word out of four denotes the smallest object (relational condition). During the test phase, three of the four studied words were repeated as single item retrieval cues. Results revealed an early frontal old/new effect in the associative but not in the relational condition. In addition, the early frontal old/new effect in the associative condition was enhanced for those words for which the complete word triplet could be recognised. These results are consistent with the view that familiarity arises during the retrieval of pre-experimentally existing semantic associations. In another ERP study, Rhodes and Donaldson (2007) obtained an early frontal old/new effect for associative recognition of word pairs rated to reflect unitised representations (e.g., traffic-jam) but not for word pairs rated to reflect unitised representations to a low degree (e.g., prince-duke).

Finally, a recent ERP study conducted in our lab provided further evidence for the "familiarity supports associative recognition memory" view using faces as stimulus materials (Jäger, Mecklinger, & Kipp, 2006). Participants memorised pairs of face stimuli depicting two *different* persons (interitem condition) or pairs of physically different but very similar face stimuli rated to be perceived as depicting the *same* person (intraitem condition). Given that recollection supports associations between arbitrarily paired information, we expected the interitem condition to elicit a parietal old/new effect during associative recognition of face pairs. Conversely, assuming that two photographs showing the same person can be unitised into a representation of a single person, we expected an early frontal old/new effect during associative recognition in the intraitem condition. Note that these associations between unitisable stimuli were formed during the experiment rather than being pre-experimentally existing unitised associations as in most of the aforementioned studies (cf., Giovanello et al., 2006; Opitz & Cornell, 2006; Quamme, 2004; Rhodes & Donaldson, 2007). As the electrophysiological data turned out to reflect the expected pattern of results, this study provided further evidence that in addition to recollection, also familiarity can subserve associative retrieval. While recollection seems to enable the retrieval of associations between arbitrarily paired items, familiarity may support associative recognition memory in situations where the to-be-associated items can be unitised.

In the present study, we aimed at further examining the circumstances under which familiarity can support associative recognition memory. We were also interested in whether the aforementioned ERP evidence (Jäger et al., 2006) would receive cross-validation through the application of alternative operational definitions of familiarity and recollection (cf. e.g., Yonelinas, 2001b; Yonelinas, Otten, Shaw, & Rugg, 2005 vs. Woodruff et al., 2006, for comparisons of alternative measures of familiarity and recollection using the same paradigm). To examine these issues, we applied modified versions of the task employed in Jäger et al. and used the behavioural measures to derive estimates for familiarity and recollection. Specifically, participants memorised pairs of faces and made intact/recombined judgements about face pairs during the test phase.

To investigate the relative contributions of familiarity and recollection, we examined the shapes of associative ROCs (e.g., Yonelinas, 1994, 1997). ROCs plot the proportion of hits and false alarms across a number of response criteria. The left-most point on the ROC function is created by relating hits and false alarms for the most strict response criterion, including only the most confident responses. The remaining points on the ROC reflect continuously more relaxed response criteria. With regard to the specific shape of an ROC, if performance relies exclusively on familiarity, then the dual-process model predicts a curvilinear ROC that is symmetrical along the diagonal (see, e.g., Yonelinas, Dobbins, Szymanski, Dhaliwal, & King, 1996). This shape emerges when the response criterion is continuously relaxed for familiarity distributions of "old" and "new" items that are assumed to be Gaussian and of equal variance (e.g., Yonelinas, 1994). By contrast, if performance relies exclusively on recollection, which is assumed to be a threshold process with items falling above a given threshold being recollected and items falling below the threshold not being recollected, then the ROC should be linear and approach the point 1,1 of the coordinate system. As recollection is associated with high-confidence responses, increasing levels of recollection shift the lower left part of the ROC upward on the y-axis, resulting in an asymmetrical ROC curve. Finally, if performance relies on both familiarity and recollection, the dual-process model predicts an ROC that is curvilinear and asymmetrical along the diagonal, because recollection pushes the ROC up at its lower left part, by this rendering the curvilinear ROC asymmetrical along the diagonal.

Capitalising on these characteristics of ROC curves, in the present study we obtained estimates of familiarity and recollection from empirically derived ROC points. We also examined ROCs plotted in z-space (i.e., z-ROCs), because if z-ROCs turn out to be linear, recognition memory performance can be regarded as mainly relying on familiarity (Wixted, 2007; Yonelinas, 1997; Yonelinas et al., 1996). By contrast, nonlinear (i.e., U-shaped) z-ROCs are predictive for the additional contribution of a threshold-like recollection process. Consistent with our hypotheses reported above, we thus predicted a nonlinear (i.e., U-shaped) z-ROC for the interitem condition, whereas a linear z-ROC was expected for the intraitem condition. Moreover, familiarity estimates as derived from ROC curves were predicted to be higher in the intra- than the interitem condition. Conversely, in light of our previous findings (Jäger et al., 2006), recollection estimates were expected to be higher in the inter- than in the intraitem condition.

EXPERIMENT 1

Method

Participants

Twenty, mostly undergraduate students (10 females) provided informed consent to participate in return for a cash payment of 8 Euro/hour. Mean age of participants was 22.95 years ($SD = 2.78$, range = 19–30). Participants were screened for conditions of neurological or psychiatric disorders using a questionnaire, which revealed no such conditions besides for one male participant reporting a history of attention-deficit hyperactivity disorder.

Materials and procedure

Face stimuli. The face stimuli used in this study were the same as those of Jäger et al. (2006), except that we did not include completely novel face stimuli. The face stimuli were greyscale photographs of unfamiliar and emotionally neutral faces taken from a picture database (Jäger, Seiler, & Mecklinger, 2005). The database contains continua of *morphed faces*, i.e., sets of two different "parent" faces that were gradually transformed into each other resulting in intermediate morphed faces. Of the available morph-continua, we selected the 0%, 35%, 70%, and 100% morphed faces to be used in the intraitem condition. The four faces of each morph-continuum were rated in a separate study for similarity on physical and identity dimensions (Jäger et al., 2005) and we selected 60 morph-continua in which faces of neighbouring morph-degrees were rated as clearly physically discriminable but still representing the same person to a high degree. Additionally, we selected a further 240 unmodified face stimuli from the same database to form 120 face pairs for the interitem condition. Note that morphed and unmodified face stimuli were carefully matched in physical characteristics such as picture sharpness (see Jäger et al., 2005). The face stimuli had a size of 257 pixels (9.07 cm) in width and 379 pixels (13.37 cm) in height, with an image resolution of 72 pixels/inch.

Associative recognition memory task. Participants performed 25 blocks of an associative recognition memory task, each consisting of a study phase, a distractor task, and a test phase. In 15 blocks, participants encoded face pairs representing two different, gender-matched persons (i.e., interitem condition). In 10 blocks, participants encoded face pairs consisting of faces that were judged to represent the same person to a high degree (i.e., intraitem condition). This was achieved by creating face pairs either consisting of a 35% and a 0% morphed face, or consisting of a 100% and a 70% morphed face. Participants were instructed that they would be presented with study–test blocks in which two photographs have to be memorised that either show two different persons or twice the same person on physically different pictures (instruction, translated from German into English: "In this task, you have to memorise face pairs that either show two different persons or the same person twice on different photographs.").

In each *study phase* (see Figure 1A for illustration), participants memorised a total of 12 or 8 face pairs for the intra- and the interitem condition, respectively. We used slightly longer blocks in the intraitem condition because performance revealed to be higher in the intraitem condition when equal numbers of study trials have to be learned in both conditions (Jäger et al., 2006). Individual photographs of each face pair were presented sequentially in the centre of the screen. Every novel face pair was announced by "next pair" (1500 ms), then a fixation cross appeared (1000 ms), and the first face of a given face pair was presented (700 ms), followed by a fixation cross (1500 ms). Then, the second face of the face pair was presented (700 ms), again followed by a fixation cross (1500 ms), and a blank screen (200 ms). Thereafter, the next study trial started. The face pairs in the *interitem condition* depicted two arbitrarily paired, but gender-matched persons. Half of the face pairs in the *intraitem condition* were a 35% and a 0% morphed face (presented in this order), whereas the other half were a 100% and a 70% morphed face (presented in this order) from the same morph-continua.

Participants were instructed to memorise the pairings of photographs for a subsequent associative recognition memory test. Additionally, participants were required to judge the gender of each face stimulus by a buttonpress. The sequence of study trials was pseudorandomly intermixed with the constraints that pairs with same gender did not appear more than twice consecutively, that pairs belonging to the same morph-continua were separated by at least three intervening study trials, and that in the interitem condition, study trials in which the faces used to form recombined pairs appeared were separated by at least three intervening study trials. After the study phase, a *distractor task* was performed for 20 s in which participants had to count aloud backwards in steps of 6, 7, 8, or 9 from a randomly presented number between 100 and 200.

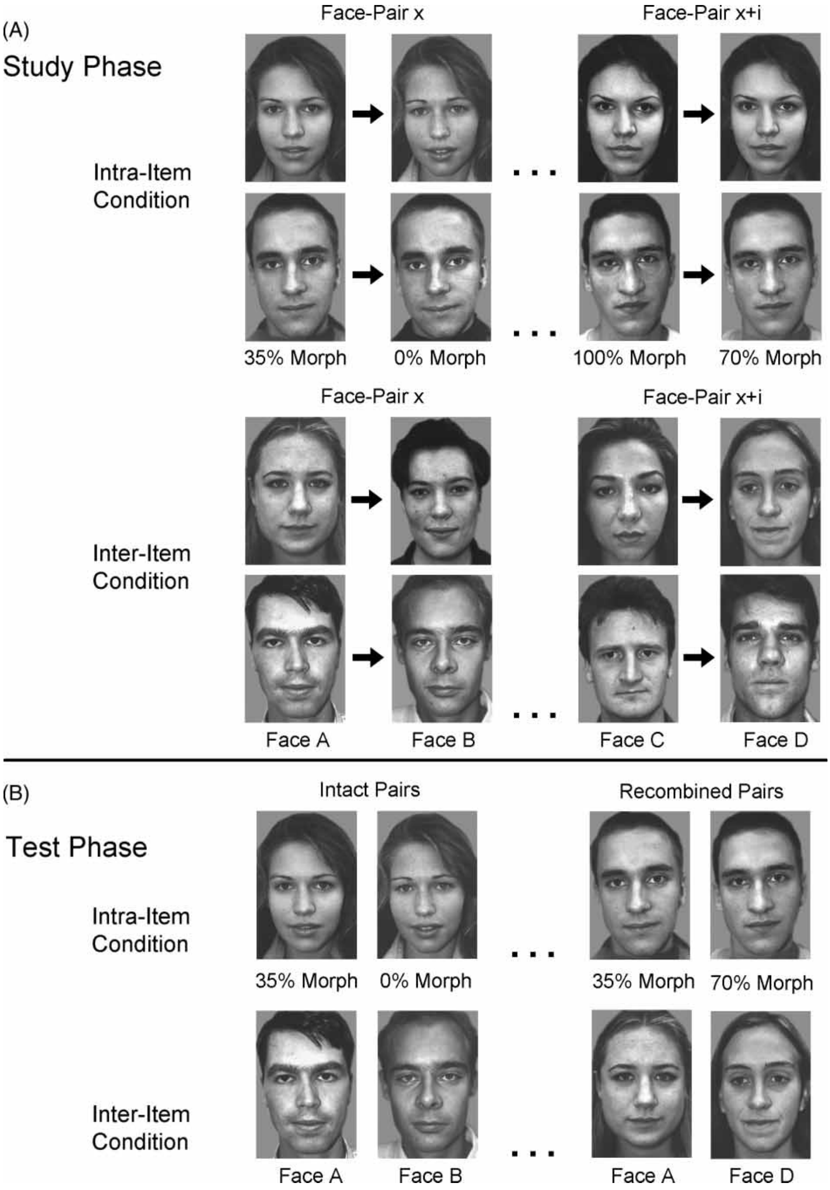

Figure 1. Illustration of the study and the test phase of the associative recognition memory task (the task as used in Experiment 1 is shown).

In each *test phase* (see Figure 1B for illustration), half of the trials consisted of *intact* and *recombined* face pairs, respectively. There were six test trials in the intraitem condition and four test trials in the interitem condition. First, a fixation cross appeared (1000 ms), followed by a pair of face stimuli presented side by side. To derive ROC curves, participants were required to judge the face pairs as "intact" or "recombined" on a 6-point confidence scale (instruction, translated from German into English: "During the test phase, you have to decide whether or not the two faces of each face pair had been paired during the study phase"), from "sure intact" (1) to "sure recombined" (6). Responses 1–3 were explained to reflect "intact" responses of different confidence levels. Responses 4–6 were explained to reflect "recombined" responses of different confidence levels. The face pairs stayed on the screen until a response was made or for maximally 2500 ms. In the intraitem condition, intact face pairs consisted of 35% and 0% morphed faces, whereas recombined face pairs consisted of 35% and 70% morphed faces (see Figure 1B). By this, intact and recombined face pairs both consisted of faces that differed by a morph-degree of 35% and thus intact/recombined decisions could not be made solely on the basis of differences in face similarity. In the interitem condition, intact face pairs consisted of faces that were paired in the study phase, whereas recombined face pairs were formed by recombining two studied faces that were not presented as pairs during the study phase (see Figure 1B). For both conditions, faces initially paired with the faces used for the recombined pairs were excluded from the test phase. Before the next test trial started, a blank screen was presented for 1000 ms. The test trials were pseudorandomly intermixed with the constraints that intact or recombined faces and pairs with same gender did not appear more than twice consecutively.

Across all intra- and interitem condition blocks, half of the face pairs were female and male, respectively. Moreover, for both intact and recombined face pairs, the assignment of the first study faces and the second study faces to the left or right side of the screen within test face pairs was counterbalanced within and across participants. The random assignment of the particular face pairs to the 25 blocks was kept constant across all participants, but the sequence of blocks was pseudorandomly intermixed for every participant with the constraints that there were no more than two consecutive blocks from the same condition and that one half of participants commenced with an intra- or an interitem block, respectively. Before starting the experiment, participants performed four practice blocks of the task using faces that did not appear during the subsequent 25 blocks. Responses were given on the computer keyboard, and the mapping of response type to response keys was counterbalanced across participants, for both the study phase and the test phase.

Associative recognition memory performance was measured by the proportion of hits (i.e., the proportion of responses 1–3 for intact pairs), the proportion of correct rejections (i.e., the proportion of responses 4–6 for recombined pairs), the area under the ROC curve (A_z; i.e., a bias-free measure of recognition sensitivity; cf. Quamme et al., 2007), and recognition decision times for hits and correct rejections.

ROC analysis

To test our specific predictions regarding the contributions of familiarity and recollection to associative recognition judgements across conditions, a formal dual-process model including the processes of familiarity and recollection was fitted to the empirically obtained ROC points (i.e., the proportions of hits and false alarms across confidence levels) in order to obtain behavioural estimates of familiarity and recollection (see Arndt & Reder, 2002; Yonelinas, 1999, 2001a; Yonelinas et al., 1996). This model conceptualises familiarity as a Gaussian equal-variance signal-detection process whereby the probability of accepting an item depends upon sensitivity (d', the distance between the means of the old and new distributions, which provides a measure of familiarity) and response criterion (c_i). If performance only relies on familiarity, the probability that an old item's familiarity exceeds the response criterion is $P(\text{“yes”}|\text{old})_i = \Phi(d'/2 - c_i)$ and the probability that a new item is sufficiently familiar to be incorrectly accepted as “old” is $P(\text{“yes”}|\text{new})_i = \Phi(-d'/2 - c_i)$.

By also taking into account the potential contributions of recollection, the model assumes that the probability of a hit is $P(\text{“yes”}|\text{old})_i = R_o + (1 - R_o) * \Phi(d'/2 - c_i)$. This equation reflects the assumption that a hit occurs when an old item is either recollected [i.e., R_o] or accepted on the basis of familiarity given that the item is not recollected [i.e., $(1 - R_o) * \Phi(d'/2 - c_i)$]. Importantly, findings show that in associative recognition memory tasks participants can also sometimes recollect new items as “new” (R_n) (Rotello & Heit, 2000; Rotello et al., 2000). For example, given that face pairs A + B and C + D were encoded, an individual may recollect a recombined pair A + C as “new” (i.e., “recombined”) because he/she can recollect that A was paired with B. Thus, in the formal dual-process model we allowed the possibility that new (i.e., recombined) items can be recollected as “new”. In consequence, false alarms only occur when a new item is sufficiently familiar to be judged as “old” in the absence of recollection that the item is new. Hence, the probability of a false alarm is $P(\text{“yes”}|\text{new})_i = (1 - R_n) * \Phi(-d'/2 - c_i)$. Note that this formal dual-process model also includes the possibility that only one of the processes (i.e., familiarity or recollection) contributes to associative recognition memory, as the process estimates can also have values of zero.

To summarise, the final equations of the applied dual-process model are: $P(\text{“yes”}|\text{old})_i = R_o + (1 - R_o)^*\Phi(d'/2 - c_i)$ and $P(\text{“yes”}|\text{new})_i = (1 - R_n)^*\Phi(-d'/2 - c_i)$. Each point on the ROC is described by these equations. Assuming that memory (i.e., R_o, R_n, and d') remains constant across the ROC and only response criterion c_i varies, then the equations can be used to derive estimates for the parameters of the model. This was done using Microsoft Excel's Solver (see Dodson, Prinzmetal, & Shimamura, 1998) to find the best fitting parameters for the equations by minimising the sum of squared errors between observed and predicted values (cf. Yonelinas et al., 1996).

Results

Study phase performance

Participants accurately judged the gender of both the first and the second faces of each face pair (96.2% and 98.8% correct judgements, respectively). An analysis of variance (ANOVA) examined decision times for gender judgements (see Table 1) using the within-subjects factors of condition (intra- vs. interitem condition) and face (first vs. second face). There was no statistically significant main effect of condition, $F(1, 19) = 4.17$, $p = .055$, but a significant main effect of face, $F(1, 19) = 7.19$, $p = .015$, reflecting faster responses for the second than the first faces. There was also a reliable Condition × Face interaction, $F(1, 19) = 13.27$, $p = .002$, reflecting faster response times for the second study faces in the intra- compared to the interitem condition.

Associative recognition memory performance

Table 1 presents the proportion of hits and correct rejections, the area under the ROC curve (A_z-values), and recognition decision times. The proportion of hits was higher in the intra- than the interitem condition, $F(1, 19) = 34.54$, $p < .001$. Conversely, the proportion of correct rejections was higher in the inter- than the intraitem condition, $F(1, 19) = 9.70$, $p = .006$. Importantly, A_z-values did not differ significantly between conditions and were only slightly higher in the intra- than the interitem condition, $F(1, 19) = 2.66$, $p = .119$, indicating comparable associative recognition memory performance across conditions. Analyses of recognition decision times revealed that hits occurred faster in the intra- than the interitem condition, $F(1, 19) = 13.64$, $p = .002$, whereas no difference in recognition decision times emerged for correct rejections, $F(1, 19) = 2.26$, $p = .149$.

TABLE 1
Study phase and test phase performance and decision times for Experiments 1 and 2

	Experiment 1		*Experiment 2*	
	Intraitem condition	*Interitem condition*	*Intraitem condition*	*Interitem condition*
Decision times for gender judgements, 1st study faces (ms)	729 (38)	734 (39)	–	–
Decision times for gender judgements, 2nd study faces (ms)	656 (49)	699 (52)	–	–
Proportion of hits	0.71 (0.02)	0.57 (0.02)	0.74 (0.03)	0.58 (0.03)
Proportion of correct rejections	0.46 (0.03)	0.55 (0.03)	0.58 (0.02)	0.66 (0.02)
Area under the ROC (A_z)	0.65 (0.03)	0.60 (0.03)	0.72 (0.02)	0.68 (0.02)
Recognition decision times for hits (ms)	1678 (97)	1859 (102)	2002 (108)	2053 (97)
Recognition decision times for correct rejections (ms)	1981 (86)	1907 (89)	2444 (161)	2307 (133)

Standard errors of the means are presented in parenthesis.

ROC analyses

First, we calculated the empirical ROC points for cumulated responses across participants. Observed proportions of hits and false alarms across response criteria are shown in Figure 2 (upper row). Next, *z*-ROC curves were derived from the empirical ROCs and are also shown in Figure 2 (lower row). We then examined the shape of the *z*-ROCs to determine whether they were linear or curvilinear. Because *x*- and *y*-axes in (*z*-)ROCs are arbitrary, *x* was regressed onto *y* in a first regression, and *y* was regressed onto *x* in a second regression (cf. Yonelinas, 1999; Yonelinas et al., 1999). For the interitem condition, both regressions revealed that the *z*-ROC had a significant linear term (first regression: $t = 42.67$, $p = .001$, second regression: $t = 42.32$, $p = .001$), and a marginally significant quadratic term (first regression: $t = 3.07$, $p = .092$, second regression: $t = -3.56$, $p = .071$; cf. Experiment 2 for evidence that these trends truly reflect statistically significant quadratic terms in the interitem condition). Hence, the *z*-ROC for the interitem condition appeared to be curvilinear rather than linear. For the intraitem condition, both regressions revealed that the *z*-ROC had a significant linear term (first regression: $t = 32.23$, $p = .001$, second regression: $t = 18.07$, $p = .003$), but no quadratic term (first regression: $t = 0.69$, $p = .563$, second regression: $t = -0.78$, $p = .518$). Hence, the *z*-ROC for the intraitem condition appeared to be linear rather than curvilinear.

Fitting the dual-process model. In the next step, we fitted the dual-process model as described above to the empirical ROC points. The model

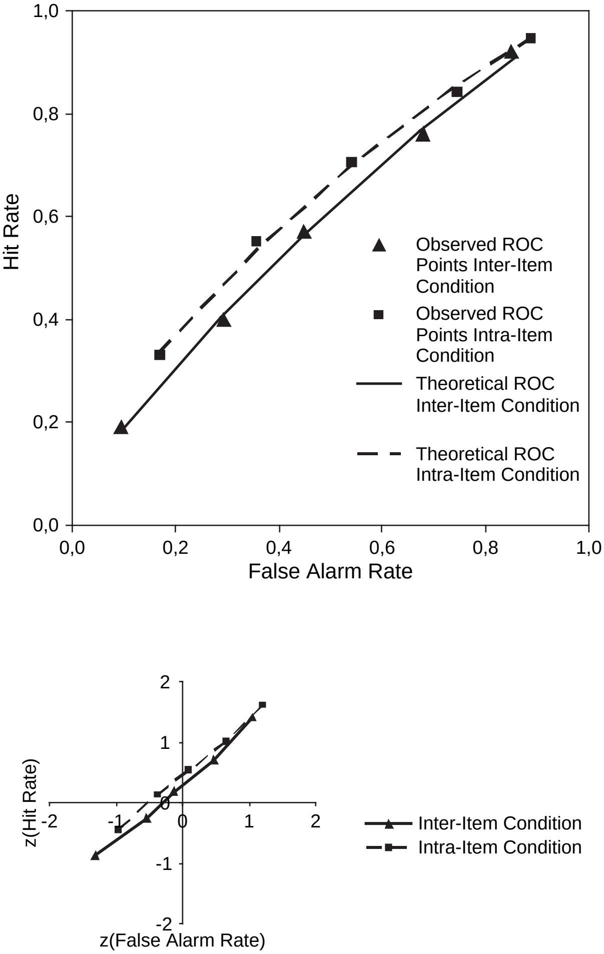

Figure 2. Observed ROC points and fitted theoretical ROC curves (upper row) and corresponding z-ROC curves (lower row) from Experiment 1. Triangles and squares represent (z-transformed) observed proportions of hits and false alarms across response criteria. In the ROC diagram (upper row), lines represent the fitted theoretical ROC curves derived from the formal dual-process model.

was used to derive estimates for familiarity (d'), recollection for intact pairs (R_o), and recollection for recombined pairs (R_n) from both cumulated and individual ROC curves. Model-generated curves for cumulated ROC points are shown as lines in Figure 2 (upper row). As can be seen in Figure 2, there was an accurate fit of the model to the empirical ROC points in both conditions. Minimising the sum of squared error terms for the difference between observed and expected values on the cumulated ROCs revealed the parameter estimates shown in Figure 3. As can be seen in Figure 3,

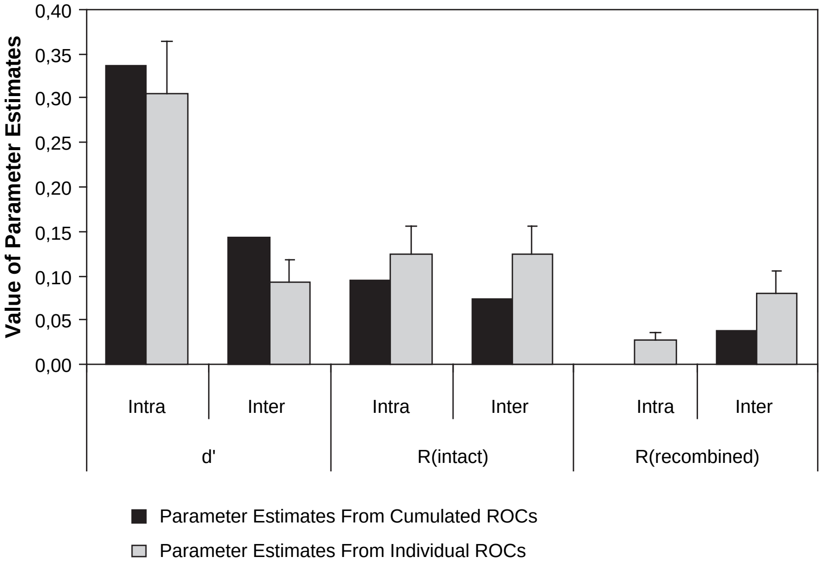

Figure 3. Parameter estimates for cumulated and individual ROCs for Experiment 1. Parameter estimates were derived using the formal dual-process model. Error bars represent standard errors of the means. In the intraitem condition, the value of *R*(recombined) is zero for parameter estimates from cumulated ROCs.

familiarity (d') was substantially higher in the intraitem condition compared to the interitem condition. By contrast, there were only small differences for recollection, such that recollection for intact pairs (R_o) was slightly higher for the intra- than the interitem condition, whereas recollection for recombined pairs (R_n) was slightly higher for the inter- than the intraitem condition.

To test the statistical significance of these observations, the model was next fit to individual ROCs in order to obtain parameters for every participant. The mean estimates for d', R_o, and R_n derived from individual ROCs are presented in Figure 3 and were of comparable magnitude as the parameter values derived from cumulated ROCs. These estimates were subjected to a Condition (inter- vs. intraitem condition) × Estimate (d', R_o, R_n) ANOVA, which revealed significant main effects of condition, $F(1, 19) = 4.92$, $p = .039$, and of estimate, $F(2, 38) = 12.24$, $p < .001$, but most importantly a significant Condition × Estimate interaction, $F(2, 38) = 10.07$, $p = .001$. The interaction supported our expectation that the three estimates were differentially modulated by the condition factor. Planned comparisons (using one-tailed p-values because of our directional hypotheses) revealed that familiarity (d') was significantly higher for the intra- than the interitem condition, $t(19) = 3.30$, $p = .002$. Conversely, recollection for recombined face pairs (R_n) was significantly larger for the inter- than the intraitem condition, $t(19) = 2.14$, $p = .023$. By contrast, there was no difference between conditions for recollection of intact face pairs (R_o), $t(19) = 0.07$, $p = .472$.

Discussion

Experiment 1 revealed several results that were consistent with our hypotheses. The main findings were that familiarity estimates as derived from ROC curves were higher in the intra- than the interitem condition. Conversely, recollection estimates for recombined pairs were higher in the inter- than the intraitem condition. Before discussing the findings in detail, two objections against the interpretation of these results in light of dual-process models of recognition memory have to be addressed. First, associative recognition memory performance was relatively low in both conditions, which might have influenced the estimates of familiarity and recollection in different ways. Second, the study and test phases were separated by a relatively short (20 s) retention interval that is shorter than retention intervals used in other tasks examining episodic long term memory (e.g., Giovanello et al., 2006), although we believe that despite the short retention interval, the task can be considered as tapping episodic long-term memory because of the large amount of to-be-remembered information and the presence of a distracting activity that prevents actively rehearsing the information during the 20 s delay.

To address these two issues, a second experiment was conducted. In this experiment, task performance was enhanced by presenting the face pairs longer and simultaneously rather than sequentially, and the retention interval was increased from 20 to 40 s.

EXPERIMENT 2

Methods

Participants

Thirty-two, mostly undergraduate students (16 females) provided informed consent to participate in return for cash payment of 8 Euro/hour. Participants were screened for conditions of neurological or psychiatric disorders using a questionnaire, which revealed no such conditions. Four participants were excluded from analyses because of their poor associative recognition memory performance (these participants produced more false alarms than hits); the data from one participant were incomplete due to computer breakdown. Thus, data from 27 participants were included in the following analyses. Mean age of the 27 participants was 24.93 years ($SD =$ 3.57, range = 20–35).

Materials and procedure

Face stimuli. The same face stimuli were used as in Experiment 1.

Associative recognition memory task. The same task as in Experiment 1 was used with the following modifications: (1) The gender judgement task was omitted in order to reduce the cognitive demands during encoding. (2) The presentation and timing of study phase stimuli was altered as follows: Each study trial started with a fixation cross (500 ms). Thereafter, the two face stimuli of each face pair that had to be associated were presented side by side (3000 ms) instead of sequentially. A blank screen was presented (1000 ms), after which the next study trial started. (3) Between the study and the test phase, a distractor task highly similar to the one in Experiment 1 was performed (i.e., participants had to count aloud backwards in steps of 6, 7, 8, or 9 from a randomly presented number between 300 and 400), but the duration of the task was increased to 40 s. (4) The presentation and timing of test phase stimuli was altered as follows: Each test trial started with a fixation cross (500 ms). Thereafter, a pair of face stimuli was presented side by side (50% intact and 50% recombined face pairs, respectively). The face pairs stayed on the screen until a response was made or for 3000 ms maximally. Before the next test trial started, a blank screen was presented for 1000 ms.

Results

Associative recognition memory performance

Table 1 presents the proportion of hits and correct rejections, A_z-values, and recognition decision times for Experiment 2. Consistent with Experiment 1, the proportion of hits was higher in the intra- than the interitem condition, $F(1, 26) = 50.08$, $p < .001$. Conversely, the proportion of correct rejections was higher in the inter- than the intraitem condition, $F(1, 26) = 16.43$, $p < .001$. The area under the ROC (A_z) did not differ significantly between conditions and was only slightly higher in the intra- than the interitem condition, $F(1, 26) = 3.07$, $p = .091$, indicating comparable associative recognition memory performance across conditions. Analyses of recognition decision times revealed no condition differences for hits, $F(1, 26) = 1.10$, $p = .303$, whereas correct rejections occurred faster in the inter- than the intraitem condition, $F(1, 26) = 8.70$, $p = .007$.

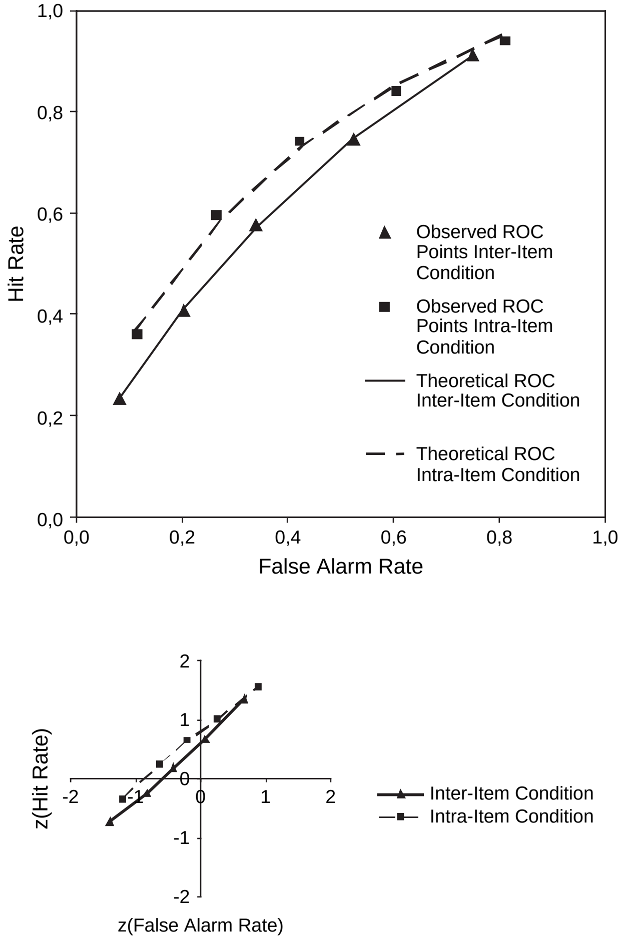

Figure 4. Observed ROC points and fitted theoretical ROC curves (upper row) and corresponding z-ROC curves (lower row) from Experiment 2. Triangles and squares represent (z-transformed) observed proportions of hits and false alarms across response criteria. In the ROC diagram (upper row), lines represent the fitted theoretical ROC curves derived from the formal dual-process model.

ROC analyses

Observed proportions of hits and false alarms across response criteria (i.e., empirical ROC points for cumulated responses across participants) are shown in Figure 4 (upper row). The derived empirical z-ROCs are also shown in Figure 4 (lower row). The shape of the z-ROCs was again examined by applying regression analyses. For the interitem condition, both regressions revealed that the z-ROC had a significant linear term (first regression: $t = 76.05$, $p < .001$, second regression: $t = 76.95$, $p < .001$) as well as a

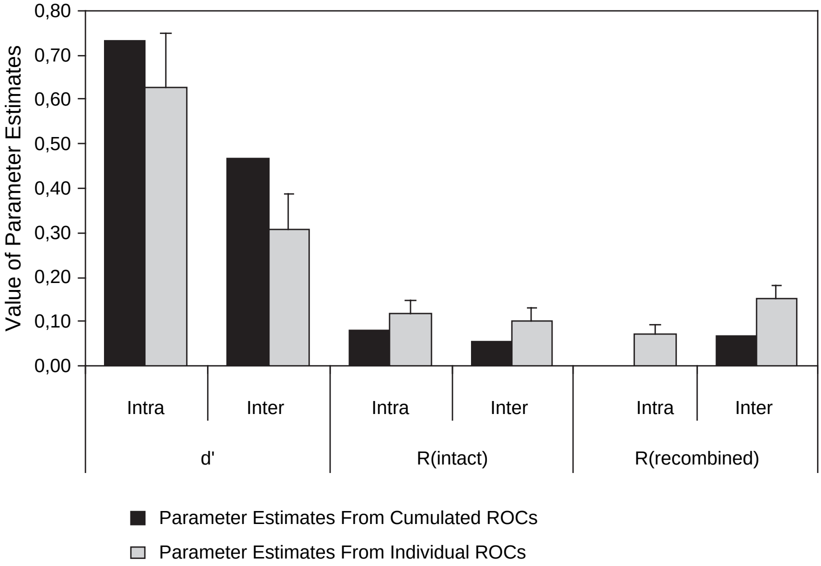

Figure 5. Parameter estimates for cumulated and individual ROCs for Experiment 2. Parameter estimates were derived using the formal dual-process model. Error bars represent standard errors of the means. In the intraitem condition, the value of *R*(recombined) is zero for parameter estimates from cumulated ROCs.

significant quadratic term (first regression: $t = 5.03$, $p = .037$, second regression: $t = -4.85$, $p = .040$). Hence, consistent with Experiment 1, the *z*-ROC for the interitem condition appeared to be curvilinear rather than linear. For the intraitem condition, both regressions revealed that the *z*-ROC had a significant linear term (first regression: $t = 29.51$, $p < .001$, second regression: $t = 18.19$, $p = .003$), but no quadratic term (first regression: $t = -1.96$, $p = .189$, second regression: $t = 2.10$, $p = .171$). Hence, consistent with Experiment 1, the *z*-ROC for the intraitem condition appeared to be linear rather than curvilinear.

Fitting the dual-process model. In the next step, we fitted the dual-process model as in Experiment 1 to the empirical ROC points. Model-generated curves for cumulated ROC points are shown as lines in Figure 4 (upper row). As can be seen in Figure 4, there was an accurate fit of the model to the empirical ROC points in both conditions. Minimising the sum of squared error terms for the difference between observed and expected values on the cumulated ROCs revealed the parameter estimates shown in Figure 5. As can be seen in Figure 5, familiarity (*d′*) was higher in the intraitem condition compared to the interitem condition. By contrast, there were only small differences for recollection, such that recollection for intact pairs (R_o) was slightly higher for the intra- than the interitem condition, whereas recollection for recombined pairs (R_n) was slightly higher for the inter- than the intraitem condition.

To test the statistical significance of these observations, the model was next fit to individual ROCs in order to obtain parameters for every participant. The mean estimates for d', R_o, and R_n derived from individual ROCs are presented in Figure 5. These estimates were subjected to a Condition (inter- vs. intraitem condition) × Estimate (d', R_o, R_n) ANOVA, which revealed significant main effects of condition, $F(1, 26) = 4.98$, $p = .034$, and of estimate, $F(2, 52) = 17.75$, $p < .001$. Most importantly and consistent with Experiment 1, there was a significant Condition × Estimate interaction, $F(2, 52) = 5.48$, $p = .007$. The interaction supported our expectation that the three estimates were differentially modulated by the condition factor. Planned comparisons (using one-tailed p-values because of our directional hypotheses) revealed that familiarity (d') was significantly higher for the intra- than the interitem condition, $t(26) = -2.40$, $p = .012$. Conversely, recollection for recombined face pairs (R_n) was significantly larger for the inter- than the intraitem condition, $t(26) = 2.53$, $p = .009$. By contrast, there was no difference between conditions for recollection of intact face pairs (R_o), $t(26) = -0.42$, $p = .388$.

Discussion

Experiment 2 revealed results that were essentially the same as those of Experiment 1. Importantly, the findings of Experiment 1 could be replicated in the second experiment by using a task that allowed a higher level of associative recognition memory performance and by introducing longer retention intervals between the study and the test phases (i.e., 40 s instead of 20 s). These results indicate that the findings of Experiment 1 were not significantly influenced by the low level of memory performance or the length of the retention interval.

GENERAL DISCUSSION

In the present experiments, we compared two types of associative recognition memory situations: Participants either memorised face pairs depicting two different, arbitrarily paired persons (interitem condition) or pairs of physically different photographs that were perceived as representing the same person (intraitem condition). Besides these differences in face similarity within face pairs, the length of study blocks was adjusted to obtain similar associative recognition memory performance across both conditions. Indeed, A_z-values reflecting associative recognition sensitivity did not differ significantly across conditions, although they were slightly higher in the intra- compared to the interitem condition (Table 1). The main aim of our study was to examine whether familiarity can support associations between unitisable stimuli. In line with previous studies revealing that familiarity may support associative recognition memory if the to-be-associated items can be integrated into a coherent whole, a bound or unitised representation (Jäger et al., 2006; Opitz & Cornell, 2006; Quamme, 2004; Quamme et al., 2007; Rhodes & Donaldson, 2007; Yonelinas et al., 1999; see also Eichenbaum, 1997), we expected a significantly higher contribution of familiarity in the intra- relative to the interitem condition.

Across both experiments, regression analyses revealed a linear z-ROC for the *intraitem condition*, indicating that mainly familiarity contributed to intact/recombined judgements, whereas recollection seemed to play a less prominent role (Figures 2 and 4). Indeed, applying the formal dual-process model to individual ROCs revealed a significantly higher estimate of familiarity for the intra- compared to the interitem condition in both experiments (Figures 3 and 5). Hence, this result provides further evidence for the hypothesis that familiarity can support associative recognition memory judgements in situations where the to-be-associated items are unitised or integrated into a coherent whole. The greater contribution of familiarity in the intraitem condition may have produced the significantly higher proportion of hits in the intra- compared to the interitem condition.

By contrast, consistent with the assumption that associative recognition memory for unrelated stimuli mainly relies on recollection, results from regression analyses suggested that the z-ROC obtained in the *interitem condition* was curvilinear (i.e., U-shaped) rather than linear (Figures 2 and 4). This result suggests the additional contribution of recollection in the interitem condition. (Note that we do not wish to claim that there is *no* contribution of familiarity in the interitem condition. Rather, we tested the hypothesis that the contribution of recollection is *greater* in the inter- than in the intraitem condition.) Applying the formal dual-process model to individual ROC curves revealed that although recollection for intact pairs (R_o) did not differ across conditions, across both experiments there was a significantly higher contribution of recollection for the rejection of recombined pairs (R_n) in the inter- compared to the intraitem condition (Figures 3 and 5). This latter finding is consistent with the expectation that participants can recollect recombined face pairs as "recombined" to a higher degree in the inter- compared to the intraitem condition, because recollection is assumed to break down when the overlap between to-be-associated information is too high, such as in the present intraitem condition (McClelland, McNaughton, & O'Reilly, 1995; Schacter, Norman, & Koutstaal, 1998). In consequence, the significantly greater proportion of correct rejections in the interitem condition may be accounted for by the fact that recollection supported the rejection of recombined pairs to a higher degree in the inter- compared to the intraitem condition.

Although recollection for intact face pairs could be expected to be higher in the inter- compared to the intraitem condition because recollection is thought to support associations between unrelated stimuli and may break down when the overlap between to-be-associated stimuli is too high (cf. Jäger et al., 2006), there were no condition differences in recollection for intact face pairs. This result may have arisen from the fact that estimates for recollection were generally relatively low in both conditions, perhaps providing little space for differences between conditions. Another argument may be that intact/recombined decision performance was slightly (but nonsignificantly) poorer in the inter- compared to the intraitem condition, which may have further lowered recollection in the interitem condition. However, the fact that recollection for the rejection of recombined face pairs was present to a significantly higher degree in the inter- relative to the intraitem condition supports the conclusion that recollection plays a more important role in associative recognition judgements for arbitrarily paired faces.

In sum, the present findings provide empirical evidence that familiarity contributes to associative judgements to a higher degree in the intraitem condition—because here the to-be-associated stimuli can be unitised—than in the interitem condition, in which to-be-associated stimuli are arbitrarily paired and nonoverlapping. Our results extend the results of previous studies by using a different paradigm, different materials (i.e., face pairs rather than words or facial features), and different operational definitions of familiarity and recollection (i.e., behavioural rather than electrophysiological measures of these processes). Moreover, in contrast to most other studies, we used a task in which associations between unitisable stimuli were formed during the experiment rather than being pre-experimentally existing associations in semantic memory.

However, the present study also has several limitations. First, the conclusions were exclusively drawn from the analyses of ROC curves. Hence, additional evidence beyond ROC analyses is needed to firmly establish that familiarity plays a greater role for the retrieval of intra- than interitem associations. However, we would like to point to findings of other studies that converge with the present results by providing support for the "unitisation hypothesis" that familiarity can contribute to associative recognition memory given that the stimuli can be unitised (for patient data, see Giovanello et al., 2006; Quamme et al., 2007; for electrophysiological evidence using a similar task as in the present study, see Jäger et al., 2006; see also Rhodes & Donaldson, 2007).

A second limitation is that the present results are constrained by specific model assumptions on the nature of familiarity and recollection as proposed by Yonelineas and colleagues (e.g., Yonelinas et al., 1996). However, several models exist that conceptualise recollection as a continuous, normally distributed memory process (see Wixted, 2007), thus raising the possibility that the specific model assumptions included in the present study may have produced invalid results. Again, we would like to refer to studies that used alternative operational definitions of familiarity and recollection and revealed converging evidence for the "unitisation hypothesis" without relying on specific model assumptions (for patient data, see Giovanello et al., 2006; Quamme et al., 2007; for electrophysiological evidence, see Jäger et al., 2006; Rhodes & Donaldson, 2007). A third limitation is that the present experiments used relatively short time intervals between study and test (i.e., 20 or 40 s). Hence, future studies should investigate whether our findings generalise to retention intervals of hours, days, or even longer. A final limitation is that the picture database used for the present experiments did not contain enough face stimuli to enable the creation of two sets of stimuli that could be used with equal probability across the intra- and the interitem condition. Hence, we were constrained to use different face stimuli across conditions.

In light of the findings supporting the "unitisation hypothesis", the question arises about the particular mechanisms through which familiarity can support associative episodic memory. One possibility could in part be derived from the neurocomputational dual-process model put forth by Norman and O'Reilly (2003; see also Aggleton & Brown, 1999). The model assumes that the hippocampal formation is critical for recollection because the hippocampus can establish connections between arbitrarily paired items represented in medial temporal lobe cortex (MTLC). Specifically, the hippocampus creates pattern-separated representations of to-be-associated stimuli in region CA3. At test, pattern completion enables recollecting the complete studied pattern in response to a partial cue. By this, the hippocampus plays an important role in establishing and retrieving associations between nonoverlapping MTLC representations such as the arbitrarily paired faces in the interitem condition. This mechanism is illustrated in Figure 6, showing how nonoverlapping MTLC representations A and B are linked to each other through sparse, pattern-separated representations in the hippocampus.

By contrast, hippocampal recollection is presumed to break down when the overlap between to-be-associated information is too high, since the hippocampus cannot create pattern-separated representations in this case (McClelland et al., 1995; Schacter et al., 1998). Importantly, this could occur for highly overlapping stimuli such as the faces of the intraitem condition. For such intraitem associations, the MTLC (i.e., perirhinal, entorhinal, and

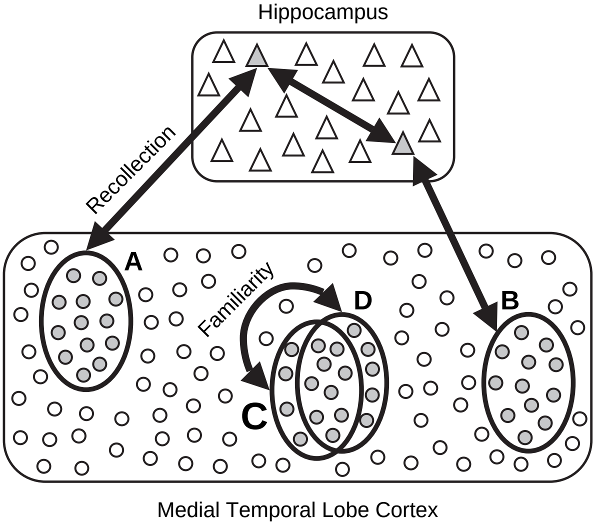

Figure 6. Hypothetical model how familiarity may support associative recognition memory. The hippocampus is suggested to support associations between nonoverlapping medial temporal lobe cortex (MTLC) representations A and B by connecting sparse, pattern-separated hippocampal representations of the stimuli (grey triangles). Pattern-completion results in recollection of Stimulus B when Stimulus A is presented at test. MTLC assigns highly overlapping representations to similar Stimuli C and D. In this case, the hippocampus has difficulty establishing pattern separation and the recollection mechanisms breaks down. By contrast, MTLC familiarity may support associations between highly overlapping Stimuli C and D. Ellipses = representations of individual faces in MTLC (i.e., A, B, C, D); triangles = individual units of hippocampus; small circles = individual units of MTLC.

parahippocampal cortices), which is thought to be able to generate familiarity signals (Gonsalves, Kahn, Curran, Norman, & Wagner, 2005; Henson, Cansino, Herron, Robb, & Rugg, 2003; Norman & O'Reilly, 2003), may play a critical role. The MTLC is suggested to assign similar representations to similar stimuli. Thus, in the intraitem condition, MTLC representations of faces of each face pair can be expected to overlap substantially, by this resulting in a connection between the two stimuli in the form of a unitised representation that involves enhanced activation of overlapping features and reduced activation of nonoverlapping ones (a process termed "sharpening"; Norman & O'Reilly, 2003). While the exact nature of these MTLC connections remains unclear, this proposed mechanism is consistent with findings that familiarity supports associative retrieval of items that can be integrated into a coherent whole, a bound or unitised representation (Jäger et al., 2006; Opitz & Cornell, 2006; Quamme, 2004; Quamme et al., 2007; Rhodes & Donaldson, 2007; Yonelinas et al., 1999; see also Eichenbaum, 1997). Figure 6 shows how MTLC familiarity may connect highly overlapping representations B and D through a unitised representation, whereas this association probably cannot be formed via hippocampal pattern-separation (note that the mechanism of MTLC familiarity to support associative memory through unitisation of representations is not explicitly included in the model of Norman & O'Reilly, 2003).

In conclusion, there is growing evidence from various studies challenging the proposal that associative recognition memory relies exclusively on recollection without benefiting from familiarity. Some of these studies used pre-experimentally associated word pairs and found that familiarity can support associative recognition memory of such bound representations (i.e., Giovanello et al., 2006; Quamme, 2004; Rhodes & Donaldson, 2007). Other studies using newly learned word pairs (Quamme, 2004; Quamme et al., 2007), facial features (Yonelinas et al., 1999), or pairs of faces (Jäger et al., 2006) revealed that unitisation of stimuli established during the experiment can also render associative recognition memory to benefit from familiarity. The present findings add to this growing body of literature investigating the subprocesses underlying associative recognition memory by indicating that familiarity and recollection may subserve distinct types of associative retrieval: While recollection seems to enable retrieval of associations between arbitrarily paired, nonoverlapping items (such as photographs from two different persons), familiarity may support associative recognition memory in situations where the to-be-associated items are unitised or integrated into a coherent whole (such as two physically different photographs depicting the same person), even in situations in which the stimuli are not pre-experimentally associated in semantic memory.

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