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The role of group configuration in the social transmission of memory: Evidence from identical and reconfigured groups

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Collaborating with others during recall shapes both group and individual memories. Individuals contribute less when recalling in groups than when recalling alone, a phenomenon called collaborative inhibition. In contrast, collaboration improves post-collaborative individual memory by providing re-exposure to information that would have been otherwise forgotten. Collaboration also influences collective memory—the overlap in post-collaborative memory among group members. We examined the role of group configuration on such transmission of memory by varying group configuration across repeated recalls. Participants (N = 162) studied words and completed three recall sessions in one of three conditions (N = 54/condition): Individual–Individual–Individual (Control), Collaborative–Collaborative (Identical group)–Individual and Collaborative–Collaborative (Reconfigured group)–Individual. Collaborative inhibition occurred in both the Identical and Reconfigured groups during the first recall but disappeared in the Reconfigured groups during the second recall. Post-collaborative individual memory was greater following Reconfigured than Identical group collaboration. This pattern reversed for collective memories; repeated collaboration increased overlap in the remembered and forgotten items in Identical groups compared to Reconfigured groups. Finally, Reconfigured groups provided a quantifiable index of the influence of distal partners (i.e., no direct collaboration involved) on post-collaborative individual memory. We conclude that group configuration has powerful consequences on the amount, the similarity and the variety of memory representations.

Keywords: Collaborative inhibition; Collaborative memory; Collective memory; Proximal-distal partners; Reconfigured groups; Social transmission of memory.

In the last decade, there has been a rapid growth in cognitive research to understand a powerful but largely understudied phenomenon that Weldon aptly called, “remembering as a social process” (Weldon, 2001, p. 1). The development of the *collaborative memory* paradigm that we describe in the next section has been in large part the catalyst for asking and answering fundamental questions about the nature of collaborative memory, and its post-collaborative consequences on individual memory. The collaborative memory paradigm has been mainly used to understand the consequences of remembering with the same group of people. In daily life, however, remembering occurs with the same group of people (e.g., family and friends gatherings) as well as with

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different groups of people (e.g., having study group sessions with different classmates each time; having rotating members in workplaces). Yet to date, the collaborative memory paradigm has not been used to examine this latter situation.

An obvious consequence of remembering the past with different partners is that any given individual's memory is influenced by a large network of people. When such larger networks come into action, a given member's memory is shaped not only by her immediate group partners, but also by the partners of these partners. As obvious and essential as such scenarios are for understanding the social transmission of memory, there remains a striking absence of experimental paradigms to operationalise and measure the transmission of memory in identical versus reconfigured groups. The current study was designed to fill this gap in the literature.

We present a critically needed methodology to study the impact of not just a few but many different partners, and examine the cumulative impact of multiple interactions on the social transmission of memory. We call this the Reconfigured Group methodology. Moreover, we show that collaborating in identical groups versus reconfigured groups influences the social transmission of memory both at the individual and the group levels. To understand the scope of these changes, we assessed the consequences of group configuration on group memory during collaboration, post-collaborative individual memory, and the formation of collective memory.

COLLABORATION AND GROUP MEMORY: COLLABORATIVE INHIBITION AND RETRIEVAL DISRUPTION

Since the seminal experimental work of Basden, Basden, Bryner, and Thomas (1997) and Weldon and Bellinger (1997), numerous studies have shown that collaboration impairs group recall, a robust phenomenon termed *collaborative inhibition*. In a typical experiment, collaborative inhibition is measured by comparing the number of items retrieved by groups (i.e., a collaborative group, commonly consisting of three individuals) to the number of non-redundant items retrieved by an equal number of individuals who have worked individually (i.e., a nominal group). In this comparison, collaborative groups recall less than nominal groups indicating that collaboration lowers individual contributions when working in groups. Contrary to intuition, social loafing does not explain collaborative inhibition because increasing motivation or personal accountability during collaboration has failed to eliminate collaborative inhibition in recall (Weldon, Blair, & Huebsch, 2000).

The most prominent theoretical explanation for collaborative inhibition is the *retrieval disruption hypothesis* (Basden et al., 1997). According to this hypothesis, each individual's idiosyncratic organisation of information is disrupted while listening to the outputs of other group members' recall during collaboration, which in turn reduces the individual's (and thus the group's) recall performance.

The retrieval disruption account of collaborative inhibition has gained considerable empirical support. For example, increased group size increases the degree of disruption that each group member experiences, and in turn, increases the size of collaborative inhibition (Basden, Reysen, & Basden, 2002; Thorley & Dewhurst, 2007). In contrast, collaborative inhibition can disappear or reduce if participants rely less on their idiosyncratic strategies. For example, recognition memory tasks and cued-recall tasks do not demand a reliance on subjective organisation of information, and provide test formats that enable all group members to use the same cues for memory retrieval (Basden et al., 1997; Clark, Hori, Putnam, & Martin, 2000; Finlay, Hitch, & Meudell, 2000). A similar outcome occurs when the use of one's idiosyncratic strategies becomes less available due to a long delay between study and group recall (Congleton & Rajaram, 2011; Takahashi & Saito 2004).

Additional support for the retrieval disruption hypothesis comes from research where collaborative inhibition was reduced or eliminated because of strengthened retrieval organisation that made participants less vulnerable to the disruptive effects of collaboration, by enabling participants to solidify their retrieval organisations through repeated study or repeated testing on the same material prior to collaboration (Blumen & Rajaram, 2008; Congleton & Rajaram, 2011; Pereira-Pasarin & Rajaram, 2011).

Repeated retrieval carried out by the group as a whole is also instrumental in reducing the costs of collaboration. This is because it gives participants opportunities to solidify their group-level retrieval organisation (Weldon & Bellinger, 1997) and enables them to benefit from *re-exposure* to the studied materials they did not recall, but that were recalled by other group members during the first collaboration (Blumen & Rajaram, 2008). Such re-exposure benefits are detected on a subsequent individual memory test, as we describe next.

POST-COLLABORATIVE INDIVIDUAL MEMORY: RE-EXPOSURE BENEFITS

Although collaboration can hurt group memory in terms of lowering group performance, collaboration benefits post-collaborative individual memory by improving recall (e.g., Basden, Basden, & Henry, 2000; Congleton & Rajaram, 2011; Thorley & Dewhurst, 2007; Weldon & Bellinger, 1997; but see Finlay et al., 2000). In a direct investigation of the beneficial effects of collaboration on later individual memory, Blumen and Rajaram (2008) devised an experimental paradigm where participants studied a list of words and completed three recall trials across different retrieval conditions. Of interest here are the comparisons of three conditions: III (individual–individual–individual recalls), CII (collaborative–individual–individual recalls) and CCI (collaborative–collaborative–individual recalls), and three key findings are directly relevant to the motivation of the present study. First, collaborative inhibition was observed during the first recall phase in both collaborative conditions (CII and CCI), and collaborative inhibition still persisted even after repeated collaboration during the second recall (CCI) compared to the control condition of three individual recalls (III).

Second, there was no benefit of single collaboration (CII) on final individual recall, but repeated collaboration (CCI) significantly improved final individual recall performance. This finding indicates that whereas single collaboration disrupts individuals' own organisation, repeated collaboration allows individuals to overcome the disruption deficit by benefitting from re-exposure to others' responses during repeated collaboration and thereby enhancing later individual memory. In Blumen and Rajaram (2008), this re-exposure benefit was captured by computing *reminiscence* scores (recall of previously unrecalled items in subsequent recall tests; Payne, 1987); whereas individuals produced reminiscence even in the absence of collaboration (the III condition), the gains from one recall to another were significantly greater in the repeated collaborative condition (CCI).

Third, collaborative inhibition was absent when comparing the second recall of participants who collaborated once in their first recall but now recalled individually (CII) and those who collaborated during the second recall as well (CCI). Relevant to the present study, this absence of collaborative inhibition was driven by a reduction of nominal group recall, i.e., a reduction in the extent of non-overlap in recall responses, when comparing CII to III. This reduction in nominal group recall occurred despite the fact that the individual recall levels between CII and III were equivalent, and implies that the initial collaboration disrupted individual retrieval organisation and lowered subsequent individual recall. More importantly, these patterns also indicate that one collaborative recall session increased overlap in individual recall later compared to an individual recall session (see also Barber, Rajaram, & Fox, 2012; Henkel & Rajaram, 2011). In other words, a single collaborative session was sufficient to start gluing the group members' memories together, suggesting the formation of overlapping, or *collective memory*.

THE ROLE OF COLLABORATION IN SHAPING COLLECTIVE MEMORY

The emergence of shared responses following collaboration has been termed "collective memory," (Hirst & Manier, 2008) where this phenomenon is said to be tied to a group's identity. In experimental studies, the role of identity is typically not measured, and collective memory is operationally defined as the number of overlapping recalled items and the number of overlapping non-recalled (or forgotten) items that the group members share in their individual final recall (Cuc, Ozuru, Manier, & Hirst, 2006; Stone, Barnier, Sutton, & Hirst, 2010). We follow the same practice in the present study. In an experimental context, the cognitive mechanisms that underlie the formation of collective (or shared) memory are tightly related to the operations of several cognitive factors that modulate collaborative memory (Rajaram & Pereira-Pasarin, 2010). Among the mechanisms that may be involved during collaboration, we focused here on *retrieval disruption*, *re-exposure benefits* and *forgetting*.

Recent theoretical work has emphasised the role of retrieval in shaping collective memory (see Roediger, Zaromb, & Butler, 2009), and our recent empirical work substantiates this idea. For example, Barber et al. (2012) reported that collaborative retrieval is not only important for collective memory but it is also more powerful in the formation of collective memory than is collaborative encoding. In as much as retrieval disruption shapes group memory by disrupting each individual's subjective organisation (Basden et al., 1997), together these findings indicate that retrieval disruption, and in turn, retrieval organisation play a critical role in the formation of collective memory. These findings also indicate the intriguing possibility that through the process of retrieval disruption to each member's individual organisation (as well as through the process of re-exposure and forgetting that are described later), a new, group-level of organisation of information can emerge through the process of collaboration. Thus, collaboration may be associated with not only greater collective memory but, as recently shown by Congleton and Rajaram (2013), also with a greater collective (or overlapping) organisation of memories among group members. These far-reaching consequences of collaboration have remained entirely untested until recently, and remain unknown for groups that vary in composition.

Re-exposure benefits of collaboration on later individual memory can also shape collective memory. For example, during collaborative recall, participants have a chance to be re-exposed to the items that are recalled by other group members that they themselves might have forgotten. Such re-exposure benefits increase the similarity in the memory of the group members because items recalled during collaboration can serve as a second-learning opportunity of the same items for all group members.

Finally, *forgetting* through the collaborative process also leads to the formation of collective memory (Coman, Brown, Koppel, & Hirst, 2009; Schwartz, 2009). Cuc, Koppel, & Hirst (2007) have shown that the to-be-remembered information that is not recalled during collaborative recall (in their case, during conversation) is less likely to be recalled in the post-collaborative individual recall. Henkel and Rajaram (2011) also reported that both young and older adults forgot significant proportions of items on the final individual recall following collaboration even though they recalled these items on the initial individual recall. Thus, whereas many items that are lost during collaboration are recovered during post-collaborative recall (Finlay et al., 2000), some items remain forgotten. Together, post-collaborative individual memory is a complex function of retrieval disruption, re-exposure benefits and forgetting costs.[1] It follows then that the extent of influence that each of these mechanisms exerts on memory during collaboration would in turn shape the divergence or consensus in memory that a group achieves.

All aforementioned studies, and those in the literature at large, on collaborative, post-collaborative individual and collective memory are based on a single interaction during recall in a small group (two to four members), or repeated interactions but again among the same group members. Whereas there have been suggestions in the memory literature on the necessity of investigating transmission of information or the formation of collective memory across larger networks or members of communities (e.g., Bartlett, 1932; Barnier, Sutton, Harris, & Wilson, 2008; Halbwachs, 1950/1980; Hirst & Manier, 2008; Wang, 2008; Wertsch & Roediger, 2008), to our knowledge this notion remains untested in an experimental paradigm. In the present study, we developed the building blocks necessary to fill this critical gap by manipulating group configuration during collaboration, thereby creating a testable empirical model for a larger network through which information flows.

THE PRESENT STUDY

The goal of the present study was to investigate the transmission of information across collaborative recall sessions in identical versus reconfigured groups (i.e., collaborating repeatedly with the same versus with a different group of people). We were particularly interested in how three key cognitive mechanisms—retrieval disruption, re-exposure benefits and forgetting—influence collaborative group memory, post-collaborative individual memory and collective memory across these different group configurations.

First, we examined whether collaborative inhibition would disappear or persist if people have a chance to recall the same information in different groups compared to repeatedly recalling

[1] Post-collaborative memory can also be affected by contagion of memory errors and, conversely, the pruning of memory errors that occur during collaboration (Rajaram & Pereira-Pasarin, 2010, for a fuller treatment of multiple mechanisms). A discussion of these mechanisms is beyond the scope of the present paradigm and thus is not included here.

with the same group. On the one hand, when collaborating with different people, the patterns of retrieval disruption are likely to change because a person is now exposed to a much greater variety of idiosyncratic organisation than when working with the same partners as before, which could increase disruption. On the other hand, the patterns of non-overlap in the retrieved items would also increase as each collaborator would bring more variety of items to the collaborative session. This would increase re-exposure benefits in the reconfigured groups; the items that were collaboratively produced during the previous group configuration would emerge as re-exposure benefits, and each member in the previous group configuration would bring this advantage to the reconfigured group collaboration. In this manner, if the non-overlap in items that contribute to the re-exposure benefits in the reconfigured groups exceeds retrieval disruption during collaboration, collaborative inhibition would be reduced or would disappear. However, if the retrieval disruption exceeds the non-overlap and re-exposure benefits, collaborative inhibition would persist. For the identical groups, based on past research, it was predicted that collaborative inhibition would persist though it could decline numerically (Blumen & Rajaram, 2008).

Second, we examined how the disappearance versus the persistence of collaborative inhibition would affect post-collaborative individual memory. If collaborative inhibition disappears when people have a chance to recall in different groups, would this then further enhance post-collaborative performance of the individuals compared to individuals who work with the same group again? The answer to this question is important for the basic understanding of how information transmits across the same versus reconfigured networks of collaborating groups. It is also important for its potential applied value; for example, this finding can help explore whether participating in different study groups is more beneficial to learning compared to working with the same group.

Third, during the final individual recall, we also examined the formation of collective memory across identical and reconfigured groups. The predictions for how these different group structures would shape collective memory hinge on the simultaneous operations of disruption to retrieval organisation, forgetting and re-exposure benefits. In the case of the identical group, each group member's subjective organisation is once disrupted during the first recall, and the disruption, along with the inclusion of re-exposure items and elimination of forgotten items, may create a group-level retrieval organisation (Congleton & Rajaram, 2013). Such group-level retrieval organisation is likely to carry over to the second recall since the same group members work together again and are bound by the group-level retrieval organisation. In the reconfigured group, as each individual works in a new group for the second recall, they are likely to experience the retrieval disruption twice, and undergo yet another iteration of re-exposure and forgetting, and the reconfiguration would require a new group-level retrieval organisation to develop. At the same time, because individuals in the reconfigured group would get larger re-exposure benefits compared to individuals in the identical group they will gain more variety in their final individual memory. As a result of these two processes, it is predicted that stronger collective memory would be formed in the identical group than in the reconfigured group.

Fourth, we quantified the changes in retrieval organisation of identical and reconfigured groups across recall sessions. We predicted that the identical group would develop a more stable organisation across recall sessions, whereas the reconfigured group would suffer from the costs of weakened retrieval organisation. We also examined the extent to which individuals in each group carry over the outcomes of the changed retrieval organisation as well as the re-exposure benefits to their post-collaborative individual recalls. We discuss the measure of retrieval organisation in more detail in the Results section.

Finally, we considered transmission of information from both the proximal and distal partners by assessing the influence of the partners and the influence of the partners' partners on a given group member's memory. We elaborate on the influences of proximal versus distal partners, and the analyses we conducted for this assessment, subsequently after we discuss our experimental paradigm in more detail in the Method section.

METHOD

Participants and design

Type of retrieval sequence was manipulated as a between-subject factor across three conditions: III (individual–individual–individual), CCI (collaborative–collaborative–individual) and CRI (collaborative-reconfigured collaborative-individual). A total of 162 Stony Brook University undergraduates participated for experimental credits, with 54 participants (i.e., 18 triads, consisting of strangers) randomly assigned to each condition.

Materials

The stimuli were adapted from Blumen and Rajaram (2008) and consisted of 50 unrelated words (46 targets, 2 primacy buffers, 2 recency buffers) taken from the Clark and Paivio (2004) word norms. We chose unrelated words as our experimental stimuli because unrelated words by definition are relatively unstructured, and thus provide the opportunity to quantify people's natural propensity to impose organisation on the recall of even unstructured studied information (Gates, 1917; Tulving, 1962). The characteristics of words were as follows: mean length = 5.63, mean imageability = 6.47, mean concreteness = 6.78, mean frequency = 1.71 and mean pleasantness = 4.19. Two study lists were created with different order of words. The order of words was fixed within each list for later use to evaluate participants' subjective organisation between the study list and recall.

Procedure

Study phase. Participants rated each word for pleasantness on a 1–5 scale (1 = very unpleasant, 5 = very pleasant; Craik & Lockhart, 1972). Each word was presented for 5 sec at the centre of a screen. Participants were not informed about the upcoming memory tests.

Filled delay with a distractor task. Immediately following the study phase, participants recalled names of US cities for seven minutes.

Retrieval phase. Three sequential free-recall tasks were administered in each experimental condition: III, CCI and CRI. Participants in the III condition completed all three recalls individually. Participants in the CCI and CRI conditions completed the first two recalls in groups of three and completed the last recall individually.

In the III condition, each participant worked individually and wrote down as many of the words they could remember in any order. They completed the subsequent two recall sessions in the same manner. For CCI and CRI, the critical difference between the conditions was the group configuration that formed after the first recall session. In CCI, three participants (i.e., one triad) were seated around a table, given a recall protocol sheet that remained in full view of all three participants, and asked to recall and write down in any order as many of the words they could remember as a group. One randomly selected group member served as a scribe to write down the recalled items (previous research shows that the scribe status does not affect the recall patterns; Blumen & Rajaram, 2008). Members were instructed to resolve on their own any disagreement that arose during the collaboration. The same procedure was used for the second group recall that was carried out by the same group members. The instructions given for the third, individual recall were identical to the instructions in the III condition.

For the CRI condition, nine participants (i.e., three triads) were recruited at a time and each triad was seated in one of three rooms with independent entrances in a laboratory, and each completed the first recall session in the same manner as participants in the CCI condition. Upon the completion of the first recall session, two participants from each triad were instructed to complete the second recall session with two new group members, neither of whom had been a part of their respective groups during the first recall session (Figure 1). Thus, each reconfigured group during second recall consisted of three members who had not collaborated with one another before but had studied the same study list and had recalled it previously with different partners. Finally, all participants in the CRI condition completed the third recall session individually, following the same instructions as those given for Recall 3 in the III and the CCI conditions. The collaborative recall sessions were also audio-recorded for data coding.

All participants were given seven minutes for each recall session (found to be sufficient in several previous experiments) and took a five-minute break between each recall session. During this break, participants were asked to remain seated, wait for the next task to be set up, and not to chat with their group partners (in case of the CCI and CRI groups). The entire experimental session took approximately one hour.

RESULTS AND DISCUSSION

Findings are presented for group recall during collaboration, post-collaborative individual recall,

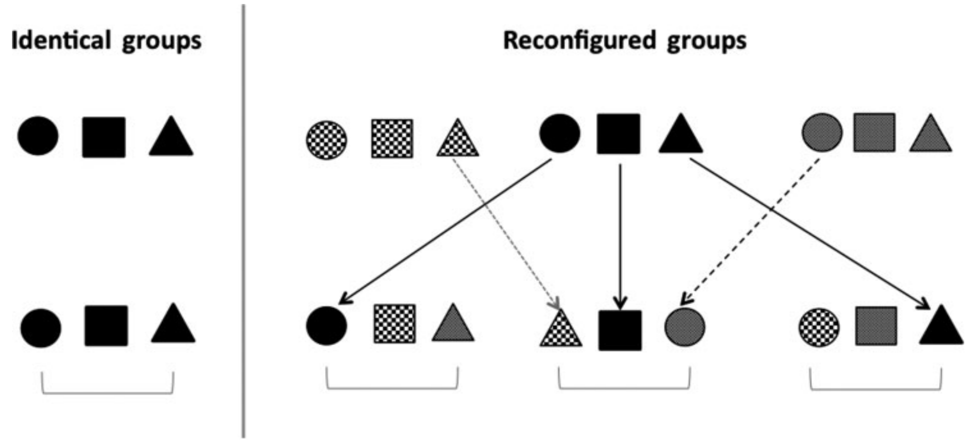

Figure 1. Group configuration in identical (CCI) and reconfigured (CRI) groups. Each different shape or filled pattern denotes an individual within a group.

collective memory, the structure of group memory and the transmission of distal partners' memory. Memory intrusions were very low (III, M = .02, SE = .02; CCI, M = .02, SE = .01; CRI, M = .004, SE = .001); therefore, we report the results for correct recall only. The proportions of correctly recalled items for each condition and each recall session are shown in Table 1. Unless otherwise indicated, the alpha level was set at .05, and all pair-wise comparisons with the Bonferroni correction were set at .015. The corresponding effect sizes were calculated with Cohen's d (Cohen, 1988).

Collaborative inhibition in identical versus reconfigured group recall

The comparisons of recall across groups are shown in Figure 2. The collaborative group performance in the CCI and CRI conditions during Recall 1 was comparable, $t < 1$, confirming the expectation of equivalent baseline recall rates for the two groups. Collaborative inhibition was examined by comparing nominal group recall from the III condition to the CCI and CRI conditions for the first and second recall sessions. As expected, a robust collaborative inhibition effect was replicated for Recall 1 in both the CCI and CRI conditions as collaborative group performance in the CCI (.51), t (34) = 5.89, SE = .03, d = 1.98, and CRI conditions (.52), t (34) = 4.90, SE = .03, d = 1.63, was significantly lower than nominal group performance in the III condition (.67).

For Recall 2, even though collaborative group recall for the CCI group increased numerically (.58) compared to Recall 1 (.51), collaborative inhibition persisted; both patterns of findings

TABLE 1
Proportions of correct recall and standard errors (in parentheses)

Condition	*Correct Recall*	*Nominal Recall*
Individual–Individual–Individual (III)		
Recall 1	.35 (.01)	.67 (.02)
Recall 2	.38 (.01)	.69 (.02)
Recall 3	.42 (.02)	.76 (.02)
Collaborative–Collaborative–Individual (CCI)		
Recall 1	.51 (.02)	–
Recall 2	.58 (.02)	–
Recall 3	.48 (.01)	.63 (.02)
Collaborative–Reconfigured Collaborative–Individual (CRI)		
Recall 1	.52 (.02)	–
Recall 2	.68 (.02)	–
Recall 3	.52 (.01)	.78 (.02)

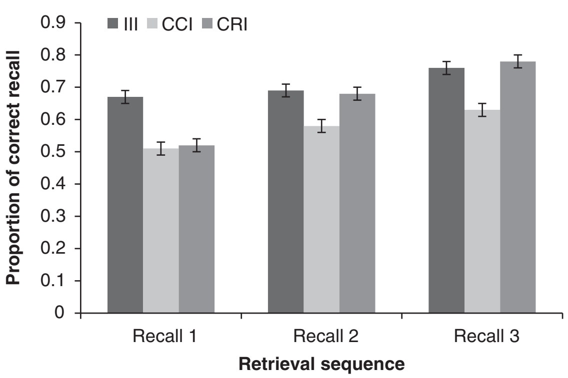

Figure 2. Mean proportion of correct nominal and collaborative group recall across group configuration as a function of retrieval sequence. For the III condition, the measure always represents nominal group recall, and Recall 3 for all conditions represents nominal group recall.

replicated Blumen and Rajaram (2008). Collaborative group recall in the CCI condition (.58) was significantly lower than nominal group performance in the III condition (.69), t (34) = 4.31, SE = .03, d = 1.43. The overall group performance of the CRI condition (.68) improved even further and was now significantly better than the CCI condition (.58), t (34) = 3.97, SE = .03, d = 1.32. Furthermore, and quite interestingly, collaborative inhibition disappeared in the CRI condition such that collaborative group recall did not differ from the nominal group recall (III) condition (.68 versus .69), t < 1. The collaborative inhibition effects across conditions replicated for corrected recall as well (correct recall minus intrusions).

The disappearance of collaborative inhibition in the CRI condition is a novel finding as past research shows that collaborative inhibition is extremely difficult to eliminate (for exceptions, see Congleton & Rajaram, 2011; Harris, Keil, Sutton, Barnier, & McIlwain, 2011; Meades, Nokes, & Morrow, 2009; for a review, see Rajaram & Pereira-Pasarin, 2010). The present results suggest that the ratio of retrieval disruption and forgetting (that lowers recall) to re-exposure benefits (that increases recall) differed across the CCI and CRI conditions, resulting in persistent collaboration inhibition in one case (CCI) and a release from collaboration inhibition in another (CRI). To examine this possibility quantitatively, we employed the *reminiscence* and *forgetting* measures reported in the literature on hypermnesia (Payne, 1987; Roediger & Payne, 1982).

Reminiscence and forgetting

Hypermnesia refers to the phenomenon that when individuals repeatedly recall information, their recall improves with each attempt without an additional study opportunity. This improvement occurs as individuals' recall of previously unrecalled items (*reminiscence*) from one recall to the next exceeds the amount of information they forget (*forgetting*). Thus, hypermnesia is a net result of reminiscence plus forgetting. In the present study, *reminiscence* (i.e., the proportions of unrecalled items during a given recall session but newly recalled during the subsequent recall session) captures the benefits from re-exposure, and *forgetting (*i.e., the proportions of unrecalled items during a given recall session but that had been recalled during the antecedent recall session) captures one of the consequences of retrieval disruption in our collaboration conditions.

The III condition in our study provided the replication of the standard hypermnesia experiments; from Recall 1 to Recall 2, reminiscence (.07) exceeded forgetting (.03), t (53) = 4.61, SE = .01, d = .92, and the same pattern held true from Recall 2 to Recall 3 as reminiscence (.06) exceeded forgetting (.02), t (53) = 5.99, SE = .01, d = 1.07. We next focused on the comparisons of reminiscence and forgetting scores in the collaboration (CCI and CRI) conditions to assess whether reminiscence and/or forgetting rates changed as a function of group configurations.

First, we assessed reminiscence and forgetting scores between Recall 1 and Recall 2 across the CCI and the CRI conditions. Reminiscence was significantly higher in the CRI (.22) than in the CCI (.09) condition, t (34) = 8.18, SE = .02, d = 2.63. This pattern explains the superior performance of the reconfigured group compared to the identical group during Recall 2, given that the baseline group recall rates (i.e., Recall 1 for each condition) were equivalent, and shows that the re-exposure benefits were significantly higher for the participants in the CRI than in the CCI condition. Interestingly, forgetting was also significantly higher in the CRI (.06) than in the CCI (.02) condition, t (34) = 4.53, SE = .01, d = 1.26. As we hypothesised earlier, the higher forgetting scores for the CRI than the CCI condition indicate that participants in the CRI condition did suffer more retrieval disruption as they switched into new groups. However, the key discovery here is that the cost of disruption from switching groups was nonetheless smaller than, and not enough to outweigh, the benefits of re-exposure when working with new group members (Figure 3). Next, we examine the extent to which the greater re-

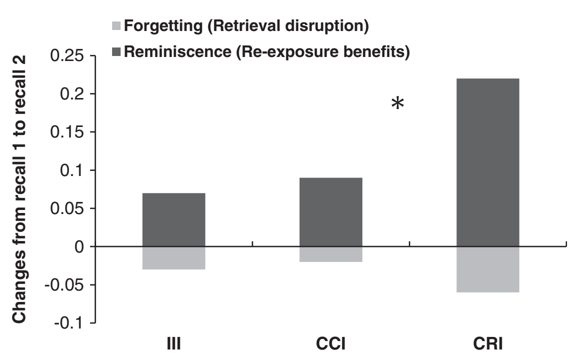

Figure 3. Reminiscence and Forgetting scores across Recall 1 and Recall 2 (*p < .05).

exposure benefits in CRI groups are carried over to post-collaborative individual recall.

Final individual recall after identical versus reconfigured group collaboration

Final individual recall (Recall 3) was significantly higher in the CCI (.48) than in the III condition (.42), t (106) = 3.13, SE = .02, d = .60, and also higher in the CRI (.52) than in the III (.42), t (106) = 5.00, SE = .02, d = .91, replicating past research that collaboration increases subsequent individual memory (e.g., Blumen & Rajaram, 2008, 2009; Congleton & Rajaram, 2011; Weldon & Bellinger, 1997). Novel to this study, the final individual recall in the CRI condition (.52) was marginally higher than in the CCI condition (.48) at the adjusted alpha level, t (106) = 2.18, SE = .02, p = .03, d = .40. These results show that participants in both CCI and CRI conditions were re-exposed to the items during collaboration they might have otherwise forgotten, but the re-exposure benefits were greater for the participants who had a chance to work with two different sets of people, as it increased the variety of items they re-experienced.

Additional secondary analyses indeed revealed that participants in the CRI condition were exposed to more variety of items during collaboration compared to the participants in the CCI condition.[2,3] To capture the increase in the variety of items remembered as a function of identical versus reconfigured group collaboration, we computed the nominal group recall on the final individual recall (Recall 3) for all three conditions. To reiterate, lower nominal group recall indexes increased redundancy in recall across individuals, and conversely higher nominal group recall shows variety of items remembered by the group members later. As expected, the final nominal recall in the CCI condition (.63) was lower than in the III condition (.76), t (34) = 4.92, SE = .02, d = 1.60, indicating that the repeated collaboration within the identical group promotes more overlaps among the items recalled during the final individual recall (see also Blumen & Rajaram, 2008). In contrast, the final nominal recall in the CRI condition (.78) was comparable to that of the III condition (.76), $t < 1$; this outcome shows that the number of non-redundant items that the participants in the CRI condition recalled during their post-collaborative individual test was comparable to that of the participants who had never collaborated with others.

Finally, the comparison between CCI and CRI conditions showed higher final nominal group recall in the CRI condition (.78) than in the CCI condition (.63), t (34) = 5.42, SE = .03, d = 1.86. This difference in the nominal group recall between CCI and CRI (15% in magnitude) should be interpreted with some caution as final individual recall in the CRI condition (.52) was also higher compared to the CCI condition (.48) (4% in magnitude). However, these patterns of nominal group recall in Recall 3 nonetheless show the convergence of memory across participants after they collaborated repeatedly with the same group members (CCI) and divergence after they collaborated with changing group members (CRI). These patterns reveal the formation of collective memory among three individuals who repeatedly worked together in the CCI condition and its relative absence in the CRI condition. We provide a more in-depth analysis of this initial preview of collective memory formation in the next section.

Collective memory

We examined the formation of collective memory by summing the proportion of items that are collectively recalled and that are collectively omitted in the final individual recall of three members who previously worked as a group (Cuc et al., 2006; Stone et al., 2010). For example, let us say three group members individually studied a list consisting of *apple*, *piano*, *water* and *meadow*, and in the post-collaborative individual recall session, the first group member recalled *apple* and *piano*, the second member recalled *apple* and *water*, and the third member recalled *apple* and *water*. In this example, *apple* would be counted towards calculating *collective recollection* scores because all three individuals recalled this item, whereas

[2] The variety was separately quantified using the audio-recorded data collected during every collaborative recall session. We examined the proportions of items recalled by other group members (i.e., re-exposure) during the first and second collaborative sessions of CCI and CRI conditions. As expected, the re-exposure was not different between CCI (M = .34, SE = .01) and CRI (M = .33, SE = .01) during Recall 1, t (88) = 1.01, SE = .02, p = .32, but significantly higher for CRI (M = .44, SE = .01) than for CCI (M = .39, SE = .01) during Recall 2, t (88) = 3.62, SE = .02, $p < .001$, d = .78.

[3] For the CRI condition, the data needed for this analysis were available for 12 triads. The findings reported using unequal sample size analyses were replicated even when using 12 triads in both conditions.

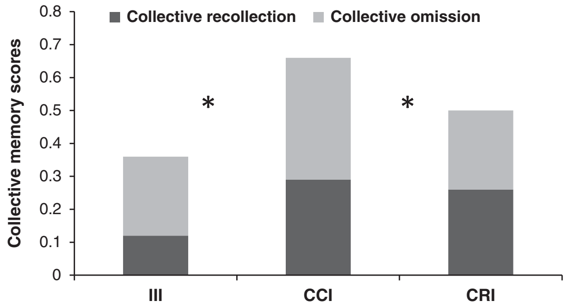

Figure 4. Collective memory scores across conditions (*$p < .05$).

meadow would be counted towards calculating *collective omission* scores because none of the individuals recalled this item. The *collective memory* score is calculated by summing the collective recollection and collective omission scores. In this context, the nominal group-recall measure described earlier is a reverse measure of the collective omission measure, such that the former indexes non-redundancies in items recalled, whereas the latter indexes the overlap in the items *forgotten by all* group members as a function of previous collaboration.

Overall, the mean collective memory score was highest for the CCI condition (.66), intermediate for the CRI condition (.50), and lowest for the III condition (.36) (Figure 4). As expected, collective memory scores in both the CCI and CRI conditions were greater (i.e., more overlap) than the III condition, t (34) = 11.39, SE = .03, d = 3.86, t (34) = 4.88, SE = .03, d = 1.62, respectively. These patterns indicate that collective memory was more likely to form when participants collaborated than when they did not. Furthermore, collective memory was greater when participants continued to work with the same group of people; collective memory scores were significantly higher in the CCI condition than in the CRI condition, t (34) = 5.08, SE = .03, d = 1.66. The higher collective memory for the CCI group was driven by lower collective omission scores in the CRI condition (.24) than in the CCI condition (.37), t (34) = 5.13, SE = .03, d = 1.46.

These findings are consistent with the idea that repeatedly collaborating with the same group members prunes away responses not shared by more than one member (see Rajaram & Pereira-Pasarin, 2010). Collective memories after repeated collaboration (CCI) also reflect incorporating of others' memories during collaboration, as indicated by higher collective recollections in the CCI (.29) group compared to the III (.12) group, t (34) = 6.63, SE = .03, d = 2.36. Yet, this process appears to be no more likely with repeated collaborations with the same members than with different members because the collective recollection scores in the CRI (.26) conditions were also higher than in the III condition, t (34) = 6.77, SE = .02, d = 2.21, with no difference between CCI and CRI, $t < 1$.

Weaving together the findings reported in this and the previous sections, an interesting pattern emerges with respect to the effects of working with different group members, or a larger network (the CRI condition). Even though the correct individual recall levels and the nominal group-recall levels (i.e., non-overlap among group members) in Recall 3 were higher in the CRI condition than in the CCI condition, collective recollections in the two conditions were comparable, whereas collective omissions in the CRI condition were lower compared to the CCI condition. These patterns show that higher individual recall does not indicate that all individuals who were exposed to two reconfigured groups would *share their memories* for all the items. Rather, these patterns show that working with a larger network of individuals (in this case, the influence of potentially eight other individuals filtered through four different partners across two group recall sessions), each individual acquired more memories but these memories did not necessarily overlap across individuals. As a result, the *variety of information* represented across the larger network of nine individuals clearly increases what each individual within the network comes to possess, but it does not result in an increased overlap of representations compared to recalling with the same people repeatedly. These findings indicate that individuals who are exposed to more collaborating partners *collectively know more*, but *do not collectively share more* than the individuals working with a smaller set of partners.

Retrieval organisation (paired frequency [PF])

Next, we used the PF measure (Sternberg & Tulving, 1977) to assess the structure of memory across the two collaborative conditions (CCI and CRI). This measure provides evidence of subjective organisation that characterises individual recall even for unrelated words. PF is calculated by measuring an observed value of frequency with which pairs of studied items are recalled together

TABLE 2
Paired frequency and standard errors (in parentheses)

Condition	*List and R1*	*R1 and R2*	*R2 and R3*	*R1 and R3*
III	.31 (.11)	2.40 (.25)	3.15 (.24)	2.46 (.23)
CCI	–	2.71 (.31)	2.42 (.22)	1.81 (.19)
CRI	–	1.42 (.21)	2.90 (.23)	1.81 (.21)

across two attempts, regardless of their relative order (e.g., "dress, bottle" or "bottle, dress"), and then correcting the observed value by subtracting an expected value of paired recall due to chance (see Sternberg & Tulving, 1977, for further computational details for this measure). This measure of adjacent recall across two attempts provides a window into the stability of the output order in recall. This measure has been widely used to assess retrieval organisation of words in individual recall as well as to assess the organisation in group recall in past collaborative memory research (Blumen & Rajaram, 2008; Finlay et al., 2000; Weldon & Bellinger, 1997).

PF values ranged from high to low (3.15 to .31; Table 2), depending on the extent of organisation promoted by different recall conditions. In line with expectations, PF measure was rather low (.31) when the order of items in the study list and the output order of the first recall in the baseline III condition were compared. This finding illustrates that people tend to impose their own subjective organisation on the information they process. Having confirmed this basic phenomenon, we assessed the PF measures for collaboration shaped individual and group organisation in recall.

As expected, the PF organisation in the III condition was substantial from Recall 1 to Recall 2 (2.40), indicating stable organisation across repeated individual recalls. This organisation further increased across Recalls 2 and 3 (3.15), and was significantly higher than the PF measure across Recalls 1 and 2 (2.40), t (53) = 2.92, SE = .25, d = .42. Group recall in the CCI condition also showed stable organisation across Recalls 1 and 2 and the PF measures for the first two recalls across the III (2.40) and the CCI conditions (2.71) did not differ statistically, t (106) = 1.02, SE = .30, p = .31. These direct replications of past findings show that groups develop a stable organisation when they repeatedly collaborate (Blumen & Rajaram, 2008; Weldon & Bellinger, 1997).

Novel to the present study, the PF measure for the first two recalls in the CRI condition (1.42) was significantly lower than in the CCI condition (2.71), t (106) = 6.04, SE = .21, d = 1.30 as well as than in the III condition (2.40), t (106) = 3.61, SE = .27, d = .69, indicating that working in the identical groups (CCI) stabilised the organisation of participants' recalls whereas working in the reconfigured groups (CRI) destabilised this organisation.

Across Recalls 2 and 3, as expected the organisation of the participants in the CCI condition was stable such that the PF measure across Recalls 1 and 2 (2.71) was comparable to the measure across Recalls 2 and 3 (2.42), t (53) = 1.29, SE = .23, p = .20. In contrast, the organisation of the participants in the CRI condition became relatively destabilised across Recalls 1 and 2 (1.42) by the effect of group reconfiguration, and in fact, the organisation was more stable from Recall 2 to Recall 3 (2.90), t (52) = 5.62, SE = .26, d = 1.09, indicating that when the disruptive influence of reconfiguration was removed, individual members followed the organisation developed by the immediately preceding group recall.

The impact of proximal versus distal partners

The CRI condition in our design enabled us to assess the extent to which a given member's memory is shaped not only by her immediate group partners (i.e., proximal partners), but also by the partners of these partners (i.e., distal partners). We took individuals' final recall from the CRI condition, sorted the recalled items into three categories based on whether an item was recalled by Oneself (the target individual in this analysis), the Proximal Partners (four partners from each collaborative recall sessions with whom the target individual collaborated) or Distal Partners (proximal partners' partners with whom the target individual never collaborated, again a total of four). Whether an item was counted as recalled by Oneself, Proximal Partners, Distal Partners was determined by who recalled the item initially across three recall sessions. For example, let us say that Participants A, B and C collaborated during Recall 1 and a given item was recalled by Participant A during this first collaborative recall. If this item was recalled by Participant B in Recall 2 (who now collaborated during this second recall with Participants D and E), and then finally recalled by Participant B during the

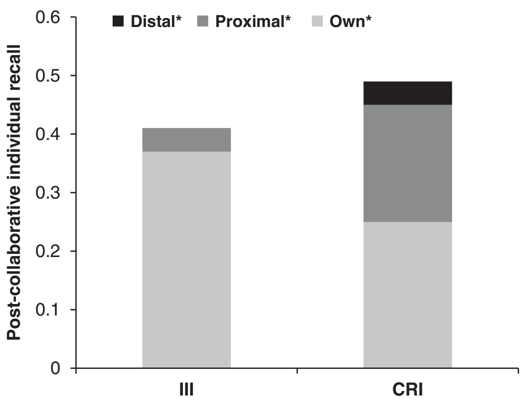

Figure 5. The influence of proximal versus distal partners during collaboration on post-collaborative individual recall (*$p < .05$).

final individual recall, the item counted as recalled by Proximal Partner (i.e., Participant A; Participant B's Proximal Partner). If this item, originally produced by Participant A, was also recalled by Participant D in the final individual recall (who only collaborated with Participant B during the second recall, and never with Participant A), this item counted as recalled by a Distal Partner (i.e., Participant A). After conducting these analyses with the CRI condition by using the audio-recorded data during collaborative recall sessions, we considered comparisons to the baseline from the nominal groups in the III. Since only one participant in the baseline (III) recalled one item that is to be counted as the influence of distal partners (M = .0004), we conducted a single-sample t-test on the influence of distal partners in the CRI condition.

The results are intriguing (Figure 5). Despite the fact that our stimuli consisted of unrelated words and thus produced small effects, we were able to detect the influence of distal partners on post-collaborative individual memory in the CRI condition; there was a 4% influence of distal partner (with whom an individual never directly collaborated) on the final individual recall (M = .04, SE = .005), t (35) = 8.15, SE = .04, $p < .001$, d = 1.36. As expected, the influence of proximal partners (M = .20, SE = .01) was greater than the influence of distal partners, t (35) = 14.83, SE = .01, $p < .001$, d = 2.47.

GENERAL DISCUSSION

The present study investigated the influence of collaboration on group and individual memory in a larger and varying network than in the small groups of two or three previously reported in the cognitive psychology literature. We were particularly interested in how collaborating with the same versus a different group of people influence group memory during collaboration, post-collaborative individual memory, and the formation of collective memory. To test this question, we introduced a new experimental paradigm that compared identical groups of three members who collaborated twice to reconfigured groups, again consisting of three members, but where the members varied across the two collaborations and thus created an influence of four proximal and eight distal partners on each individual participant. Our results reveal that (1) collaborative inhibition was eliminated when people engage in repeated collaboration with different sets of people each time, whereas repeatedly collaborating with the same sets of people does not show such elimination; such an absence of collaborative inhibition is rarely seen in the literature and it came about in this study from the fact that forgetting that occurs through retrieval disruption during collaboration is outweighed by the re-exposure benefits that are particularly large when collaborating with different sets of people; (2) such re-exposure effects benefitted post-collaborative individual memory to a greater extent for the reconfigured group compared to the identical group; (3) collaborating with the same or different sets of people was equally effective for creating shared memories that group members collectively remember, but collaborating with different people led to less collective forgetting, compared to collaborating with the same people; (4) collaborating with the same group of people stabilised retrieval organisation, whereas group re-configuration had a de-stabilising effect on retrieval organisation of groups; (5) the most recent collaboration influenced how people structure memories; and (6) post-collaborative memory was influenced not only by the partners with whom individuals collaborated but also by their partners' partners with whom the individual never directly collaborated.

When re-exposure benefits exceed retrieval disruption

Although collaborative inhibition is a very robust phenomenon and is difficult to eliminate, a few studies have reported instances where the degree of the disruptive effect can be diminished. For example, Finlay et al. (2000) found an absence of collaborative inhibition when their study design allowed participants to share similar retrieval strategies with another group member (using cued-recall). Congleton and Rajaram (2011) also observed a complete elimination of collaborative inhibition where repeated individual retrieval (II) before collaborative recall solidified participants' retrieval organisation. Thus, the extent of retrieval disruption these participants suffered during collaboration was buffered by a strong retrieval organisation, and as a result, collaboration inhibition did not occur. Meade et al. (2009) showed a reversal of the collaborative inhibition effect, such that when a collaborating group consisted of members who had expertise in the topic of discussion—indicating a strongly organised set of information—collaborative inhibition did not occur, and in fact flipped to what is termed collaborative facilitation. These studies demonstrated a powerful role of retrieval organisation in modulating collaborative inhibition. In the present study, we identified another critical circumstance where collaborative inhibition can be eliminated; when the benefits of re-exposure are increased simply by working with a different group of people.

The enhanced benefit of re-exposure in the reconfigured collaboration condition is especially evident in comparison to the repeated identical group collaboration. It is noteworthy that although collaborative inhibition persisted during the second recall of the identical group (CCI), the size of the collaborative inhibition effect was reduced (from 16% in Recall 1 to 11% in Recall 2). This is a direct replication of the findings for the CCI condition in Blumen and Rajaram (2008). As the authors noted, this reduction of collaborative inhibition could be due to the re-exposure benefits participants gained during the first collaborative recall session, but the benefit was not enough to entirely offset the operation of the retrieval disruption mechanism during the second collaborative recall session. Thus, the study opened the question about the circumstances where re-exposure benefits can exceed retrieval disruption and benefit subsequent individual memory the most. In the present study, we demonstrated that re-exposure benefits can offset the retrieval disruption when people work with different set of people.

Collective memory and retrieval organisation

In considering the nature of collective memory in identical versus reconfigured (and thus, larger) networks, we considered both collective recollection and collective forgetting. Whereas collective recollection was equally high across the two groups, the identical group showed significantly higher collective forgetting that, in turn, resulted in stronger collective memory for the identical group compared to the reconfigured group.

However, even though collective recollection was equally high in both groups, these scores for each group should be attributed to two different independent processes. As we reasoned in the introduction, the identical group was expected to have more solidified group-level organisation across recall sessions, which would increase the degree of shared representation among group members. This expectation was supported by the significantly higher PF scores across the first and second recall sessions in the identical group compared to the reconfigured group. On the other hand, the reconfigured group was expected to gain more variety in their memory through re-exposure benefits from changing group members during the second recall and make the properties of their collective memory different from that of the identical group. This prediction was supported by the fact that the final individual recall level of the reconfigured group was higher than that of the identical group, and therefore whereas their collective recollection was no higher than that of the identical group, their collective forgetting was lower than the identical group.

Furthermore, in the PF measure, we observed a recency effect of sorts also reported by Congleton and Rajaram (2013). People exhibited greater reliance on the second collaborative recall structure in their post-collaborative individual recall, compared to the first collaborative recall structure. Whereas in Congleton and Rajaram (2013) this pattern was observed by examining the performance of participants who participated in different recall sequences such as collaboration first, individual second or vice versa, or collaboration with the same groups, we were able to establish this effect with different reconfigured groups across two recall sessions. Thus, our reconfigured group condition provides converging evidence to the discovery that the most recent, preceding collaboration has the greatest impact on post-collaborative memory organisation.

The impact of proximal versus distal partners

The practice of varying group configuration in an experimental setting has great potential for expanding the current understanding of social influences on memory. Current laboratory reports come from small groups of dyads, triads and occasionally tetrads. Needless to say, however, social transmission of information is a frequent and ubiquitous practice in human culture, and it certainly occurs beyond small groups. As such, there are many potential applications of our laboratory paradigm to understanding social transmission of information in the real world. To illustrate with a simple example, let us say two friends, Amy and Emily, talk about a book they both read, *Moonwalking with Einstein*. Later Amy may go on to discuss the book with her boyfriend Mike. Even if Mike and Emily never discussed the book together, Mike's final representation of the book would be likely influenced by Emily's representation that she shared with Amy who did discuss it with Mike. One can further extrapolate such spread of transmission through larger networks of friends and family for information of personal relevance (e.g., family weddings, sickness, childbirth), as well as information of broader interest, ranging from positive to traumatic, that spreads through wider social and public-level networks as well, (e.g., royal weddings, sports, elections, war, natural disasters). In fact, many researchers have noted the importance of investigating such social transmission of each individual's representation across a larger network of communities and societies that would eventually shape group memories at the familial, societal and cultural levels (e.g., Bartlett, 1932; Barnier, Sutton, Harris, & Wilson, 2008; Coman & Hirst, 2012; Halbwachs, 1950/1980; Hirst & Manier, 2008; Wang, 2008; Wertsch & Roediger, 2008).

To this end, devising approaches that test larger groups is an important goal in this area of study. One such recent approach is the use of computational models that provides an effective tool to deal with "real world" scales, e.g., large number of individuals, arbitrary arrangements of individuals in social networks (Coman, Kolling, Lewis, & Hirst, 2012; Luhmann & Rajaram, 2013). Our reconfigured group paradigm provides another such approach, and does so in the experimental domain. This laboratory preparation enables an empirical test of participants in groups that are effectively larger than two to four in size because we can examine the impact of not only the immediate partners but also the potential impact of the partners' partners. In other words, this paradigm creates a situation in the laboratory that resembles the real-world context of the prior example on Persons Amy–Emily–Mike, and thus provides a critical bridge between small-group experiments and large-scale computational approaches. As we showed through the effects of both the proximal and the distal partners on memory, such laboratory designs provide a building block for future research on how variations in the group structure can reveal the process of social transmission of memory.

CONCLUSION

In conclusion, our findings on each dimension—group memory, post-collaborative individual memory, collective memory, transmission of memory through distal partners, and organisational structure of the memories—showed very distinct patterns for transmission of memory across different network configurations of identical groups and reconfigured groups. The present study presents an experimental approach, and transports investigations of social memory propagation in humans to a new level of empirical analysis.

The present study also provides potential practical applications to educational settings where students often engage in multiple study group sessions to study the same lecture materials. Whereas repeated group collaboration benefits later individual memory (see also Blumen & Rajaram, 2008, 2009), as shown in the present study the benefits become greater by simply switching study partners.

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