



## Optimizing group collaboration to improve later retention



Helena M. Blumen<sup>a,\*</sup>, Kayla E. Young<sup>b</sup>, Suparna Rajaram<sup>c</sup>

<sup>a</sup> Albert Einstein College of Medicine, United States

<sup>b</sup> Virginia Commonwealth University, United States

<sup>c</sup> Stony Brook University, United States

### ARTICLE INFO

#### Article history:

Received 15 February 2014

Received in revised form 15 May 2014

Accepted 30 May 2014

Available online 10 June 2014

#### Keywords:

Collaborative memory

Group memory

Collaborative inhibition

Collaboration benefits

Post-collaborative recall benefits

Retrieval disruption

Re-exposure

Cross-cuing

### ABSTRACT

In educational settings, collaborative learning and recall are often encouraged and sometimes required. Yet, we know very little about the cognitive processes that operate during collaboration, and how they can be optimized to improve later individual retention. The current study aimed to address this gap by testing how the operations of three cognitive processes during collaboration: (1) retrieval disruption, (2) re-exposure and (3) cross-cuing, influence the formation of individual and group recall strategies. Across two experiments, 252 undergraduates studied a word list and recalled it in a Collaborative–Collaborative–Individual–Individual (CCII), an Individual–Collaborative–Individual–Individual (ICII), or an Individual–Individual–Individual–Individual (IIII) sequence. A 40-min delay was inserted early (CC-delay-II, IC-delay-II and II-delay-II; Experiment 1) or later in the recall sequence (CCI-delay-I, ICI-delay-I and III-delay-I; Experiment 2) to assess the differential benefits of different recall sequences. Regardless of where the delay occurred in the recall sequence, both collaboration conditions (CC and IC) benefited later individual recall to a greater extent than the individual recall condition (CCII > III and ICII > IIII). Repeated collaboration (CC) generated greater post-collaborative recall benefits than single collaboration (IC) when the delay was inserted early in the recall sequence (CC-delay-II > IC-delay-II), but the benefits were equivalent when the delay was inserted later in the recall sequence (CCI-delay-I–ICI-delay-I). Implications for future research and educational applications are discussed.

© 2014 Society for Applied Research in Memory and Cognition. Published by Elsevier Inc. All rights reserved.

Collaborative learning and recall are an often encouraged and sometimes required component of undergraduate, graduate, and medical students' course work and exam preparation; for reviews see (Johnson & Johnson, 2009; Michaelsen, Knight, & Fink, 2002). Yet, the cognitive processes that operate during collaboration are not well-understood. The influence of group interactions on learning and recall has been a popular research topic in anthropology, history, social psychology, and sociology for quite some time (Bartlett, 1932; Halbwachs, 1950/1980; Wegner, 1987; Wertsch & Roediger, 2008). In social and educational psychology, for example, several studies have shown that cooperative learning can be beneficial, and is influenced by social factors such as individual accountability and the appropriate use of social skills (Johnson & Johnson, 2009). In cognitive psychology, however, collaborative

memory remains a relatively novel research topic, and has primarily focused on the costs of recalling in a group setting – i.e. the counterintuitive finding that a collaborating group recalls less information than the pooled or non-overlapping recall produced by the same number of persons recalling alone, a phenomenon termed *collaborative inhibition* (Basden, Basden, Bryner, & Thomas, 1997; Weldon & Bellinger, 1997); for reviews see (Barnier & Sutton, 2008; Barnier, Sutton, Harris, & Wilson, 2008; Blumen, Rajaram, & Henkel, 2013; Harris, Paterson, & Kemp, 2008; Hirst & Manier, 2008; Rajaram & Pereira-Pasarin, 2010; Weldon, 2001).

A key reason for the emergence of collaborative inhibition during group recall is *retrieval disruption* (Basden et al., 1997). Retrieval disruption occurs when one group member's output disrupts another group member's retrieval organization (or retrieval plan), and leads the latter member to contribute less information than they would if they had worked alone. The retrieval disruption account is supported by the fact that collaborative inhibition increases as the number of varied retrieval plans increase. For example, a large group of collaborating persons likely have a large number of varied retrieval plans, and therefore they experience

\* Corresponding author at: Albert Einstein College of Medicine, 1165 Morris Park Avenue, Room 434, Bronx, NY 10461, United States. Tel.: +1 718 430 3810.

E-mail addresses: [helena.blumen@einstein.yu.edu](mailto:helena.blumen@einstein.yu.edu), [helenablumen@gmail.com](mailto:helenablumen@gmail.com) (H.M. Blumen).

more collaborative inhibition during group recall, compared to a small group of collaborating persons with fewer retrieval plans (Basden, Basden, & Henry, 2000; Thorley & Dewhurst, 2007). This account is also supported by the fact that collaborative inhibition decreases in situations that are characterized by strong individual retrieval plans that are less susceptible to disruption than retrieval plans that are relatively weaker (Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Pereira-Pasarin & Rajaram, 2011). For example, collaborative inhibition decreases following repeated study or repeated testing because individual or group retrieval plans are solidified with repeated individual study or repeated group recalls (Blumen & Rajaram, 2008; Pereira-Pasarin & Rajaram, 2011). Finally, this account is supported by the fact that collaborative inhibition is usually reduced or it disappears in memory tasks that do not require strong retrieval plans. For example, on memory tasks such as cued recall and recognition, where strong retrieval cues are provided, collaborative inhibition usually disappears (Basden et al., 1997; Clark, Hori, Putnam, & Martin, 2000; Finlay, Hitch, & Meudell, 2000; Thorley & Dewhurst, 2009); although see (Danielsson, Dahlström, & Andersson, 2011; Kelley, Reysen, Ahlstrand, & Pentz, 2012; Meade & Roediger, 2009).

Prior group collaboration can also have robust benefits on later individual memory (Barnier & Sutton, 2008; Barnier et al., 2008; Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Harris, Barnier, & Sutton, 2011a; Harris, Barnier, & Sutton, 2013; Henkel & Rajaram, 2011). For example, we have shown that *post-collaborative recall benefits* depend on the particular sequence in which collaborative and individual recalls are arranged (Blumen & Rajaram, 2008). More specifically, we have shown that the sequences of repeated collaborative recall trials, and a single collaborative recall trial preceded by an individual recall trial, benefit later individual recall (CCI & ICI > III). However, the sequence of a single collaborative recall trial followed by an individual recall trial does not generate such post-collaborative recall benefits (CII–III). We have also shown that the benefits of repeated collaborative recalls over repeated individual recalls holds up to a week following collaboration in improving later individual recall (Blumen & Stern, 2011). Finally, we have shown that repeated collaboration with different groups of people generates greater post-collaborative recall benefits than repeated collaboration with the same group of people (Choi, Blumen, Congleton, & Rajaram, 2014). The broad educational implications of these findings are that repeated group assignments and an individual assignment that is followed by a group assignment can potentially benefit later individual exam performance. In the present study, we focused on a relatively specific goal, i.e. we compared the patterns of post-collaborative recall benefits between the ICI and the CCI recall sequences in the context of specific cognitive processes – namely, retrieval disruption, re-exposure, cross-cuing, and the emergence of individual and group-level retrieval plans – that are presumed operate in these conditions. We pursued this goal because it provides a critical first step toward developing more targeted, applied studies as well as recommendations for educational settings. Using the outcomes of such investigations, future research using educationally relevant materials in educational settings will help generalize these findings and broaden the applied impact of this research.

Post-collaborative recall benefits are considered to be primarily a function of two cognitive processes: *re-exposure* and *cross-cuing* (Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Harris et al., 2011a; Harris, Keil, Sutton, Barnier, & McIlwain, 2011b; Meudell, 1996; Meudell, Hitch, & Boyle, 1995; Meudell, Hitch, & Kirby, 1992; Weldon & Bellinger, 1997). Re-exposure benefits arise during collaboration when a person hears group members recall study information that they themselves had forgotten. This process essentially creates a second study

opportunity for the listening member. Past research shows that benefits of re-exposure are best when a group member has had the opportunity to previously strengthen their own *individual recall strategies*, via an individual recall session prior to collaboration, e.g. in the ICI sequence of recalls (Blumen & Rajaram, 2008; Congleton & Rajaram, 2011). This strengthened retrieval plan protects the individual against experiencing retrieval disruption and enables them to benefit from the input of other group members without losing their own recallable items. As a result, individuals show greater post-collaborative recall in an ICI recall sequence than in a CII recall sequence (Blumen & Rajaram, 2008).

Re-exposure also increases post-collaborative recall following two consecutive collaboration sessions (CCI) to a greater extent than a single collaboration session (CII) (Blumen & Rajaram, 2008). Here, although the first collaborative recall session is subject to collaborative inhibition and leads to temporary loss in recall of an individual's own memories, the second collaborative recall session provides repeated re-exposure to other's recall, thereby reinforcing the input of others and facilitating the development of *group recall strategies*. Together, these reinforced re-exposure benefits and the emergence of group-level recall strategies can offset the costs of retrieval disruption associated with collaborative recall. This proposition is supported by the evidence that collaborative inhibition is either reduced or eliminated during a second, consecutive collaboration session (Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Congleton & Rajaram, 2014).

Cross-cuing arises during collaborative recall when a person hears other group members recall study information that they themselves had forgotten and uses it as a cue to recall additional information. The cross-cuing process is intuitive, and it has been also documented in conversational output (Harris, Keil et al., 2011). However, its contributions to collaborative recall productivity are relatively difficult to distinguish from the benefits associated with re-exposure. This is because re-exposure and cross-cuing operate concurrently and are contingent on each other (Blumen et al., 2013; Meudell, 1996; Meudell et al., 1995, 1992). Specifically, when re-exposure to forgotten study information increases, the opportunities for cross-cuing also increase because more cues become available to support additional recall. Also, while cross-cuing occurs during collaboration, its effects only emerge in post-collaborative recall and may be more easily detected after a delay (Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Takahashi & Saito, 2004). This is because cross-cuing evokes additional or repeated retrieval whereas re-exposure evokes repeated study. Research on individual learning and recall shows that repeated individual retrieval produces more long-term benefits on later individual retrieval than does repeated study (Karpicke & Roediger, 2008; Roediger & Karpicke, 2006). Finally, cross-cuing benefits may also be more likely to occur after repeated collaborative recall trials than after a single collaborative recall. This is because we know from the literature on individual recall that repeated retrieval promotes the integration or organization of information (Rundus, 1971). For collaborative situations, we expect this process of integration to be stronger when recalls (or retrieval plans) begin to converge through repeated collaboration (i.e. when both recalls are collaborative) rather than when a sequence of individual and collaborative recalls is implemented (Congleton & Rajaram, 2011; Congleton & Rajaram, 2014; Weldon & Bellinger, 1997).

In the current study we aimed to determine how retrieval disruption, re-exposure, and cross-cuing during collaboration influence the formation of individual retrieval plans, group retrieval plans and later individual retention, as a function of different collaborative recall sequences. We were also interested in how these processes influence the amount of shared (or overlapping) and non-shared (or unique) information that is remembered following

collaboration (Congleton & Rajaram, 2014; Cuc, Ozuru, Manier, & Hirst, 2006; Stone, Barnier, Sutton, & Hirst, 2010). This is because the extent to which students come to share the same knowledge base may depend on the type of collaborative learning sequence, and our experiments can provide the initial explorations of this issue. The ultimate goal of this study was to begin to provide evidence-based suggestions for optimizing later individual retention in educational settings.

To gain maximum experimental control in these foundational experiments, we presented participants with a list of words to study and then they were asked to recall them in a Collaborative–Collaborative–Individual–Individual (CCII), an Individual–Collaborative–Individual–Individual (ICII) or an Individual–Individual–Individual–Individual (IIII) recall sequence. The ICII condition enabled a test of the efficacy of securing individual retrieval strategies prior to collaboration on post-collaborative recall benefits. The CCII condition enabled a test for promoting cross-cuing and for the efficacy of strengthening group recall strategies during repeated collaboration. In Experiment 1, a 40-min delay was inserted early in the recall sequence (CC-delay-II, IC-delay-II and II-delay-II). In Experiment 2, a 40-min delay was inserted later in the recall sequence (CCI-delay-I, ICI-delay-I and III-delay-I).

*Insertion of delay early in the recall sequence:* We predicted that inserting a delay early in the recall sequence would lead to greater post-collaborative recall benefits in the CC-delay-II condition than in the IC-delay-II condition, for reasons described above. We also predicted that individuals would recall more shared information (Barber, Rajaram, & Fox, 2012; Blumen & Rajaram, 2008; Congleton & Rajaram, 2014; Cuc et al., 2006; Henkel & Rajaram, 2011; Stone et al., 2010) following repeated collaboration (CC-delay-II) than following an individual recall trial and a single collaborative recall trial (IC-delay-II). This is because repeated collaboration promotes cross-cuing and, over delay, supports the transfer of other group members' input to later individual recall. Further, items that are not produced during the first collaborative recall trial due to retrieval disruption are likely to be absent during the second collaborative recall trial as well, thereby increasing the number of items that are jointly 'forgotten' (Choi et al., 2014; Stone et al., 2010) compared to the ICII condition. In contrast, we predicted that individuals would recall more non-shared (unique) information when the sequence of an individual recall trial and a single collaborative recall trial was performed prior to the delay (IC-delay-II) than when repeated collaborative recalls were performed prior to the delay (CC-delay-II). This is because an individual recall trial and a single collaborative recall trial permit individuals to benefit not only from re-exposure during collaboration, but also from strong individual recall strategies that were solidified prior to collaboration, thus maintaining their individual recall products in later recalls. Taken together, the predictions of Experiment 1 aimed to highlight the importance of repeated collaboration for reinforcing the effects of re-exposure, cross-cuing and the formation of group recall strategies to support post-collaborative recall benefits over a delay.

*Insertion of delay later in the recall sequence:* We predicted that inserting a delay later in the recall sequence would lead to similar post-collaborative recall benefits in the ICI-delay-I condition and the CCI-delay-I condition. This is because an individual recall trial prior to collaboration facilitates the integration and organization of one's own recall information and the individual recall after collaboration (but preceding the delay) facilitates the integration of both re-exposure and cross-cuing benefits in the ICI-delay-I condition. This advantage of immediately integrating all three sources of memory improvement can bring the performance in the ICI-I sequence on par with the CCI-I sequence where the initial retrieval organization (first individual recall) is not available but enhanced benefits of repeated re-exposure and cross-cuing from

repeated collaboration are integrated in individual recall preceding the delay. We also predicted that individuals would recall similar amounts of shared information following repeated collaborations (CCI-delay-I) and the recall sequence that included a single collaborative recall trial (ICI-delay-I) because in both conditions they were given the opportunity to integrate the other group members' input through individual recall prior to the delay. With respect to the non-shared information, however, we once again expected the non-shared recall to be greater in the ICI-delay-I condition than the CCI-delay-I conditions because (as in the IC-delay-II condition of Experiment 1) this condition permits individuals to strengthen the recall of their own remembered information prior to entering collaboration, and then to return to that recall organization during the subsequent individual recall. Taken together, the predictions of Experiment 2 aimed to highlight the importance of solidifying individual recall strategies prior to a single collaborative recall trial in order to benefit from re-exposure and cross-cuing during group recall.

## 1. Method

The methods for both experiments are presented together because the only critical change was the time point at which a delay of 40 min was inserted during the recall sequence.

### 1.1. Participants

A total of 252 undergraduates from Stony Brook University participated in the experiments for partial course credit or a small payment ( $n = 126$  in each experiment). Participants provided written consent before the experiment and were debriefed upon its completion.

### 1.2. Design

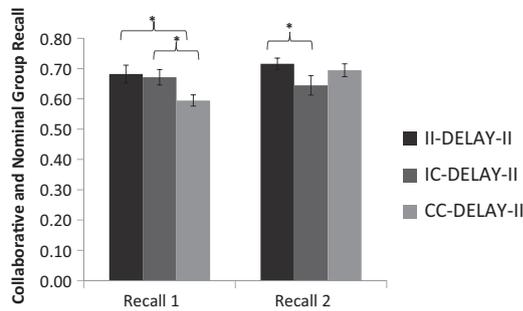
In both experiments, recall sessions was the within-subjects factor (Recall 1, Recall 2, Recall 3 and Recall 4) and type of recall sequence was the between-subjects factor. In Experiment 1, the recall sequence was CC-delay-II, IC-delay-II and II-delay-II (the third condition served as the control condition). In Experiment 2, the recall sequence was CCI-delay-I, ICI-delay-I and III-delay-I (the third condition served as the control condition). In both experiments, 14 three-person groups (i.e. 42 individuals), always strangers, were assigned to each of the three recall sequence conditions.

### 1.3. Materials

Fifty-four concrete nouns (40 targets, 7 primacy buffers, 7 recency buffers) were selected as study items from an updated and extended version of Paivio, Yuille & Madigan word norms (Clark & Paivio, 2004; Paivio, Yuille, & Madigan, 1968). Two randomly ordered study lists were used to minimize order effects. Study items were presented on a computer screen. Participants recorded their responses using paper and pen.

### 1.4. Procedure

The methodology and procedure were modeled after Blumen and Rajaram (2008), and the experiment sequence consisted of a study phase, a distracter phase, and four consecutive recall phases. During study, each item was presented for 6 s and the participants were asked to rate the pleasantness of the meaning of study items from 1 (very unpleasant) to 5 (very pleasant). During the distracter phase, participants were asked to record as many U.S. cities as they could for 7 min. During the recall phase, participants were given



**Fig. 1.** Collaborative and nominal group recall (in proportion) during Recall 1 and Recall 2 as a function of recall sequence condition in Experiment 1.

10 min in each recall session to individually and/or collaboratively recall as many study items as possible. Collaborative recall was completed in groups of three individuals working together and collaborating individuals were encouraged to contribute as many study items as possible. Collaborating individuals were also told to resolve disagreements among themselves. One individual was randomly selected to record the group's responses on a piece of paper. In Experiment 1, a 40-min delay was inserted after the second recall trial. In Experiment 2, a 40-min delay was inserted after the third recall trial. All other recall trials were separated with a shorter (5-min) delay. Participants were permitted to leave the experiment room during the 40-min delay, but were asked to return promptly for follow-up questions and not discuss the experiment with each other (or others) during this break. They were also uninformed about the upcoming recall session/s. The entire procedure lasted about 2 h.

## 2. Results and discussion

In both experiments, we examined collaborative and individual recall performance in three different ways:

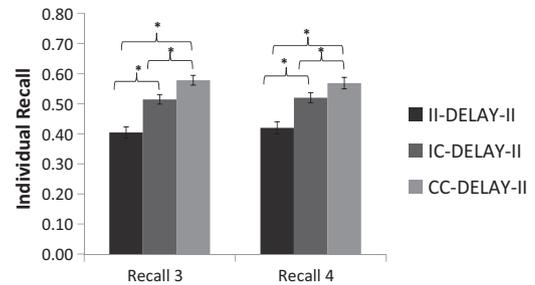
- (1) We assessed the presence of collaborative inhibition during Recall 1 and Recall 2. Nominal group recall was computed by randomly pooling the non-redundant responses of three individual working alone (in the IIII condition) and compared to the corresponding collaborative recall (Weldon & Bellinger, 1997).<sup>1</sup>
- (2) We examined the presence of collaboration benefits on later individual recall during Recall 3 and Recall 4, in terms of the proportion of correct individual recall, against the control condition of IIII recall (Blumen & Rajaram, 2008).
- (3) The cascading effects of collaboration on later individual recall was also examined in terms of the proportion of overlap (shared recall following collaboration) and non-redundant information (unique recall following collaboration), provided during Recall 3 and Recall 4 (Choi et al., 2014).

## 3. Experiment 1

### 3.1. Collaborative inhibition

The proportions of collaborative and nominal group recall during Recall 1 and Recall 2, as a function of recall sequence condition, are displayed in Fig. 1. The presence of collaborative inhibition was

<sup>1</sup> The nominal group recall obtained from this random pooling of individuals was very similar to the nominal group recall obtained with the computational approach developed by (Kelley and Wright, 2010; Wright, 2007), which identifies the grouping that best fits the mean of the entire data set. For the sake of brevity, we therefore, chose to report only the former.



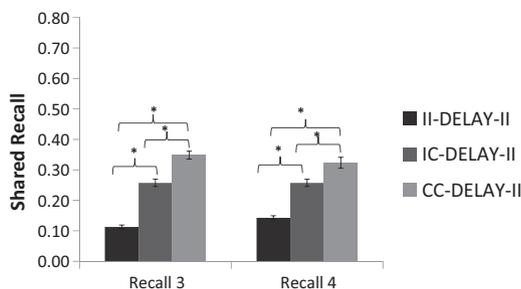
**Fig. 2.** Individual recall (in proportion) during Recall 3 and Recall 4 as a function of recall sequence condition in Experiment 1.

examined in a repeated-measure ANOVA with recall trial (Recall 1, Recall 2) as the within-subjects variable and recall sequence condition (CC-delay-II, IC-delay-II and II-delay-II) as the between subjects variable. There was a main effect of recall trial  $F(1, 39) = 7.84, p < .01, \eta^2 = .17$ , no main effect recall sequence condition  $F(2, 39) = 1.62, p > .05$ , and an interaction between recall trial and recall sequence condition  $F(2, 39) = 8.24, p < .01, \eta^2 = .29$ . Follow-up contrasts indicated that during Recall 1, nominal group recall was greater than collaborative group recall when the II-delay-II condition was compared to the CC-delay-II condition,  $t(39) = 2.48, p < .05$ , and when the IC-delay-II condition was compared to the CC-delay-II,  $t(39) = 2.18, p < .05$ . These findings show that collaborative inhibition was present during the first recall trial, and replicates previous findings; e.g. (Basden et al., 1997; Blumen & Rajaram, 2008; Weldon & Bellinger, 1997). Follow-up contrasts also indicated that during Recall 2, nominal group recall was greater than collaborative group recall when the II-delay-II condition was compared to the IC-delay-II condition,  $t(39) = 2.03, p < .05$ . Interestingly, when the II-delay-II condition was compared to the CC-delay-II condition,  $t(39) = .61, p > .05$  the collaborative inhibition effect did not persist. These findings suggest that collaborative inhibition may persist when preceded with an individual recall trial, but can disappear when preceded by a collaborative recall trial, and are consistent with previous findings (Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Congleton & Rajaram, 2014).

### 3.2. Post-collaborative recall benefits

The proportions of individual recall during Recall 3 and Recall 4 as a function of recall sequence condition are displayed in Fig. 2. Collaboration benefits on later individual recall as a function of recall sequence condition was examined in a repeated-measure ANOVA, with recall trial (Recall 3, Recall 4) as the within-subjects variable and recall sequence condition (CC-delay-II, IC-delay-II, and II-delay-II) as the between subjects variable. There was a main effect of recall sequence condition,  $F(2, 123) = 22.59, p < .001, \eta^2 = .27$ , but no main effect of recall trial,  $F(1, 123) = .49, p > .05$ , and no interaction between recall sequence condition and recall trial  $F(2, 123) = 1.80, p > .05$ . Follow-up contrasts (collapsed across Recall 3 and Recall 4) indicated that individual recall was greater in the IC-delay-II and CC-delay-II conditions, than in the II-delay-II condition,  $t(123) = 4.32, p < .001$  and  $t(123) = 6.62, p < .001$ , respectively. These findings show that prior collaborative recall benefits later individual recall to a greater extent than prior individual recall, regardless of whether preceded by an individual recall trial or a collaborative recall trial.

More importantly, for the present purposes, follow up contrasts also indicated that individual recall was greater following repeated collaborative recall trials (CC-delay-II) than following a single collaborative recall trial preceded by an individual recall trial



**Fig. 3.** Shared recall (in proportion) during Recall 3 and Recall 4 as a function of recall sequence condition in Experiment 1.

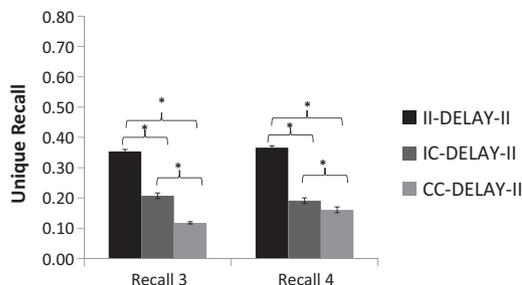
(IC-delay-II),  $t(123)=2.31, p<.05$ . This finding is consistent with our prediction that repeated collaborative recall trials provides increased benefits of re-exposure and cross-cuing, and support the transfer of group recall strategies to later individual recall over a delay compared to a single collaboration session. It is also consistent with the group recall findings from Recall 1 and Recall 2 we reported in an earlier section where repeated collaborative recall (CCII) eliminated collaborative inhibition but a single collaborative session (ICII) did not.

### 3.3. Shared and non-shared recall

The proportion of shared (or overlapping) and non-shared (or unique) recall during Recall 3 and Recall 4, are displayed in Figs. 3 and 4, respectively. In the two experimental conditions (CC-delay-II, IC-delay-II) shared information was shared by all three of the previous group members, while non-shared information was unique to one of the previous group members. In the control condition (II-delay-II), shared information was shared by three randomly grouped individuals, while non-shared information was the unique or non-overlapping recall of three randomly grouped individuals.

Shared recall as a function of recall sequence condition was examined in a repeated-measures ANOVA with recall trial (Recall 3, Recall 4) as the within-subjects variable and recall sequence condition (CC-delay-II, IC-delay-II and II-delay-II) as the between subjects variable. There was no significant main effect of recall trial,  $F(1, 39)=.04, p>.05$  or of interaction between recall sequence condition and recall trial  $F(2, 39)=1.76, p>.05$ , but there was a main effect of recall sequence condition,  $F(2, 39)=21.53, p<.001, \eta^2=.53$ . Follow-up contrasts (collapsed across Recall 3 and Recall 4) indicated that shared recall was greater following the collaboration conditions (IC-delay-II and CC-delay-II), than following repeated individual recall trials (II-delay-II),  $t(39)=4.04, p<.001$  and  $t(39)=6.49, p<.001$ , respectively. Shared recall in the CC-delay-II condition was also greater than the IC-delay-II condition,  $t(39)=2.45, p<.05$ . This finding provides additional support for the proposal that repeated collaboration promotes re-exposure and cross-cuing and the integration of other group members input, and supports its transfer to later individual recall over a delay, to a greater extent than an individual recall trial followed by a single collaborative recall trial.

Unique recall as a function of recall sequence condition was also examined in a repeated-measures ANOVA with recall trial (Recall 3, Recall 4) as the within-subjects variable and recall sequence condition (CC-delay-II, IC-delay-II and II-delay-II) as the between subjects variable – and yielded a consistent, yet opposite pattern of results compared to shared recall. There was no significant main effect of recall trial,  $F(1, 39)=1.51, p>.05$ , but there was a main effect of condition,  $F(2, 39)=81.02, p<.001, \eta^2=.81$ , and a marginally significant interaction between recall sequence



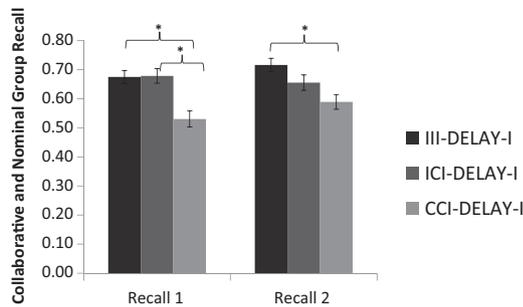
**Fig. 4.** Unique recall (in proportion) during Recall 3 and Recall 4 as a function of recall sequence condition in Experiment 1.

condition and recall trial  $F(2, 39)=2.55, p=.09$ . Follow-up contrasts (collapsed across Recall 3 and Recall 4) indicated that unique recall was lower following collaboration conditions (IC-delay-II and CC-delay-II) than following repeated individual recall trials (II-delay-II),  $t(39)=8.97, p<.001$  and  $t(39)=12.31, p<.001$ , respectively. Unique recall in the CC-delay-II condition was also lower than the IC-delay-II condition,  $t(39)=3.34, p<.01$ . This finding indicates that, while any collaboration increases overlap in recall, an individual recall trial followed by a single collaborative recall trial allow individuals to generate more unique information during subsequent individual recall than repeated collaboration. This is presumably because in the IC recall sequences each group member is able to strengthen their individual retrieval strategies prior to collaboration.

## 4. Experiment 2

### 4.1. Collaborative inhibition

The proportions of collaborative and nominal group recall during Recall 1 and Recall 2 as a function of recall sequence condition are displayed in Fig. 5. The presence of collaborative inhibition was examined in a repeated-measure ANOVA with recall trial (Recall 1, Recall 2) as the within-subjects variable and recall sequence condition (CCI-delay-I, ICI-delay-I and III-delay-I) as the between subjects variable. There was a main effect of recall trial,  $F(1, 39)=4.75, p<.05, \eta^2=.11$ , and recall sequence condition,  $F(2, 39)=4.51, p<.05, \eta^2=.19$ . There was also an interaction between recall trials and recall sequence condition,  $F(2, 39)=9.74, p<.001, \eta^2=.33$ . Follow-up contrasts indicated that during Recall 1, collaborative group recall was lower than nominal group recall when the III-delay-I condition was compared to the CCI-delay-I condition,  $t(39)=4.07, p<.001$  and when the ICI-delay-I condition was compared to the CCI-delay-I condition,  $t(39)=4.17, p<.001$ . These findings show the presence of collaborative inhibition during the first recall trial, replicate previous findings, and are consistent with the findings of Experiment 1. Note that, as would be expected, nominal group recall did not differ when the ICI-delay-I condition was compared to the III-delay-I condition,  $t(39)=.10, p>.05$ . Follow-up contrasts also indicated that during Recall 2, collaborative inhibition was present when the III-delay-I condition was compared to the CCI-delay-I condition,  $t(39)=3.58, p<.01$  and marginally significant when the III-delay-I condition was compared to the ICI-delay-I condition,  $t(39)=1.87, p=.07$ . The marginally significant collaborative inhibition effect when collaborative recall was preceded by an individual recall trial (ICI-delay-I) is consistent with the findings of Experiment 1, but the presence of collaborative inhibition when preceded by a collaborative recall trial (CCI-delay-I) is inconsistent with the findings of Experiment 1, where collaborative inhibition disappeared when preceded by a



**Fig. 5.** Collaborative and nominal group recall (in proportion) during Recall 1 and Recall 2 as a function of recall sequence condition in Experiment 2.

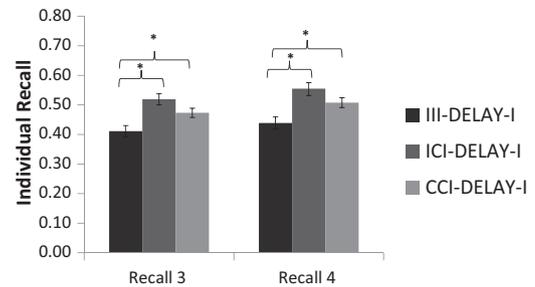
collaborative recall trial. This discrepancy, however, is largely due to a baseline difference in collaborative group recall in the CCI-delay-I condition here and CC-delay-II condition in Experiment 1, and further is not problematic for the key questions tested in this project.

#### 4.2. Post-collaborative recall benefits

The proportions of individual recall during Recall 3 and Recall 4 as a function of recall sequence condition are displayed in Fig. 6. Collaboration benefits on later individual recall as a function of recall sequence condition was examined in a repeated-measures ANOVA, with recall trial (Recall 3, Recall 4) as the within-subjects variable and recall sequence condition (CCI-delay-I, ICI-delay-I and III-delay-I) as the between subjects variable. There was a main effect of recall trial,  $F(1, 123) = 38.28, p < .001, \eta^2 = .24$ , and recall sequence condition,  $F(2, 123) = 9.17, p < .001, \eta^2 = .13$ , but no interaction between recall trial and recall sequence condition,  $F(2, 123) = .25, p > .05$ . Follow-up contrast indicated that individual recall (collapsed across recall conditions) increased across the 40-min delay,  $t(125) = 6.23, p < .001$ . Follow-up contrasts also indicated that individual recall (collapsed across Recall 3 and Recall 4) was greater following the collaboration conditions (ICI-delay-I and CCI-delay-I) than following repeated individual recall trials (III-delay-I),  $t(123) = 4.26, p < .001$  and  $t(123) = 2.49, p < .05$ , respectively. Individual recall (collapsed across Recall 3 and Recall 4) was also marginally greater in the ICI-delay-I condition than in the CCI-delay-I condition,  $t(123) = 1.77, p = .08$ . This marginal difference in individual recall between ICI-I and CCI-I conditions is consistent with the idea that an individual recall trial following collaboration, but preceding the delay, facilitates the integration of the input of others during collaboration to the same extent as repeated collaboration. It is also possible that such integration is more beneficial to later individual memory than the integration that occurs during repeated collaboration, but future studies are necessary to determine if this marginal advantage is indeed reliable.

#### 4.3. Shared and non-shared recall

Shared recall as a function of recall sequence condition was examined in a repeated-measures ANOVA with recall trial (Recall 3, Recall 4) as the within-subjects variable and recall sequence condition (CCI-delay-I, ICI-delay-I and III-delay-II) as the between subjects variable. There was a main effect of recall trial,  $F(1, 39) = 6.58, p < .05, \eta^2 = .14$ , and condition,  $F(2, 39) = 20.23, p < .001, \eta^2 = .51$ , but no interaction between recall sequence condition and recall trial  $F(2, 39) = .44, p > .05$ . Follow-up contrast (collapsed across recall conditions) indicated that shared recall increased from Recall 3 to 4 or over the delay,  $t(41) = 2.60, p < .05$ . Follow-up contrasts (collapsed across Recall 3 and Recall 4) indicated that shared recall was greater following the collaboration conditions



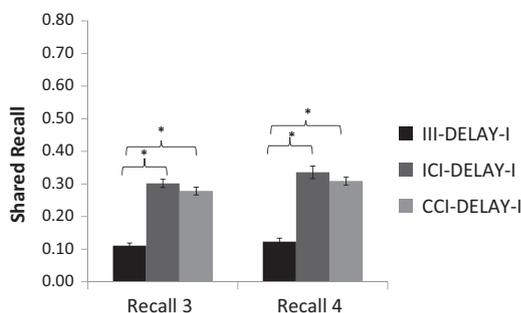
**Fig. 6.** Individual recall (in proportion) during Recall 3 and Recall 4 as a function of recall sequence condition in Experiment 2.

(ICI-delay-I and CCI-delay-I) than following repeated individual recall trials (III-delay-II),  $t(39) = 5.14, p < .001$  and  $t(39) = 4.49, p < .001$ , respectively. However (and in contrast to Experiment 1), shared recall did not differ between the CCI-delay-I and the ICI-delay-I conditions,  $t(39) = .65, p > .05$ . This finding provides further support for our proposal that an individual recall trial following collaboration, but preceding the delay, facilitates the integration of the input of others during collaboration to the same extent as does repeated collaboration (Figs. 7 and 8).

Unique recall as a function of recall sequence condition was also examined in a repeated-measures ANOVA with recall trial (Recall 3, Recall 4) as the within-subjects variable and recall sequence condition (CCI-delay-I, ICI-delay-I and III-delay-II) as the between subjects variable. There was no main effect of recall trial,  $F(1, 39) = .23, p > .05$ , or interaction between recall sequence condition and recall trial  $F(2, 39) = 2.30, p > .05$ . However, there was a main effect of condition,  $F(2, 39) = 46.75, p < .001, \eta^2 = .71$ . Follow-up contrasts (collapsed across Recall 3 and Recall 4) indicated that unique recall was lower following the collaboration conditions (ICI-delay-I and CCI-delay-I) than following repeated individual recall trials (III-delay-II),  $t(39) = 6.67, p < .001$  and  $t(39) = 9.39, p < .001$ , respectively. Unique recall in the CC-delay-II condition was also lower than the IC-delay-II condition,  $t(39) = 2.73, p < .01$ . As in Experiment 1, this finding indicates that an individual recall trial followed by a single collaborative recall trial allow individuals to generate more unique information during subsequent individual recall than repeated collaboration. Together, the shared and unique recall patterns suggest that if people get the opportunity to integrate responses from prior recalls before a delay occurs then there is an increase in the number of items members they come to share. At the same time, there still remains the influence of initial strengthening of individual strategies (ICI-I) on each member's ability to retain items that are unique to their own recall strategies.

## 5. General discussion

Collaborative learning and recall are common practices in many educational settings, but the operations of the cognitive processes that generate post-collaborative recall benefits are not well-defined. In two experiments we showed that both repeated collaborative recall trials and an individual recall trial followed by a single collaborative recall trial benefit later individual memory to a greater extent than repeated individual recall trials. Such post-collaborative recall benefits were observed regardless of whether a 40-min delay was inserted shortly following collaboration (Experiment 1) or after individuals were given the opportunity to also strengthen individual recall strategies following collaboration (Experiment 2). These findings nicely replicate previous findings (Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Henkel & Rajaram, 2011; Weldon &



**Fig. 7.** Shared recall (in proportion) during Recall 3 and Recall 4 as a function of recall sequence condition in Experiment 2.

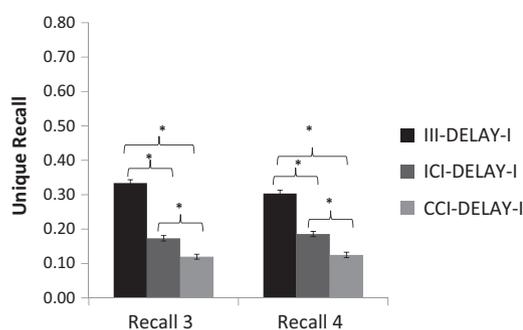
Bellinger, 1997), but also extend them by showing that, in general, collaboration benefits on later individual memory are impervious to a 40-min delay inserted at different time points following collaboration.

Novel to these experiments, the collaboration benefits observed on later individual recall in Experiment 1 provide strong support for the proposal that, (a) both re-exposure and cross-cuing are reinforced during repeated collaborative recall trials, and (b) when a delay is inserted between collaboration and individual recall cross-cuing supports the transfer of other group members' input and group retrieval plans to individual recall. We predicted and found that inserting a delay early in the recall sequence would benefit later individual recall to a greater extent when it followed repeated collaborative recall trials (CC-delay-II) than when it followed a single collaborative recall trial (IC-delay-II condition). Also consistent with this proposal, when this delay occurred after repeated collaboration it led to more shared responses and less unique responses than after a single collaboration.

The results of Experiment 2 provide strong support for the proposal that solidifying individual recall strategies prior to a single collaborative recall trial can support the transfer of other group members input over a delay. We predicted and found that inserting a delay later in the recall sequence – after the individuals have had the opportunity to integrate both individual and collaborative recall advantages – benefit later individual recall to a similar extent following repeated collaborative recall trials (CCI-delay-I) and a single collaborative recall trial (ICI-delay-I). Giving individuals the opportunity to strengthen their individual recall strategies after collaboration, but preceding the delay, also led to similar amounts of shared responses following repeated collaboration and following single collaboration. Unique responses, however, remained lower following repeated collaboration than following single collaboration.

## 6. Practical applications

These two routes (ICI and CCI) to generating post collaborative recall benefits encourage further research because they have important implications for applied settings such as undergraduate, graduate and medical education. Specifically, here we used word lists in order to exert strong experimental control in our foundational experiments, but the questions that drove our hypothesis testing were motivated by our interest in identifying mechanisms that have applied relevance. Future research can leverage these findings to seek generalizations to applied settings by using educationally relevant materials. The theoretical and educational implications of our findings can be summarized as follows: (1) both repeated group work and individual work prior to group work benefits later individual retention, (2) inserting a delay shortly following collaboration leads to greater benefits following repeated



**Fig. 8.** Unique recall (in proportion) during Recall 3 and Recall 4 as a function of recall sequence condition in Experiment 2.

collaboration than a single collaboration, (3) inserting a delay at a later point in the recall sequence leads to similar benefits following repeated collaboration and a single collaboration session, (4) if the educational goal is to generate shared information across group members, repeated collaboration is a good choice, and (5) if the educational goal is to supplement individually learned information with group input, then a single collaboration session is a good choice. In other words, choosing between a repeated collaboration strategy and a single collaboration strategy should depend on the specific learning goals of in the classroom context. With these initial tests of memory obtained with word lists in a laboratory setting, one can begin to examine the generalizability of these learning conditions (and of the underlying mechanisms) across tasks and settings that extend beyond word recall. Such an approach has the potential to refine the recommendations for our classrooms where it is common practice to incorporate group and individual exercises prior to midterm and final exams.

## Conflict of interest

The authors declare that there are no conflicts of interest.

## References

- Barber, S. J., Rajaram, S., & Fox, E. B. (2012). Learning and remembering with others: The key role of retrieval in shaping group recall and collective memory. *Social Cognition*, 30(1), 121–132. <http://dx.doi.org/10.1521/soco.2012.30.1.121>
- Barnier, A. J., & Sutton, J. (2008). From individual to collective memory: Theoretical and empirical perspectives. *Memory*, 16(3), 177–182. <http://dx.doi.org/10.1080/09541440701828274>
- Barnier, A. J., Sutton, J., Harris, C. B., & Wilson, R. A. (2008). A conceptual and empirical framework for the social distribution of cognition: The case of memory. *Cognitive Systems Research*, 9(1–2), 33–51. <http://dx.doi.org/10.1016/j.cogsys.2007.07.002>
- Bartlett, F. C. (1932). *Remembering*. London: Cambridge University Press.
- Basden, B. H., Basden, D. R., Bryner, S., & Thomas, R. L., III. (1997). A comparison of group and individual remembering: Does collaboration disrupt retrieval strategies? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23(5), 1176–1191.
- Basden, B. H., Basden, D. R., & Henry, S. (2000). Costs and benefits of collaborative remembering. *Applied Cognitive Psychology*, 14(6), 497–507.
- Blumen, H. M., & Rajaram, S. (2008). Influence of re-exposure and retrieval disruption during group collaboration on later individual recall. *Memory*, 16(3), 231–244. <http://dx.doi.org/10.1080/09541440701804495>
- Blumen, H. M., Rajaram, S., & Henkel, L. (2013). The applied value of collaborative memory research in aging: Behavioral and neural considerations. *Journal of Applied Research in Memory and Cognition*, 2(2), 107–117. <http://dx.doi.org/10.1016/j.jarmac.2013.03.003>
- Blumen, H. M., & Stern, Y. (2011). Short-term and long-term collaboration benefits on individual recall in younger and older adults. *Memory & Cognition*, 39(1), 147–154. <http://dx.doi.org/10.3758/s13421-010-0023-6>
- Choi, H.-Y., Blumen, H. M., Congleton, A. R., & Rajaram, S. (2014). The role of group configuration in the social transmission of memory: Evidence from identical and reconfigured groups. *Journal of Cognitive Psychology*, 26(1), 65–80. <http://dx.doi.org/10.1080/20445911.2013.862536>
- Clark, J. M., & Paivio, A. (2004). Extensions of the Paivio, Yuille, and Madigan (1968) norms. *Behavior Research Methods, Instruments, & Computers*, 36(3), 371–383. <http://dx.doi.org/10.3758/BF03195584>

- Clark, S., Hori, A., Putnam, A., & Martin, T. P. (2000). Group collaboration in recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 25(6), 1578–1588.
- Congleton, A. R., & Rajaram, S. (2011). The influence of learning methods on collaboration: Prior repeated retrieval enhances retrieval organization, abolishes collaborative inhibition, and promotes post-collaborative memory. *Journal of Experimental Psychology: General*, 140(4), 535–551. <http://dx.doi.org/10.1037/a0024308>
- Congleton, A. R., & Rajaram, S. (2014). Collaboration changes both the content and the structure of memory: Building the architecture of shared representations. *Journal of Experimental Psychology: General*, <http://dx.doi.org/10.1037/a0035974>
- Cuc, A., Ozuru, Y., Manier, D., & Hirst, W. (2006). On the formation of collective memories: The role of a dominant narrator. *Memory & Cognition*, 34(4), 752–762.
- Danielsson, H., Dahlström, Ö., & Andersson, J. (2011). The more you remember the more you decide: Collaborative memory in adolescents with intellectual disability and their assistants. *Research in Developmental Disabilities*, 32(2), 470–476. <http://dx.doi.org/10.1016/j.ridd.2010.12.041>
- Finlay, F., Hitch, G. J., & Meudell, P. R. (2000). Mutual inhibition in collaborative recall: Evidence for a retrieval-based account. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26(6), 1556–1567.
- Halbwachs, M. (1950/1980). In E. M. Douglas (Ed.), *The collective memory*. New York: Harper & Row.
- Harris, C. B., Barnier, A. J., & Sutton, J. (2011). Consensus collaboration enhances group and individual recall accuracy. *Quarterly Journal of Experimental Psychology*, 65(1), 179–194. <http://dx.doi.org/10.1080/17470218.2011.608590>
- Harris, C. B., Keil, P. G., Sutton, J., Barnier, A. J., & McIlwain, D. J. F. (2011). We remember, we forget: Collaborative remembering in older couples. *Discourse Processes*, 48(4), 267–303. <http://dx.doi.org/10.1080/0163853X.2010.541854>
- Harris, C. B., Barnier, A. J., & Sutton, J. (2013). Shared encoding and the costs and benefits of collaborative recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 39(1), 183–195. <http://dx.doi.org/10.1037/a0028906>
- Harris, C. B., Paterson, H. M., & Kemp, R. I. (2008). Collaborative recall and collective memory: What happens when we remember together? *Memory*, 16(3), 213–230. <http://dx.doi.org/10.1080/09658210701811862>
- Henkel, L. A., & Rajaram, S. (2011). Collaborative remembering in older adults: Age-invariant outcomes in the context of episodic recall deficits. *Psychology and Aging*, 26(3), 532–545. <http://dx.doi.org/10.1037/a0023106>
- Hirst, W., & Manier, D. (2008). Towards a psychology of collective memory. *Memory*, 16(3), 183–200. <http://dx.doi.org/10.1080/09658210701811912>
- Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational Researcher*, 38(5), 365–379. <http://dx.doi.org/10.3102/0013189x09339057>
- Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science*, 319(5865), 966–968. <http://dx.doi.org/10.1126/science.1152408>
- Kelley, M. R., Reysen, M. B., Ahlstrand, K. M., & Pentz, C. J. (2012). Collaborative inhibition persists following social processing. *Journal of Cognitive Psychology*, 24(6), 727–734. <http://dx.doi.org/10.1080/20445911.2012.684945>
- Kelley, M. R., & Wright, D. B. (2010). Obtaining representative nominal groups. *Behavior Research Methods*, 42(1), 36–41. <http://dx.doi.org/10.3758/BRM.42.1.36>
- Meade, M. L., & Roediger, H. L. (2009). Age differences in collaborative memory: The role of retrieval manipulations. *Memory & Cognition*, 37(7), 962–975. <http://dx.doi.org/10.3758/MC.37.7.962>
- Meudell, P. R. (Ed.). (1996). *Remembering in a social context: Experimental methods for the evaluation of collaborative recall*. Florence, KY, USA: Taylor & Francis/Routledge.
- Meudell, P. R., Hitch, G. J., & Boyle, M. M. (1995). Collaboration in recall: Do pairs of people cross-cue each other to produce new memories? *Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, 48(1), 141–152.
- Meudell, P. R., Hitch, G. J., & Kirby, P. (1992). Are two heads better than one? Experimental investigations of the social facilitation of memory. *Applied Cognitive Psychology*, 6(6), 525–543. <http://dx.doi.org/10.1002/acp.2350060606>
- Michaelsen, L. K., Knight, A. B., & Fink, L. D. (2002). *Team-based learning: A transformative use of small groups*. Westport, Connecticut, USA: Greenwood Publishing Group.
- Paivio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery, and meaningfulness values for 925 nouns. *Journal of Experimental Psychology*, 76(1p2), 1.
- Pereira-Pasarin, L. P., & Rajaram, S. (2011). Study repetition and divided attention: Effects of encoding manipulations on collaborative inhibition in group recall. *Memory & Cognition*, 39(6), 968–976. <http://dx.doi.org/10.3758/s13421-011-0087-y>
- Rajaram, S., & Pereira-Pasarin, L. P. (2010). Collaborative memory: Cognitive research and theory. *Perspectives on Psychological Science*, 5(6), 649–663. <http://dx.doi.org/10.1177/1745691610388763>
- Roediger, H. L., & Karpicke, J. D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological Sciences*, 17(3), 249–255. <http://dx.doi.org/10.1111/j.1467-9280.2006.01693.x>
- Rundus, D. (1971). Analysis of rehearsal processes in free recall. *Journal of Experimental Psychology*, 89(1), 63–77. <http://dx.doi.org/10.1037/h0031185>
- Stone, C. B., Barnier, A. J., Sutton, J., & Hirst, W. (2010). Building consensus about the past: Schema consistency and convergence in socially shared retrieval-induced forgetting. *Memory*, 18(2), 170–184. <http://dx.doi.org/10.1080/09658210903159003>
- Takahashi, M., & Saito, S. (2004). Does test delay eliminate collaborative inhibition? *Memory*, 12(6), 722–731.
- Thorley, C., & Dewhurst, S. A. (2007). Collaborative false recall in the DRM procedure: Effects of group size and group pressure. *European Journal of Cognitive Psychology*, 19(6), 867–881. <http://dx.doi.org/10.1080/09541440600872068>
- Thorley, C., & Dewhurst, S. A. (2009). False and veridical collaborative recognition. *Memory*, 17(1), 17–25. <http://dx.doi.org/10.1080/09658210802484817>
- Wegner, D. M. (1987). Transactive memory: A contemporary analysis of the group mind. *Theories of Group Behavior*, 185, 208.
- Weldon, M. S. (2001). Remembering as a social process. In D. L. Medin (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 40) (pp. 67–120). San Diego, CA: Academic Press.
- Weldon, M. S., & Bellinger, K. D. (1997). Collective memory: Collaborative and individual processes in remembering. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23(5), 1160–1175.
- Wertsch, J. V., & Roediger, H. L. (2008). Collective memory: Conceptual foundations and theoretical approaches. *Memory*, 16(3), 318–326. <http://dx.doi.org/10.1080/09658210701801434>
- Wright, D. B. (2007). Calculating nominal group statistics in collaboration studies. *Behavior Research Methods*, 39(3), 460–470. <http://dx.doi.org/10.3758/BF03193015>