Memory & Cognition
https://doi.org/10.3758/s13421-024-01647-z

Modeling collaborative memory with SAM

Willa M. Mannering[1] · **Suparna Rajaram**[2] · **Richard M. Shiffrin**[1] · **Michael N. Jones**[1]

Accepted: 29 August 2024

Abstract

While humans often encode and retrieve memories in groups, the bulk of our knowledge of human memory comes from paradigms with individuals in isolation. The primary phenomenon of interest within the relatively new field of collaborative memory is *collaborative inhibition*: the tendency for collaborative groups to underperform in free recall tasks compared with noncollaborative groups of the same size. This effect has been found in a variety of materials and group compositions. However, most research in this field is led by verbal conceptual theories without guidance from formal computational models. We present a framework to scale the Search of Associative Memory model (SAM) to collaborative free recall paradigms with multiple models working together. Multiple SAM models recalling together naturally produce collaborative inhibition when the group members use recalls by the group as cues to retrieve from memory, strongly supporting the "retrieval disruption" hypothesis. This work shows that SAM can act as a unified theory to explain both individual and collaborative memory effects and offers a framework for future predictions of scaling to increased group sizes, shared knowledge, and factors facilitating the spread of false memories in groups.

Keywords Collaborative memory · Collaborative inhibition · Cognitive modeling

Outside of the laboratory we regularly encode and retrieve memories in collaboration with others, but almost all empirical research in human memory has involved participants performing tasks in isolation. The experimental study of collaborative memory is a comparatively young field focused on uncovering the cognitive mechanisms involved in group interaction in memory tasks. The field primarily adapts experimental paradigms and theories originating in individual memory to the collaborative group level.

The primary focus within this new field is *collaborative inhibition*—the tendency for collaborative groups to underperform in free recall tasks compared to noncollaborative groups of the same size. This effect is robust and has been found in a variety of materials and group compositions (Marion & Thorley, 2016; Rajaram & Pereira-Pasarin, 2010). Currently, there are multiple explanations for the recall deficit, but the explanation with the most empirical support is the retrieval disruption hypothesis. This hypothesis posits that the deficit from collaboration occurs because individual retrieval strategies are disrupted during group activities (Basden et al., 1997). While a body of experimental research and verbal conceptual frameworks exist for connecting individual and collaborative memory, there are currently no formal computational cognitive models to guide the field. The present research adapts a prominent model of individual memory recall, the Search of Associative Memory model (SAM; Raaijmakers & Shiffrin, 1980, 1981), to predict the results of collaborative recall. Our simulations support the retrieval disruption hypothesis and provide a formal framework unifying individual and collaborative memory research.

Collaborative inhibition

The experimental paradigm typically used within the collaborative memory field is an extension of classic paradigms previously used and validated in the field of individual memory. This paradigm involves participants learning a list of words, performing a distractor task individually, and then performing a recall task (typically free recall) together in

✉ Willa M. Mannering
manneringwilla@gmail.com

1 Department of Psychological and Brain Sciences, Indiana University, Bloomington, IN, USA

2 Department of Psychology, Stony Brook University, Stony Brook, NY, USA

small groups (Harris et al., 2008). As expected, groups perform better in the recall task than individuals. However, to be fair, group recall should be compared with the same number of individual recalls, in what is termed a nominal group. In both collaborative and nominal group conditions, subjects learn a list of items individually in the study phase. Then, in the collaborative group condition, subjects are asked to work together with other group members to recall items on the list. The collaborative group response is calculated by counting all nonoverlapping responses produced by the group. In the nominal group condition, subjects are asked to recall items on the list independently. The nominal group response is calculated by counting the total, nonoverlapping responses produced by all the group members. When collaborative group recall performance is compared with nominal group recall performance in this way, there is a significant deficit in recall in the collaborative group (Basden et al., 1997; Weldon & Bellinger, 1997)—termed *collaborative inhibition*.

Mechanistic hypotheses of collaborative inhibition

Currently, several explanations have been proposed in the literature that may underlie the collaborative inhibition effect. One set of theories originate from theoretical paradigms developed within the individual memory literature. The individual memory analogue to the collaborative inhibition effect is commonly believed to be the part-list cuing effect (Andersson et al., 2006; Basden et al., 1997, 2000). Typically, when an individual is asked to use cues to aid recall, their recall performance increases (Tulving, 1974). However, the part-list cuing effect predicts the opposite. When an individual is presented with a random selection of a memorized list as cues, their recall for the remaining words on the list is inhibited (Nickerson, 1984; Slamecka, 1968). Crucially, the part-list cues must be a random subset of the study list for the effect to occur. The similarities between the part-list cuing and collaborative inhibition effects are clear. In both cases, previously studied items are given to a subject as externally produced cues, which then cause disruption in recall. There are three prominent explanations for the part-list cuing effect that may also be responsible for collaborative inhibition: retrieval disruption, retrieval inhibition, and retrieval blocking. All three suggest that the *product* of recall is responsible for the inhibitory effect of collaboration.

The most popular mechanistic hypothesis for collaborative inhibition is the retrieval disruption hypothesis, which posits that the inhibitory effects of collaboration occur because individual retrieval strategies are disrupted during group recall (Basden et al., 1997). This hypothesis was originally used to explain the part-list cuing effect: when randomly chosen, part-list cues interfere with the subject's internal organization of the study list, thus interrupting their idiosyncratic retrieval strategy (Basden & Basden, 1995). It is theorized that in a collaborative setting, group members provide part-list cues for others in the group—causing collaborative inhibition. According to this hypothesis, each group member develops an idiosyncratic organization of information in memory during the study phase of a recall task, which is then disrupted by mismatched cues from other group members when asked to recall in a group. Additionally, once the disruption is removed (i.e., no more group members producing cues), subjects are assumed to remember study items that weren't produced during collaborative recall on subsequent individual recall tasks; that is, memory disruption is not long lasting, and evidence supports this assumption (Basden et al., 2000; Congleton & Rajaram, 2011).

A second possible mechanistic explanation for collaborative inhibition is retrieval inhibition, which posits that strengthening of cue words inhibits the memory for noncued words by suppressing memory representations, which prevents those words from being retrieved (Bäuml & Aslan, 2004). In a collaborative setting, words that are cued by group members would be strengthened in memory and words that are not recalled by the group would be weakened, causing extended suppression of unrecalled words for all group members. It is also important to note that this memory impairment should persist after collaboration regardless of the method in which memory is cued. That is, the impairment should also be noticeable in postcollaborative free recall and recognition tests (Bäuml & Aslan, 2006). Several studies have found supporting evidence for retrieval inhibition by observing an incomplete release from inhibition during postcollaborative individual recall tasks, which is not predicted by retrieval disruption (Blumen & Rajaram, 2008; Congleton & Rajaram, 2011), suggesting a long-lasting detrimental effect of collaboration. These findings indicate that both retrieval inhibition and retrieval disruption may jointly contribute to collaborative inhibition.

A third possible mechanism for collaborative inhibition is retrieval blocking, which posits that cue words become stronger candidates for retrieval and people are more likely to recall previously cued words as opposed to new words. During the part-list cuing task, participants are more likely to think of the cued words, which blocks access to noncued words (Rundus, 1973). In a collaborative setting, group members would be more likely to recall previously recalled words than produce novel responses. While retrieval blocking prevents access to noncued words, the memory representation itself is not suppressed. That is, the memory deficit should remain when memory search is self-guided but be eliminated when cues are provided, such as on a recognition test. Barber et al. (2015) found that inhibition was present in both postcollaborative free recall and recognition tests, suggesting that retrieval blocking may not play an active role in collaborative inhibition.

Yet another set of theories that often originate from the social psychology literature, suggest the social process of recall may be responsible for collaborative inhibition. These theories posit that there's something about the collaborative process itself (independent of the items produced) that inhibits group performance. There are a few studies suggesting that social factors may also have an effect on collaborative inhibition. For example, a few studies have shown that when group members have a prior relationship (married couples, groups of friends, etc.) collaborative inhibition can be reduced (Andersson & Ronnberg, 1995, 1996; Johansson et al., 2000). However, it may also be the case that people with preexisting relationships have more shared background knowledge and experience, which could result in a more similar organization of study list items. In support of this possibility, Meade et al. (2009) reported a reversed pattern—that is, collaborative facilitation—among expert pilots in their collaborative recall of aviation scenarios, while the usual collaborative inhibition pattern was observed for the novice pilots and nonpilots in the same study. The reversed pattern in expert pilots' collaborative recall is attributed to their shared domain knowledge about and experience with aviation scenarios.

In any context where group interaction occurs, it seems intuitive that social interaction and motivation would be important. Therefore, it follows that collaborative inhibition could be caused by a variety of social factors. One such social factor is social loafing, the tendency for group members to not work as hard in a group setting as they would have alone (Latane et al., 1979). Social loafing as a possible mechanistic explanation for collaborative inhibition is implied by previous group research in a wide variety of fields that show a similar loss of individual productivity. These areas include bystander intervention (Latane & Nida, 1981), physical activities such as rope-pulling (Ingham et al., 1974), and cognitive tasks like brainstorming (Diehl & Stroebe, 1987; Taylor et al., 1958). Given the similarity between brainstorming and collaborative recall tasks, it is possible that the same mechanisms could be responsible for both inhibitory effects.

However, while there is some evidence that social loafing may play a detrimental role in brainstorming activities (Diehl & Stroebe, 1987), the experimental evidence available is not enough to account for the whole effect. Experiments that manipulated factors important for social loafing, such as personal accountability and individual motivation, were not able to decrease collaborative inhibition (Weldon et al., 2000). However, collaborative inhibition *can* be decreased or even eliminated by manipulating cuing or the order in which items are learned (Andersson et al., 2006). If social factors were the sole cause of collaborative inhibition, such manipulations would not decrease the inhibitory effect. The inability to reduce collaborative inhibition by eliminating possible social factors suggests that other mechanisms may be responsible for the effect.

Another potential account of collaborative inhibition is the production blocking hypothesis (distinct from retrieval blocking described earlier), which posits that waiting to contribute while other group members produce responses blocks the ability to recall information (Diehl & Stroebe, 1987). For example, while recalling in a group, individuals might forget their response while waiting for other group members to finish talking. Thus, the cause of collaborative inhibition would not be because of the responses produced by the group but because the process of collaboration forces participants to wait to produce responses.

Most studies involving production blocking during collaborative and individual recall have either concluded that there isn't enough supporting evidence to fully account for collaborative inhibition or that production blocking cannot be the cause of collaborative inhibition (Andersson et al., 2006; Finlay et al., 2000; Wright & Klumpp, 2004). Wright and Klumpp (2004) demonstrated that production blocking is most likely not responsible for collaborative inhibition. They compared nominal group performance to two conditions of collaborative recall: seeing and not-seeing. In both conditions, groups of two used the turn-taking method. In the seeing condition, participants shared a sheet, wrote down responses after their partner's turn, and could review each other's responses. In the not-seeing condition, participants had separate sheets, could not see each other's responses, and were physically separated by a divider. If production blocking were responsible for collaborative inhibition, participants assigned to the not-seeing collaborative condition should still experience inhibition due to having to wait for their partner's turn before producing their own response. However, this was not the case, suggesting that production blocking is not responsible for collaborative inhibition.

Several mechanisms have been discussed, each with differing levels of experimental support. However, among the range of mechanisms suggested in the literature, and despite emerging indications of a multiprocess explanation for collaborative inhibition, retrieval disruption is still considered the primary mechanism responsible for collaborative inhibition. Thus, the goal of this paper is to introduce and validate the collaborative Search of Associative Memory (cSAM) model by observing whether retrieval disruption is present in the model. Then, after this fundamental validation, future work will aim to use cSAM as a tool for investigating the possibility of a multiprocess account of collaborative inhibition.

Modeling retrieval disruption

The retrieval disruption hypothesis is closely related to a mechanistic explanation for the part-list cuing effect found in the individual memory literature, an idea modeled formally by Raaijmakers and Shiffrin (1981; see also Andersson et al., 2006; Basden et al., 1997, 2000). The explanation afforded by the SAM model is based on the fact that the cues are chosen randomly by the experimenter; when these cues are used to retrieve from memory they often mismatch the subject's internal organization of the study list, hindering recall (Basden & Basden, 1995). For example, suppose the experimenter provides three words W1, W2, and W3 that are used by the participant as cues to search memory. Suppose this participant has stored words in memory in groups of three, and one such group happened to be [W1, W2, W3]. If all three are provided as cues, the participant would tend to retrieve experimenter-provided words, and those retrievals would not be counted as successful. Another stored group might be [W4, W5, W6]; all might fail to be recalled because none happen to be provided as cues. It would be best if the experimenter provided one word from each stored group, but the provided words are chosen randomly. Raaijmakers and Shiffrin (1981) used this idea in SAM to explain why critical word recall is better without randomly provided list words as cues.

The extension of this idea to collaborative inhibition is straightforward: When a group member attempts to retrieve using a word recalled by another group member that word will often mismatch the member's subjective organization, causing collaborative inhibition. Basden et al. (1997) were the first to provide experimental evidence tying collaborative inhibition to the part-list cuing effect and supporting retrieval disruption as a mechanistic explanation for collaborative inhibition. Whether or not retrieval disruption can account for all extant findings (Barber et al., 2015; Lehmer & Bäuml, 2018) the present simulation modeling shows that retrieval disruption implemented by the SAM model provides an excellent account of the basic phenomenon of collaborative inhibition in free recall.

Modeling collaborative memory

Research focusing on social media information presently dominates the group behavior literature, and includes topics such as community identification, "fake news" detection, topic modeling, and misinformation prevention. This research stems from the fields of network science and linguistics and tends not to incorporate or consider cognitive mechanisms in their models. Until now, the only attempt at modeling collaborative memory was made by Luhmann and Rajaram (2015) whose main goal was to model information transmission at network-scale by taking an agent-based modeling approach. Though their main goal was not to model collaborative inhibition, during the verification phase of their model, the authors were able to produce collaborative inhibition when groups of three agents were tasked with performing collaborative recall. Additionally, they were able to model the effect of group size on collaborative memory. However, while this model included psychologically based agents that were able to encode and retrieve memories, the main goal of the study was to examine the effect of information transmission on network behaviors, not to investigate individual and collaborative memory processes responsible for collaborative inhibition, the broader goal of the current work.

The motivation for using SAM over other possible cognitive models is as follows. First, SAM is well studied, is one of the most widely used recall models in episodic memory research (Wilson & Criss, 2017; Wilson et al., 2020), and is arguably the simplest. Second, SAM has successfully modeled the part-list cuing effect in individual memory (Raaijmakers & Shiffrin, 1981), and the same principles may explain collaborative inhibition. Finally, the architecture of the model affords a coherent framework that is easily applied to both individual recall and recall in groups. We therefore take a SAM model for individual recall and use it almost completely intact and unchanged to model each member of a group recalling collaboratively. A demonstration that this group model predicts collaborative inhibition will go a long way toward producing a unified account of both individual and collaborative memory phenomena and processes.

Search of associative memory (SAM) model

SAM is a cue-dependent probabilistic search theory of retrieval and is typically applied to simulations of free and cued recall. The model makes use of a two-stage memory system: short-term memory and long-term memory. The short-term memory system is where processes such as encoding and rehearsal are carried out during study and where retrieval is controlled during testing. Long-term memory contains traces represented as an association matrix of study items and environmental context (context-item information) and item to item-plus-context information (item-item information). Context information represents information available during encoding that identifies the context of the list rather than any specific study item, such as emotions, sensations, or environmental details.

The traces in long-term memory are formed and stored during the time that items are present in short-term memory in a limited capacity rehearsal buffer. The items present in the buffer together at each moment are determined probabilistically, so that different participants form different subjective organizations (different associative strengths) in long-term memory. The associative strength between a context cue and a context-item trace is a linear function of the time that item was rehearsed in short-term memory. The associative strength between an item-plus-context cue and an item-item trace that contains the same item (i.e., item-to-self relationship) is a different linear function of the time that item was rehearsed in short-term memory. The associative strength between an item-plus-context cue and an item-item trace containing a different item (i.e., item-to-other relationship) is a third linear function of the time the two items were together in the rehearsal buffer. In many tasks, including the present ones, the contents of short-term memory are cleared by a distractor task such as arithmetic before recall begins.

Retrieval from long-term memory is then carried out by probing memory either with a context cue alone (at the start of retrieval or when an item cue is no longer helpful) or with an item-plus-context cue. Learning during retrieval is represented by additions to the associative strengths between cues and traces when a successful recall occurs. Recall due to context-only cuing increments strengths from the context cue to that trace and the strength of the that item to its own trace. Recall due to item-plus-context cuing increments those strengths and also increments the strength of the item cue to the trace containing the recalled item. Table 1 gives a brief description of the standard parameters included in SAM. The first 11 parameters are for SAM applied to both nominal and collaborative groups free recalling uncategorized lists. The last two parameters apply to models free recalling from categorized lists. The columns to the right provide the parameter values used to predict collaborative inhibition for nominal and collaborative groups, for both uncategorized and categorized lists (explained in detail later).

Retrieval in SAM

As mentioned, short-term memory is cleared in the present task, so that all recall comes from long-term memory. Retrieval begins by probing memory with a context cue. Traces are activated in proportion to their associative strength to the context cue, and one trace is sampled in proportion to that strength. The probability of recalling the item in the sampled trace (termed recovery) rises with the associative strength. If recall fails, either because a word is not recovered from the sampled trace, or because a word is recovered but had been recalled previously, another trace is sampled and this continues until an item is recalled, or until *Kmax* total accumulated failures occur (*Kmax* is never reached at the start of recall, but eventually is reached and terminates recall).

If an item is recalled, then that item plus context is used next to probe long-term memory. Traces are activated in accordance with the associative strength between the item and context probe and each trace. A trace is sampled in proportion to its strength. The probability of recalling the item in that trace rises with the associative strength between the cue and trace, but successful recall only occurs if that item had not already been recalled (which counts as a failure). If recall fails another sample is made and this continues until a new item is recalled, in which case the new item plus

Table 1 SAM parameter descriptions

Parameter	Description	Uncategorized values	Categorized values
t	Presentation time per word during encoding	2s	2s
r	Short-term memory buffer size	4	4
a	Weight for context-to-word association during encoding	.08	.07
b	Weight for word-to-word association during encoding	.08	.07
c	Weight for word-to-self association during encoding	.08	.07
d	Associative strength for words not appearing in buffer together	.02	.02
e	Incrementing parameter for context-to-word association during retrieval	.70	.70
f	Incrementing parameter for word-to-word association during retrieval	.70	.70
g	Incrementing parameter for word-to-self association during retrieval	.70	.70
Kmax	Number of retrieval failures that end retrieval	30	30
Lmax	Number of retrieval failures before returning to context cues	3	3
h	Starting association for words in the same category (categorized)	–	.25
i	Starting association for words in different categories (categorized)	–	.005

context is used to probe memory, or until *Lmax* is reached. If *Lmax* is reached, then retrieval ends if *Kmax* failures have accumulated overall; if *Kmax* has not been reached, then the retrieval cue is changed to a context only probe. In this way, the memory search continues until *Kmax* total failures accumulate, at which point recall stops.[1]

Equation 1a gives the probability of sampling a context-word trace, W_{iS}, using only context, C_T, as a memory probe. Equation 1b gives the probability of sampling a context-word trace, W_{iS}, given both context, C_T, and a word cue, W_{kT}, as a memory probe. The S subscript indicates the item as it is stored in memory.

$$P_S\left(W_{iS}|C_T\right) = \frac{S\left(C_T, W_{iS}\right)}{\sum_{j=1}^{n} S\left(C_T, W_{jS}\right)} \tag{1a}$$

$$P_S\left(W_{iS}|C_T, W_{kT}\right) = \frac{S\left(C_T, W_{iS}\right)S\left(W_{kT}, W_{iS}\right)}{\sum_{j=1}^{n} S\left(C_T, W_{jS}\right)S\left(W_{kT}, W_{jS}\right)} \tag{1b}$$

Once an item is sampled from memory, the recovery process begins. Equation 2a shows the probability of recovering the word, W_i, in the sampled trace given only context as a memory probe. Equation 2b shows the probability of recovering the word in the sampled trace given both context and a word cue as a memory probe. The recovered word is counted as a failure if already recalled and otherwise a success.

$$P_R\left(W_i|C_T\right) = 1 - exp\left\{-S\left(C_T, W_{iS}\right)\right\} \tag{2a}$$

$$P_R\left(W_i|C_T, W_{kT}\right) = 1 - exp\left\{ \begin{array}{c} -S\left(C_T, W_{iS}\right) \\ -S\left(W_{kT}, W_{iS}\right) \end{array} \right\} \tag{2b}$$

Part-list cuing in SAM

Raaijmakers and Shiffrin (1980, 1981) used this model to explain and predict many results in free recall, cued recall, and categorized free recall. Of greatest present relevance, it predicted the negative effects of part-list cuing, despite storing and retrieving associations. To apply SAM to part-list cuing, retrieval begins with an experimenter provided cue and continues until an item is recalled or until *Lmax* failures occur in which case retrieval uses the next experimenter provided cue. As usual, recall stops when *Kmax* failures accumulate. If all experimenter provided cues are used before *Kmax* failures, then self-guided search begins. The negative effects of part-list cuing are due largely to the use of a random set of experimenter-provided cues. Rehearsal processes during study produce a certain structure of associations in long-term memory causing certain items to be strongly associated, while others are not. The cues provided by the experimenter will seldom match the stored associative structure, causing poor retrieval. For example, the experimenter provided cues will often lead to failures because the strongly associated items will be other experimenter provided cues. In normal free recall, retrieval after *Lmax* failures switches to context, which can lead to previous untapped regions of the associative structure. However, instructions used in part-list cuing lead instead to the use of the next experimenter-provided cue, a cue that is often unhelpful. This can be seen as a form of retrieval disruption and suggests that a similar process may explain collaborative inhibition in cSAM: If a member of a group uses for retrieval an item just recalled by another group member, that item will often mismatch the member's personal associative structure in long-term memory. That is, the recalls of other group members may play the role of the experimenter provided cues seen in the part-list cuing effect.

Adapting SAM to collaborative free recall

Given its success at modeling the part-list cuing effect in individual memory, adapting the SAM model to collaborative recall could provide valuable insights into the cognitive mechanisms behind collaborative inhibition. The SAM model could have been adapted to use either of the two prominent recall methods seen in collaborative recall tasks. The first possibility was the turn-taking method, which captures everyday turn-taking in conversations and produces collaborative inhibition, and was used by Basden et al. (1997) and Luhmann and Rajaram (2015). However, this method is less common in the literature, partly because the turn-taking method has been shown to increase memory intrusions (Meade & Roediger, 2009; Rajaram & Pereira-Pasarin, 2010). The second possibility was a free-for-all recall method in which participants recall freely whenever they retrieve a new word. This paradigm is the most popular

[1] If *Kmax* is reached while search is using a word cue and *Lmax* has not yet been reached, then search continues until a new word is recalled and used, or until *Lmax* is reached and then search ends. This happens very seldom, not enough to alter any of the present simulation results significantly. Also, the original version of SAM did not end search when *Kmax* was reached but had a process of 'rechecking', using words recalled earlier as cues. Rechecking was not used in any of the present modeling. As cSAM is described it will become clear that rechecking added to both the nominal and collaborative groups would increase the degree of collaborative inhibition predicted by inducing the use of ineffective cues by the collaborative group. We did not include rechecking because we wanted to show that basic SAM predicts collaborative inhibition without it.

within collaborative recall behavioral experiments and thus we implemented this recall method for cSAM. The following sections outline the adaption of the SAM model to free recall in both uncategorized (words unrelated to one another) and categorized lists of words (several exemplars presented from each category in a randomized order within a study list). We chose these stimuli as they are widely studied within the free recall literature and will serve as a benchmark for evaluating the performance of our model. These word lists are also useful because in free recall tasks people tend to organize retrieval even for unrelated stimuli (Gates, 1917; Tulving, 1962) , indicating that retrieval disruption would play a role in the recall of both unrelated words and categorically related words under conditions of collaborative recall. Consistent with this, collaborative inhibition has been reported during recall for both uncategorized lists (e.g., Blumen & Rajaram, 2008; Choi et al., 2014; Weldon & Bellinger, 1997) and categorized lists (Basden et al., 1997; Congleton & Rajaram, 2011, 2014). As such, our use of both types of word lists makes this approach a robust way to test the SAM model.

Free recall of uncategorized lists

We note at the outset that the cSAM model here uses free recall output. Any reference to cues is specific to the items recalled by any model in free recall format that then serves as a cue for another model to freely recall other items. The cSAM framework is defined as follows: A nominal group of *N* members has *N* models each carrying out free recall independently. A collaborative group of the same size with *N* members has *N* models storing associations independently (exactly as in the nominal group) but interacting during retrieval. The key assumption is that all *N* models within a collaborative group use the most recent recall by any of the models as the next cue for retrieval, and all models increment associative strengths for any word recalled by the group. Note that these assumptions match the analogous assumptions for SAM applied to individual recall. All models in both groups use the same method for storing traces in memory, based on the SAM rehearsal buffer. Short-term memory is cleared before retrieval begins.

During retrieval for the nominal group, each of the *N* models retrieves independently in the typical SAM method that is summarized above. Figure 1 provides a general flowchart of the free-for-all retrieval method used by the collaborative group. There is a shared buffer, called the group response, between the *N* models; which represents words "spoken aloud" by the models. The *N* models of the collaborative group are assumed to use each other's recalls as they occur, so it is necessary that their timing during retrieval be synchronized.

Retrieval failures for each model can occur in such a way that different models may reach *Lmax* or *Kmax* at different times. There are two types of retrieval failures

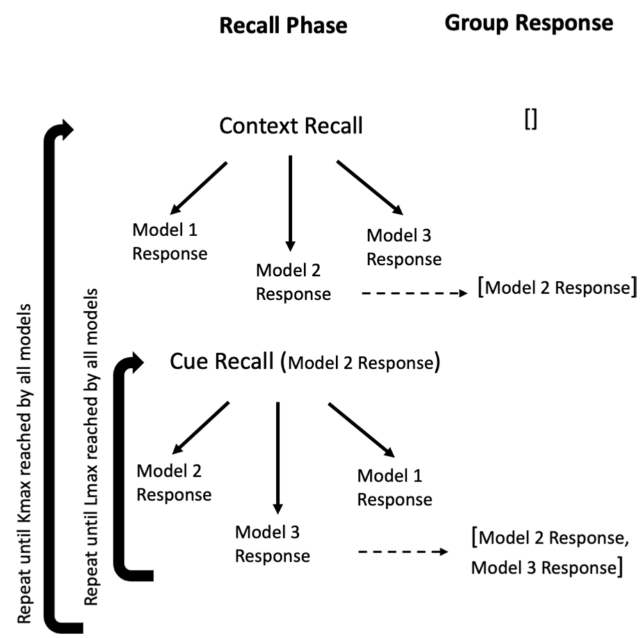

Fig. 1 Flowchart of collaborative recall between two or more SAM models. To begin recall, all models in the group start performing context recall. All models do this separately and the model with the fastest response (in this example Model 2's response was fastest) is added to the group response. Then, each model in the group uses the previous response (Model 2's response) to perform cued recall with the previous response as the cue word. Once again, the fastest model response is added to the group response (in this example Model 3's response was fastest). Cued recall continues until the stopping parameter *Lmax* is reached by each model in the group at which point the models begin context recall again. Once the stopping parameter *Kmax* is reached by all models recall ends

which can occur when a model is attempting to recall a word. First is a sampling failure where no word is recovered after sampling. Second, if a word is recovered it must then be checked to see if the group has recalled it previously. If the word has been recalled already, then a failure is counted. Each type of failure counts toward *Lmax* and *Kmax*. If the recovered word had not been previously recalled by a group member, then it is successfully recalled and every model in the group uses it as a probe cue for the next step of the search. Depending on whether the first or second failure type occurs during each recall phase, the models can reach *Lmax* (and *Kmax*) at different times which can result in some models probing memory with context only while others are probing memory with word plus context. Nonetheless, when any successful recall occurs, all models switch and use it to search memory. In addition, because the models can reach *Kmax* at slightly different times, models that have reached *Kmax* before other group members can continue to use retrieved items produced by other models as probes until *Lmax* is reached but cannot produce new items from context only search.

Thus, to summarize, the models for the nominal group (SAM) and the collaborative group (cSAM) are the same—only the experimental condition differs. Both types of models perform free recall, however, where the nominal group models use as a next cue the most recent word recalled by themselves; the collaborative group models use as a next cue the most recent word recalled by the group. The nominal group models increment associative strengths from cues used to traces of the current word recalled; the collaborative group models increment associative strengths from their cues used to traces of the current word recalled by the group.[2]

Free recall of categorized lists

Basden et al. (1997) explored collaborative groups free recalling categorized lists with categories of two different sizes. Collaborative inhibition was found, and the magnitude was larger for six categories of size 15 than 15 categories of size six. To simulate their design, we assume that all items in all categories are presented to each individual for study in mixed order, and retrieval begins after short-term memory is cleared. Nominal and collaborative groups are assumed to have three members. The models applied are very similar to those for uncategorized lists with a few slight modifications. During storage, the buffer model is applied as usual, except that the total association between two words in the same category is larger than in the uncategorized model by .25, and the association between two words in different categories is larger than in the uncategorized model by .005. Retrieval is the same as for the uncategorized model (except that the various associative strengths will be different, due to the category structure of the lists).

Modeling results

Parameter estimation of individual data

Before attempting to fit cSAM to aggregate recall data, we fit three parameters for the nominal and collaborative models (*e, f,* and *g*) using individual data (from Choi et al., 2014) to investigate any informative parameter differences between nominal and collaborative groups. The data provided consisted of recalls from a list of 50 uncategorized words for both nominal and collaborative groups. There were 36 groups represented in this data set, 18 nominal and 18 collaborative. To estimate these parameters using individual level data, we used the forest.minimize optimization function from the scikit-optimize Python library. This optimization function begins by modeling a function, in this case the retrieval process of cSAM, using a decision tree-based regression model. The model is then improved by evaluating the function at the next best point—thus finding the minimum value of the function in the smallest number of steps.

Table 2 Descriptive statistics of parameter distributions comparing collaborative and nominal groups

Parameter		Collaborative	Nominal	Mood's test *p* value
e	Mean (*SD*):	.72 (.14)	.71 (.14)	.11
	Median:	.70	.70	
f	Mean (*SD*):	.73 (.14)	.74 (.14)	.42
	Median:	.71	.71	
g	Mean (*SD*):	.73 (.14)	.73 (.15)	.74
	Median:	.70	.70	

e=Incrementing parameter for context-to-word association during retrieval

f=Incrementing parameter for word-to-word association during retrieval

g=Incrementing parameter for word-to-self association during retrieval

A Kolmogorov–Smirnov test for goodness-of-fit was performed on each parameter distribution to check for normality. All were found to be significantly nonnormal, leading us to employ a nonparametric test to compare collaborative and nominal distributions for each parameter. Table 2 displays the means, standard deviations, and medians for best-fitting parameter values across the participants. There were no significant differences in the median parameters for the collaborative and nominal groups, suggesting that collaborative inhibition is an emergent characteristic of the model and is not reliant on parameter tuning to produce the effect. Thus, all further comparisons we make between the collaborative and nominal groups keeps all parameters constant between groups.

Fitting cSAM to aggregate collaborative recall data

We then used SAM and cSAM to predict nominal and collaborative groups of three members freely recalling an uncategorized list of 40 words (Weldon & Bellinger, 1997) and the major findings by Basden et al. (1997) for groups of three members freely recalling categorized lists of two types (Basden et al., 1997). Because no significant parameter differences emerged in the previous section when the

[2] Some group members continue recall beyond the point they would have done (at *Kmax*) because they are induced to continue search by a recall by some other group member that has not yet reached *Kmax*. This factor helps increase group recall compared with nominal (to a tiny degree). Collaborative inhibition occurs regardless.

parameters were optimized, SAM and cSAM were both set to use the same fixed parameter values (Table 1) from the original Raaijmakers and Shiffrin (1981) simulations. The only difference in the model conditions lies in the fact that the collaborative group members use the most recent recall by any group member for their next searches of memory while the nominal group members use their own most recent recall for their next searches of memory.

We found that when all the values were set to those used in Raaijmakers and Shiffrin (1981) for part-list cuing, collaborative inhibition emerged. However, the levels of recall predicted for uncategorized and categorized word lists were slightly off target. Thus the values of *a*, *b*, and *c* were slightly changed from the original values in Raaijmakers and Shiffrin (1981) to the values seen in Table 1. The values of *h* and *i* were not needed to predict collaborative inhibition but were adjusted so that the predictions for categorized lists would better match the observed data. The results of fitting the models show that parameter estimation is ultimately unnecessary as no significant differences emerge and collaborative inhibition is predicted for almost any parameter value. This implies that collaborative inhibition is an emergent property of the model and that some mechanistic processes are responsible for the effect, as opposed to relying on altering the parameters to produce the effect.

Figure 2 shows the results of fitting the model to individual, nominal, and collaborative recall of uncategorized lists, using the parameters shown in Table 1. Figures 3 and 4 show the results of fitting the model to individual, nominal, and collaborative recall of categorized lists, using parameters shown in Table 1. We focus on accurate recall. Free recall of unrelated words yields very low intrusions, and for categorized lists where collaborative recall can produce higher intrusions, collaborative inhibition occurs even when recall is corrected for intrusions (Congleton & Rajaram, 2011). Thus, collaborative inhibition is robust to the differences in intrusions seen in uncategorized and categorized list recall.

The experimental data from Basden et al. (1997) (used to fit the model in Figs. 3 and 4) supports the retrieval disruption hypothesis because collaborative inhibition is stronger when study materials are less organized. In the first condition (Fig. 3) study materials are less organized because the category sizes are larger, allowing more room for idiosyncratic organization within categories. In the second condition (Fig. 4) the study materials are more organized because the category sizes are smaller, allowing less room for idiosyncratic organization within categories. When the internal organization of study items is dissimilar between group members, collaborative inhibition increases because the cues from other group members are more likely to disrupt individual search strategies. Thus, Figs. 2, 3, and 4 show that the cSAM model is capable of naturally reproducing the key findings of collaborative inhibition.

Discussion

The implications of collaborative memory research are much larger than participants recalling lists of words in experimental settings. Collaborative group interactions at smaller

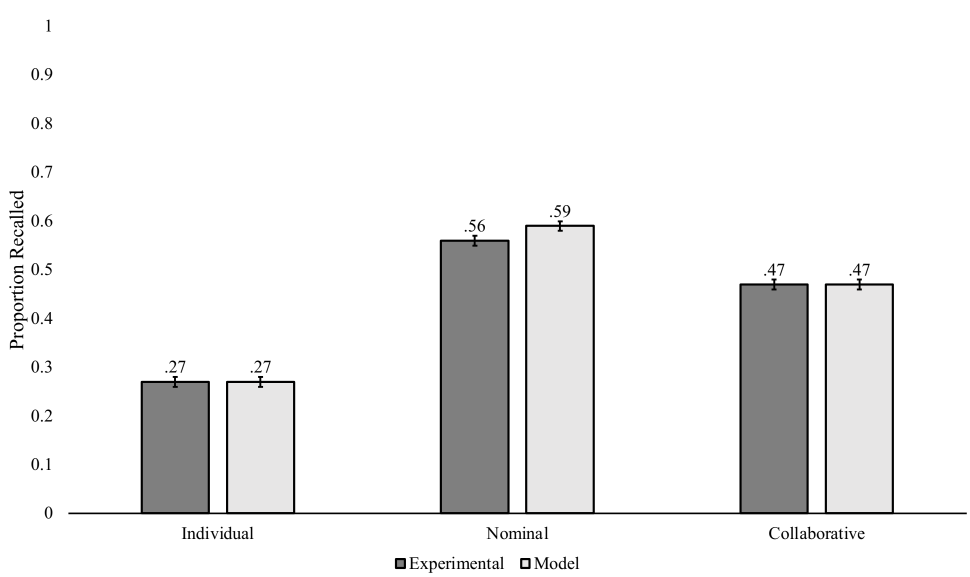

Fig. 2 cSAM model fit to uncategorized list data taken from the original Weldon and Bellinger (1997) paper detailing collaborative inhibition. Subjects were tested in groups of three on a list of 40 unrelated words. The error bars represent the standard error

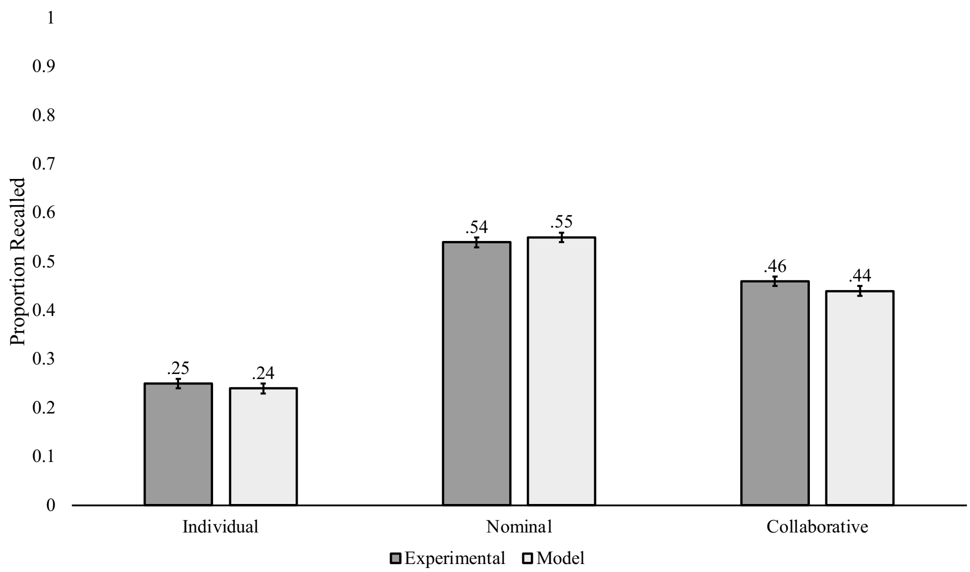

Fig. 3 cSAM model fit to categorized list data from Basden et al. (1997). Subjects in groups of three were asked to recall from a list of 90 words grouped into six total categories with 15 items in each category. The larger category size results in a more prominent collaborative inhibition effect. The error bars represent the standard error

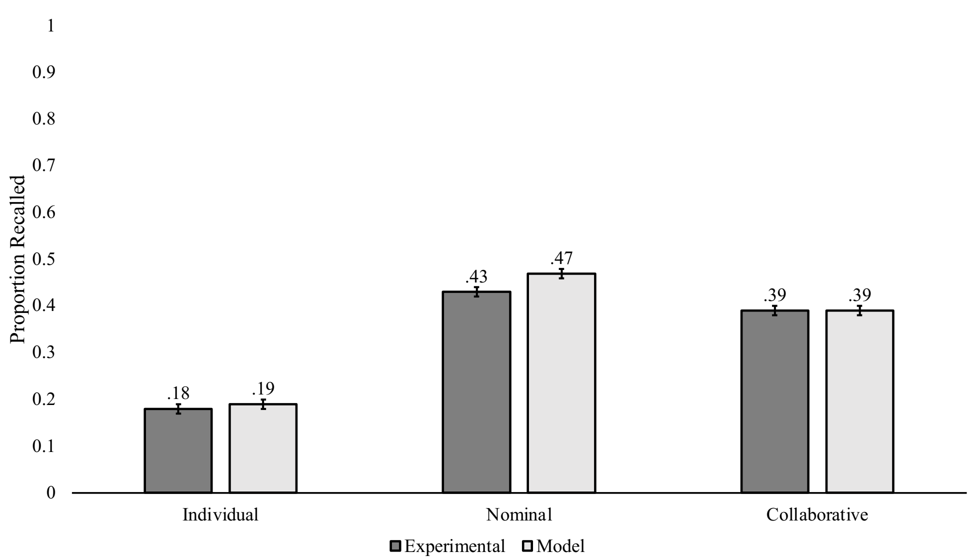

Fig. 4 cSAM model fit to categorized list data from Basden et al. (1997). Subjects in groups of three were asked to recall from a list of 90 words grouped into 15 total categories with six items in each category. The smaller category size results in a less prominent collaborative inhibition effect. The error bars represent the standard error

scales (such as the interactions studied within the collaborative memory field) are believed to create the groundwork for larger scale group dynamics (Choi et al., 2017; Maswood & Rajaram, 2019), thus the cognitive mechanisms being studied by this basic science are the same that play a role in crucial applied phenomena such as the spread of misinformation, memory contagion, fake news, eyewitness testimony, and even conspiracy theories (Choi et al., 2014, 2017). To date, there are no formal computational frameworks within which to understand how the memory mechanisms of individuals interact to produce emergent phenomena when collaborating.

In this paper, we took a first step towards this goal by modifying the well-validated SAM model of Raaijmakers and Shiffrin (1981), and providing an existence proof that the collaborative SAM framework can produce the basic patterns of collaborative inhibition seen in experimental data. In addition to basic uncategorized lists, cSAM naturally produces the patterns seen in categorized lists—namely, greater collaborative inhibition when study materials are less organized. Importantly, each SAM model in isolation would still retain the explanatory power for the range of behavioral phenomena in individual memory paradigms, providing a unified model to understand both individual and collaborative memory.

When fitting the three learning parameters, *e* (context-to-word association learning), *f* (word-to-word association learning), and *g* (word-to-self association learning), we found that there were no significant differences between nominal and collaborative groups. We then compared the performance of the collaborative and nominal groups while keeping all model parameters the same between both groups and found that collaborative inhibition persisted. We believe these results indicate that collaborative inhibition is being caused by a mechanistic or structural difference in cSAM that is not captured by parameter differences.

One such mechanism is likely the same mechanism responsible for part-list cuing deficits shown in SAM: retrieval disruption. SAM produces part-list cuing deficits when a retriever uses each provided word as the cue for the next memory search. Similarly, cSAM predicts collaborative inhibition when the retrievers use the most recent recalled word by any group member as a cue for the next memory search. In both cases, the cue words being used are ineffective compared with the ones used individually because the cues are mismatched to the subjective organization formed by the individual during list study. In the case of part-list cuing, the experimenter might randomly provide cues that are strongly associated with each other and poorly associated with the words that are the object of retrieval. In the case of collaborative inhibition, when group member A recalls W_1 it could be a good cue for A because A has stored a strongly interconnected group [W_1,W_2,W_3] and none of these words have yet been recalled. But group members B and C might have nothing in their memory that is strongly connected to W_1 other than words previously recalled by the group. Thus, B and C would have their retrieval disrupted when they use W_1 that was produced by A.

The simulations produced in this work show that the net effect of these retrieval disruption factors, instantiated in cSAM as induced use of ineffective cues, produces collaborative inhibition. In addition, Figs. 3 and 4 show that the amount of predicted collaborative inhibition is slightly increased for larger categories, as observed by Basden et al. (1997) and used to argue for retrieval disruption. That is, when the categories are smaller, there is less opportunity for idiosyncratic organization within each category, and hence less opportunity for different subjective organizations by different group members. It should be noted that the differences in subjective organization in cSAM are produced by differences in the way different models rehearse during study, because rehearsal in SAM and cSAM is a stochastic process. There are of course numerous other reasons why subjective organization might differ among group members, so it is interesting that the limited degree of subjective organization produced by stochastic storage is sufficient to produce significant collaborative inhibition.

While the simulations in this paper suggest that collaborative inhibition arises from a mismatch of the cues used to search memory and the differing subjective organizations of the group members, recently, the possibility of a multiprocess account of collaborative inhibition has gained traction in the experimental literature. Researchers that support a multiprocess account typically consider both retrieval disruption and retrieval inhibition as contributing to collaborative inhibition. Retrieval inhibition posits that strengthening of cue words inhibits the memory for noncued words by suppressing memory representations, which prevents those words from being retrieved (Bäuml & Aslan, 2004). In a collaborative setting, words that are cued by group members would be strengthened in memory and words that are not recalled by the group would be weakened, causing extended suppression of unrecalled words for all group members. It is also important to note that this memory impairment should persist after collaboration regardless of the method in which memory is cued. That is, the impairment should also be noticeable in postcollaborative free recall and recognition tests (Bäuml & Aslan, 2006).

Several recent studies have found supporting evidence for a multiprocess account of collaborative inhibition. Behavioral studies have found that retrieval inhibition may contribute to collaborative inhibition alongside retrieval disruption, by observing an incomplete release form inhibition during postcollaborative individual recall tasks (which is not predicted by retrieval disruption). On postcollaborative individual tasks, subjects often forget to recall words they contributed to earlier collaborative recall (Blumen & Rajaram, 2008), and this effect increases as the effect size of collaborative inhibition increases (Congleton & Rajaram, 2011), suggesting a long-lasting detrimental effect of collaboration. It is possible that retrieval inhibition and postcollaborative forgetting occur but are offset by reexposure effects during collaborative recall. Barber et al. (2015) avoid this entanglement by having participants study nonoverlapping lists, which prevents reexposure benefits, before performing collaborative recall. They found that without reexposure benefits, recall remained inhibited on subsequent individual free recall and recognition tests. However, the postcollaborative inhibition effect was reduced compared with collaborative inhibition, suggesting a partial release from retrieval disruption. These findings support a multiprocess account of collaborative inhibition with both retrieval inhibition and retrieval disruption contributing towards the effect.

Additionally, a new possible contributor to collaborative inhibition has been proposed from previous modeling work. Before the cSAM framework, the only other attempt at modeling collaborative memory was a verification step of a study looking at collaborative recall across different group sizes and information transmission in networks using an agent-based modeling approach (Luhmann & Rajaram, 2015). While verifying their agent-based model, Luhmann and Rajaram (2015) found evidence of collaborative inhibition. Their explanation for why collaborative inhibition occurred in their model attributed it to the agents' memories converging as they collaborated. They explain that after the study phase of the collaborative recall task, the agents each had an idiosyncratic activation pattern over the study items. Learning during the collaborative recall task decreases the diversity of the agents' memory representations, which the authors noted as the basis for reduced collaborative recall performance and collaborative inhibition. While the agent-based model was able to successfully induce collaborative inhibition, the explanation of memory convergence may seem to contradict predictions of the retrieval disruption hypothesis. According to the hypothesis, if group members memories are more similar, and their retrieval strategies are more similar, then external cues provided by group members should not disrupt retrieval nearly as much. Several studies have shown that collaborative encoding, which causes more similar retrieval organization, reduces collaborative inhibition (Basden et al., 1997; Finlay et al., 2000).

It is possible that there is a dual effect of both memory convergence and retrieval disruption at play in both experimental and modeling studies in that the two processes are related to each other. For example, in a behavioral study, Congleton and Rajaram (2014) found that an increase in collaborative inhibition was accompanied by an increase in memory convergence, leading them to propose a relationship between retrieval disruption, collaborative inhibition, and memory convergence (or shared memory). In other words, retrieval disruption is a prominent mechanism during collaboration that is implicated in memory convergence, such that the greater the extent to which people experience disruption to their own idiosyncratic retrieval organization, the greater the collaborative inhibition they will exhibit, and consequently come to report similar memories as collaborating partners. Unfortunately, isolating memory convergence in a behavioral study is a highly challenging task because we cannot observe this process during collaboration and can assess it only on a subsequent task. Formally exploring the relationship between retrieval disruption and memory convergence is important for demonstrating these mechanisms and consequences of collaborative recall, presenting a significant opportunity for investigation using cSAM given its focus on the role of retrieval disruption in modulating memory.

The SAM model has been shown to capture the primary processes of recall by individuals, and the present results go further to show that the same processes of recall and memory search provide a unified model to understand both individual and collaborative memory. This unified model offers the first formal approach for exploring connections between individual and collaborative memory processes. Given that cSAM has been shown to capture the standard patterns of collaborative inhibition seen in the literature, it would be natural to extend it to make predictions and suggestions for future experimental studies. Recent studies in the collaborative memory field (Barber et al., 2015; Gates et al., 2022; Luhmann & Rajaram, 2015) suggest that more attention should be paid to studying alternative mechanisms to the retrieval disruption hypothesis. In future studies, cSAM will be able to address the possibility of a multiprocess account by investigating possible alternative mechanisms responsible for collaborative inhibition in the model. For example, memory convergence, shared background knowledge (expertise), group size, and postcollaborative effects have all been shown to moderate collaborative inhibition and provide insight into additional mechanistic group differences (Barber et al., 2015; Luhmann & Rajaram, 2015; Meade et al., 2009; Thorley & Dewhurst, 2007). Investigating these areas will play a critical role in gaining a deeper understanding of what is driving collaborative inhibition in cSAM while also making predictions about understudied effects in the experimental literature. The use of a formal computational framework can differentiate between theories of group memory that are currently unresolvable through experimental data alone and can generate new predictions and experiments to advance the study of memory storage and retrieval.

Funding Not applicable.

Availability of data and materials None of the experiments was preregistered, the data used to optimize the model parameters can be requested from the authors of Choi et al. (2014). The aggregate data used to fit the models for uncategorized lists (Weldon & Bellinger, 1997) and categorized lists (Basden et al., 1997) are available in the respective published manuscripts.

Code availability The code for the uncategorized and categorized cSAM models is available here: https://github.com/willa-mannering/Modeling-Collaborative-Memory-SAM.

Declarations

Conflicts of interest We have none to declare.

Ethics approval Not applicable.

All data used to fit our models were collected and published in previous works and were either publicly available or made available to us by request.

Consent to participate Not applicable.

All data used to fit our models were collected and published in previous works and were either publicly available or made available to us by request.

Consent for publication Not applicable.

References

Andersson, J., & Ronnberg, J. (1995). Recall suffers from collaboration: Joint recall effects of friendship and task complexity. *Applied Cognitive Psychology, 9*, 199–211.

Andersson, J., & Ronnberg, J. (1996). Collaboration and memory: Effects of dyadic retrieval on different memory tasks. *Applied Cognitive Psychology, 10*, 171–181.

Andersson, J., Hitch, G., & Meudell, P. (2006). Effects of the timing and identity of retrieval cues in individual recall: An attempt to mimic cross-cueing in collaborative recall. *Memory, 14*(1), 94–103. https://doi.org/10.1080/09658210444000557

Barber, S. J., Harris, C. B., & Rajaram, S. (2015). Why two heads apart are better than two heads together: Multiple mechanisms underlie the collaborative inhibition effect in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*(2), 559–566.

Basden, D. R., & Basden, B. H. (1995). Some tests of the strategy disruption interpretation of part-list cuing inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 1656–1669.

Basden, B. H., Basden, D. R., Bryner, S., & Thomas, R. L. (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. https://doi.org/10.1037/0278-7393.23.5.1176

Basden, B. H., Basden, D. R., & Henry, S. (2000). Costs and benefits of collaborative remembering. *Applied Cognitive Psychology, 14*(6), 497–507. https://doi.org/10.1002/1099-0720(200011/12)14:6%3c497::Aid-Acp665%3e3.0.Co;2-4

Bäuml, K.-H., & Aslan, A. (2004). Part-list cuing as instructed retrieval inhibition. *Memory & Cognition, 32*(4), 610–617.

Bäuml, K.-H., & Aslan, A. (2006). Part-list cuing can be transient and lasting: The role of encoding. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(1), 33.

Blumen, H. M., & Rajaram, S. (2008). Influence of re-exposure and retrieval disruption during group collaboration on later individual recall. *Memory, 16*, 231–244.

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.

Choi, H.-Y., Kensinger, E. A., & Rajaram, S. (2017). Mnemonic transmission, social contagion, and emergence of collective memory: Influence of emotional valence, group structure, and information distribution. *Journal of Experimental Psychology: General, 146*(9), 1247.

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.

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, 143*(4), 1570.

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups—Toward the solution of a riddle. *Journal of Personality and Social Psychology, 53*(3), 497–509. https://doi.org/10.1037/0022-3514.53.3.497

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. https://doi.org/10.1037/0278-7393.26.6.1556

Gates, A. I. (1917). *Recitation as a factor in memorizing*. University Printing Office.

Gates, V., Suchow, J. W., & Griffiths, T. L. (2022). Memory transmission in small groups and large networks: An empirical study. *Psychonomic Bulletin & Review, 29*(2), 581–588.

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. https://doi.org/10.1080/09658210701811862

Ingham, A. G., Levinger, G., Graves, J., & Peckham, V. (1974). The Ringelmann effect: Studies of group size and group performance. *Journal of Experimental Social Psychology, 10*(4), 371–384.

Johansson, O., Andersson, J., & Ronnberg, J. (2000). Do elderly couples have a better prospective memory than other elderly people when they collaborate? *Applied Cognitive Psychology, 14*, 121–133.

Latane, B., & Nida, S. (1981). Ten years of research on group size and helping. *Psychological Bulletin, 89*(2), 308.

Latane, B., Williams, K., & Harkins, S. (1979). Many hands make light the work: The causes and consequences of social loafing. *Journal of Personality and Social Psychology, 37*, 822–832.

Lehmer, E.-M., & Bäuml, K.-H.T. (2018). Part-list cuing can impair, improve, or not influence recall performance: The critical roles of encoding and access to study context at test. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 44*(8), 1186.

Luhmann, C. C., & Rajaram, S. (2015). Memory transmission in small groups and large networks: An agent-based model. *Psychological Science, 26*(12), 1909–1917.

Marion, S. B., & Thorley, C. (2016). A meta-analytic review of collaborative inhibition and postcollaborative memory: Testing the predictions of the retrieval strategy disruption hypothesis. *Psychological Bulletin, 142*(11), 1141–1164.

Maswood, R., & Rajaram, S. (2019). Social transmission of false memory in small groups and large networks. *Topics in Cognitive Science, 11*(4), 687–709.

Meade, M. L., & Roediger, H. L. (2009). Age differences in collaborative memory: The role of retrieval manipulations. *Memory & Cognition, 37*(7), 962–975.

Meade, M. L., Nokes, T. J., & Morrow, D. G. (2009). Expertise promotes facilitation on a collaborative memory task. *Memory, 17*(1), 39–48. https://doi.org/10.1080/09658210802524240

Nickerson, R. S. (1984). Retrieval inhibition from part-set cueing—A persisting enigma in memory research. *Memory & Cognition, 12*(6), 531–552. https://doi.org/10.3758/Bf03213342

Raaijmakers, J. G. W., & Shiffrin, R. M. (1980). SAM: A theory of probabilistic search of associative memory. *The Psychology of Learning and Motivation: Advances in Research and Theory, 14*, 207–262.

Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review, 88*, 93–134.

Rajaram, S., & Pereira-Pasarin, L. P. (2010). Collaborative memory: Cognitive research and theory. *Perspective on Psychological Science, 5*(6), 649–663. https://doi.org/10.1177/1745691610388763

Rundus, D. (1973). Negative effects of using list items as recall cues. *Journal of Verbal Learning and Verbal Behavior, 12*(1), 43–50.

Slamecka, N. J. (1968). An examination of trace storage in free recall. *Journal of Experimental Psychology, 76*(4p1), 504–513. https://doi.org/10.1037/h0025695

Taylor, D. W., Berry, P. C., & Block, C. H. (1958). Does group participation when using brainstorming facilitate or inhibit creative thinking? *Administrative Science Quarterly, 3*, 23–47.

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.

Tulving, E. (1962). Subjective organization in free recall of "unrelated" words. *Psychological Review, 69*(4), 344.

Tulving, E. (1974). Cue-dependent forgetting. *American Scientist, 62*, 74–82.

Weldon, M. S., & Bellinger, K. D. (1997). Collective memory: Collaborative and individual processes in remembering. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 1160–1175.

Weldon, M. S., Blair, C., & Huebsch, D. (2000). Group remembering: Does social loafing underlie collaborative inhibition? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 1568–1577.

Wilson, J. H., & Criss, A. H. (2017). The list strength effect in cued recall. *Journal of Memory and Language, 95*, 78–88.

Wilson, J. H., Kellen, D., & Criss, A. H. (2020). Mechanisms of output interference in cued recall. *Memory & Cognition, 48*(1), 51–68.

Wright, D. B., & Klumpp, A. (2004). Collaborative inhibition is due to the product, not the process, of recalling in groups. *Psychonomic Bulletin & Review, 11*(6), 1080–1083.