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Joint contributions of collaborative facilitation and social contagion to the development of shared memories in social groups

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ABSTRACT

Social interactions can shape our memories. Here, we examined two well-established effects of collaborative remembering on individual memory: collaborative facilitation for initially studied and social contagion with initially unstudied information. Participants were tested in groups of three. After an individual study phase, they completed a first interpolated test either alone or collaboratively with the other group members. Our goal was to explore how prior collaboration affected memory performance on a final critical test, which was taken individually by all participants. Experiments 1a and 1b used additive information as study materials, whereas Experiment 2 introduced contradictory information. All experiments provided evidence of collaborative facilitation and social contagion on the final critical test, which affected individual memory simultaneously. In addition, we also examined memory at the group level on this final critical test, by analyzing the overlap in identical remembered contents across group members. Here, the experiments showed that both collaborative facilitation for studied information and social contagion with unstudied information contributed to the development of shared memories across group members. The presence of contradictory information reduced rates of mnemonic overlap, confirming that changes in individual remembering have repercussions for the development of shared memories at the group level. We discuss what cognitive mechanisms may mediate the effects of social interactions on individual remembering and how they may serve social information transmission and the formation of socially shared memories.

1. Introduction

Social interactions permeate many of our daily actions. On a cognitive level, they are by no means neutral, but leave their distinct footprints behind. Research in the past decades has identified several ways in which social interactions can influence and shape our memories, both positively and negatively (for reviews, see Andrews & Rapp, 2015; Hirst & Echterhoff, 2012; Rajaram, in press).

Collaborative facilitation, for instance, refers to the finding that individuals who studied the same information and engaged in collaborative remembering together with others, later show enhanced memory, relative to individuals who took the same previous test alone, in isolation (e.g., Blumen & Stern, 2011; Blumen et al., 2014; Weldon & Bellinger, 1997). This positive effect is ascribed to group members reexposing each other to contents that they otherwise would have forgotten. Yet, social interactions can also have negative effects. The term social contagion refers to the finding that social interactions can also increase (false) remembering of information that was not initially studied (Roediger et al., 2001; Wright et al., 2000; see also Maswood & Rajaram, 2019). When social sources bring up new information that was not previously encountered, it can distort memory of what was originally experienced. Social contagion is attributed to impaired source monitoring (Meade & Roediger, 2002; see also Andrews & Rapp, 2014; Jalbert et al., 2021), with information from a social source being incorrectly attributed to a personally encoded episode.

1.1. The recognition-based collaboration task

Collaborative facilitation of studied information and social contagion with new information are usually examined separately, in different paradigms. Recently, however, we introduced a task, which allows examining the two effects simultaneously (see Abel & Bäuml, 2020). (Basden et al., 1997, 2000; Weldon & Bellinger, 1997), subjects complete the task in groups of three. Moreover, following prior work on social contagion (Gabbert et al., 2003; Garry et al., 2008; Mori, 2003), information distribution during initial encoding is varied and only partly the same across group members (i.e., different pieces of information are initially studied by 1, 2, or 3 group members). After a distractor phase, an interpolated memory test is completed either

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collaboratively or individually. Importantly, this interpolated test is a recognition test, comprising all pieces of information (studied by 1, 2, or 3 group members). After another distractor, all participants complete a final critical memory test individually, which reveals how prior collaboration affects memory for information initially studied by each participant — but also for information initially studied by the other group members only.

Abel and Bäuml (2020) applied this task for the first time and showed that interpolated collaborative (relative to individual) remembering can simultaneously enhance and distort memories on the final critical test. Enhancement was observed for initially studied information, but consistently only for information that was initially studied by all group members (not for information studied by 1 or 2 group members). This fits well with prior work on collaborative facilitation (e.g., Abel & Bäuml, 2017; Bärthel et al., 2017; Blumen & Stern, 2011; Blumen et al., 2014; Weldon & Bellinger, 1997) and the proposal that the effect arises due to reexposure with information that individuals would otherwise have forgotten. Chances for reexposure are greatest when all group members initially studied the information. When it was studied by single group members only, reexposure becomes less likely.

In addition to collaborative facilitation for fully shared information, Abel and Bäuml (2020) found that collaboration simultaneously also distorted individual memories on the final critical test. In particular, participants incorporated information into their memory of the study phase that they had not studied themselves, but that had in fact been studied by other group members. This social contagion with initially unstudied information was present for information that had been studied by one other group member, but it was even more pronounced for information that had been studied by both other group members. The recognition-based collaboration task thus shows that the same social interactions can simultaneously enhance and distort memories. By capturing both effects at the same time, the task offers a new way to examine the many ways in which social interactions shape our memories.

1.2. The development of shared memories

Indeed, another proposal in the literature is that social interactions support the emergence of collective memories. By definition, collective memories are shared by members of (larger) social groups and relate to the group's social identity (e.g., Hirst et al., 2018; Rajaram, in press; Roediger & Abel, 2015). Studies on collaborative remembering in small groups usually neglect the aspect of social identity, but still suggest that social interactions can encourage the development of shared memories. Individuals who initially studied the same information and then engaged in collaborative remembering later show higher overlap in the specific contents that they remember (e.g., Blumen & Rajaram, 2008; Cuc et al., 2006; Pepe et al., 2021). In other words, collaboration prompts greater mnemonic overlap based on increased remembering of the same contents across group members (Barber et al., 2012; Congleton & Rajaram, 2014; see also Choi et al., 2014, 2017; Stone et al., 2010).

One obvious candidate that may contribute to the development of shared memories at the group level is collaborative facilitation. When participants studied the same information initially, collaboration provides a chance for reexposure, and such reexposure may not only enhance individual memory, but also increase mnemonic overlap across group members. Another, maybe less obvious candidate is however social contagion. The social transmission of new, initially unstudied information across group members may also contribute to the development of shared memories (Cuc et al., 2006; Hirst & Echterhoff, 2012). Although straightforward empirical evidence for this proposal is still lacking, one previous study is particularly supportive. Choi et al. (2017) manipulated information distribution in triads, such that one group member studied some information that was unshared with the other two group members. Focusing on memory of the other two group members, Choi et al. (2017) reported higher mnemonic overlap after collaborative retrieval for the information initially studied by the third group member. Due to the way in which information distribution was manipulated in this study, mnemonic overlap could however not be directly examined as a function of information distribution and for all group members. Notably, if social contagion contributed to the development of shared memories, this could render one of the "sins" of memory (its susceptibility to misinformation; Schacter, 1999, 2022a, 2022b; Whitehead & Marsh, 2022) potentially adaptive and maybe even useful in daily life.

1.3. The present study

The first goal of the present study was to use the recognition-based collaboration task to directly address the contributions of collaborative facilitation and social contagion to the development of shared memories. Subjects participated in triads. At encoding, information distribution was varied, such that each participant studied some information that was unshared with the other group members (studied by 1), some that was shared with one other group member (studied by 2), and some that was shared with both other group members (studied by 3). After an interpolated collaborative vs. individual recognition test, individual memory was assessed on a final critical test. For individual performance on this critical test, we expected to replicate results by Abel and Bäuml (2020), i.e., collaborative facilitation for fully shared information (studied by 3), as well as social contagion effects, most pronounced when the transmitted information was initially studied by both other group members. Regarding group-level analyses of performance on the final critical test, we expected participants to be more likely to remember identical contents after collaborative vs. individual remembering (e.g., Choi et al., 2017; Congleton & Rajaram, 2014). Importantly, if social contagion contributes to the development of shared memories, such mnemonic overlap should not just be enhanced for fully shared information (studied by 3), but also for originally unshared information (studied by 1 or 2).

The second goal of the present study was to address the role of additive vs. contradictory information for the development of shared memories. In individual remembering, misinformation effects can be reduced when misinformation contradicts one's own prior encoding (e.g., Frost, 2000; Huff & Umanath, 2018; Moore & Lampinen, 2016). Experiment 1 of the present study only applied additive information; i.e., the information exclusively studied by other group members did not relate to one's own encoding. Experiment 2 however introduced contradictory information, such that what was studied by each participant partly contradicted what was studied by one or both other group members. If social contagion is reduced when socially transmitted information directly contradicts previously studied information, this should also have repercussions for the creation of shared memories at the group level. In particular, collaboration should result in lower degrees of mnemonic overlap when group members study contradictory information.

2. Experiment 1a

2.1. Method

2.1.1. Participants

180 undergraduates at Regensburg University received partial course credit for participating. Subjects participated in groups of three, with 30 triads (n=90) in each condition (collaborative vs. nominal groups). When signing up, subjects knew that they would complete the experiment together with two other participants. Mean age was 21.5 years ($SD = 2.4$); 39 subjects were male, 141 subjects were female. Participants in 9 triads reported not knowing each other at all before the experiment; in 16 triads, two of the three participants

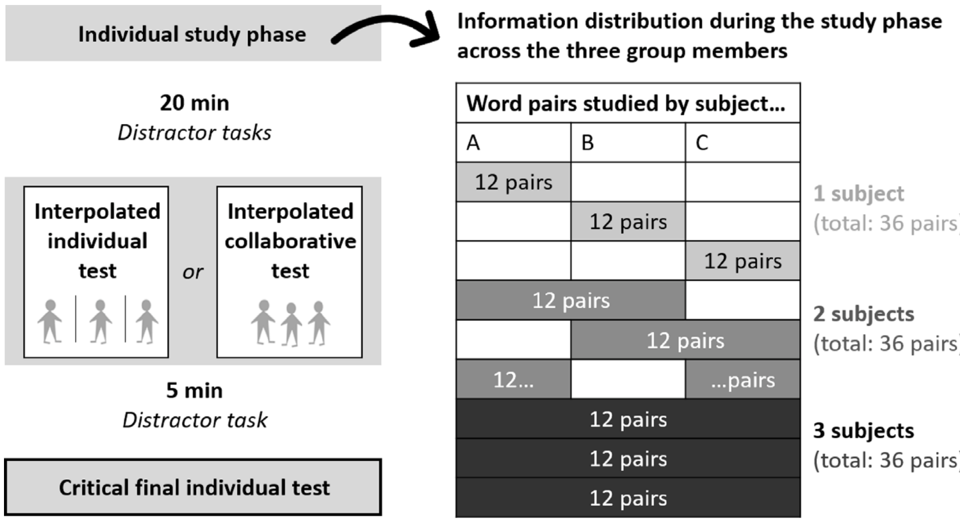

Fig. 1. Schematic visualization of experimental procedure (left) and manipulation of information distribution during the study phase (right) in Experiment 1a.

knew each other beforehand, and in 35 triads all three participants were acquainted.[1]

Sample size was determined on the basis of power analyses for within-between interactions in repeated-measures ANOVAs. Power was set to .80, $alpha$ to .05, and correlations among repeated measures to .50. The unit of interest for analyzing shared memories and mnemonic overlap across group members on the final critical test is the number of triads. With two between-subjects conditions and three repeated measures, a total of 58 triads is necessary to detect small- to medium-sized interaction effects of $f = .17$. Thus, we recruited 60 triads for the experiment (30 collaborative groups, 30 nominal groups). In addition to group-level analyses, we were however also interested in examining individual memory performance on the final critical test. Here, the planned sample of 180 participants enabled us to detect small-sized interaction effects of $f = .10$ (to assess collaborative facilitation for initially studied information with three repeated measures) and $f = .11$ (to assess social contagion with unstudied information with two repeated measures).

2.1.2. Material

Materials and data are available on the Open Science Framework (https://osf.io/mkzfn/). Two sets of 108 weakly related word pairs each were selected from the database provided by Nelson et al. (2004). Importantly, word pairs were chosen such that, across the two sets, there were always two word pairs that started with the same word. For example, the word pair "gift - surprise" was part of Set A, whereas the word pair "gift - ribbon" was part of Set B. The two sets were roughly matched regarding mean forward association strength of the word pairs ($M = 0.029$, $SD = 0.016$). Across subjects, both sets were equally often used as study materials at encoding and as distractor materials at test.

For use as study materials, each set was randomly grouped into 36 items that would be studied by all three subjects, 36 items that would be studied by two subjects, and 36 items that would be studied by one subject. When used as distractor material, the corresponding groups of 36 items were applied as distractors.

2.1.3. Design

The experiment had a two-factorial mixed design. The first factor of group type (nominal vs. collaborative) was manipulated between-subjects. All subjects were tested in groups of three, but in the nominal group condition, subjects completed all memory tests in the course of the experiment alone, and never engaged in social interactions with the other group members during these tests. In the collaborative group condition, subjects engaged in the same two tests, but completed the first interpolated test collaboratively, freely interacting with the other group members. Subsequently, they completed the same final critical individual recognition test as subjects from the nominal group condition.

The second factor of information distribution was manipulated within-subject and concerned the distribution of word pairs across group members during the study phase. Our first interest was in analyzing individual performance on the final critical memory test. For these analyses, the factor had a total of five levels, but can be further split up into information that was initially studied (three factor levels) or initially unstudied (two factor levels). For each subject, word pairs that were initially studied could be sorted into pairs that had initially only been studied by the respective subject (studied by 1), by the respective subject and one further group member (studied by 2), or by all group members (studied by 3). These word pairs were used to examine collaborative facilitation effects for originally studied information. In addition, for each subject, there were also word pairs that they themselves had not studied initially, but that had been studied by other group members instead (studied by 1 or 2 other group members). These word pairs were used to examine social contagion with originally unstudied information (for an overview of the manipulation of information distribution, see Fig. 1). For analyses on initially studied information, we used the hit rate on corresponding trials of the final critical 2AFC recognition test as the dependent variable; for analyses on initially unstudied information, we used the respective false alarm rate. A breakdown of responses across all response options per trial can additionally be found in the Appendix.

Our second interest was in analyzing mnemonic overlap on the final critical memory test at the group level to assess the development of shared memories for the same contents. For these analyses, the dependent variable of interest was the proportion of identical contents that were uniformly remembered by all members of a triad on the final recognition test. Here, the factor of information distribution had three levels, distinguishing between information that had initially been studied by 1, 2, or all 3 group members.

[1] We ran additional analyses to examine if pre-existing acquaintance affected the main results, but this was not the case in any of the experiments. Acquaintance is therefore not included as an additional factor in the results sections.

2.1.4. Procedure

2.1.4.1. Study phase. Experiment 1a was conducted in the lab, with each subject seated in front of a different computer. After providing informed consent, subjects were asked to try to memorize a relatively high number of word pairs to the best of their abilities. Subjects were neither warned that they would study partly different materials, nor was it suggested to them that they would all study the same materials. During study, word pairs were presented back to back, in a random sequence, and for 3 s each, centrally on the computer screens. Subjects were asked to silently focus on the study materials. All subjects studied 72 word pairs in this manner: 36 pairs that were studied by all 3 group members, 24 pairs that were studied by themselves and one further group member, and 12 pairs that were only studied by themselves (see Fig. 1 for an overview). Thus, a total of 108 (partly different) word pairs was distributed and studied across the three group members.

2.1.4.2. Distractor phase. After study, all subjects were distracted for 20 min. First, they were asked to provide some demographic information about themselves, which took about 2 min. Subsequently, they solved decision problems (Tversky & Kahneman, 1974) for about 6 min. Next, participants worked on the connect-the-numbers test (Oswald & Roth, 1987) for about 5 min. To fill the remaining time until the 20-min interval was over, subjects completed standard progressive matrices (Raven, 2000). This mix of tasks was used to keep participants engaged; all participants in all conditions completed the same distractor tasks.

2.1.4.3. Interpolated collaborative vs. individual recognition test. Next, subjects were asked to complete an interpolated recognition test for the materials studied in the beginning of the experiment. Unbeknownst to participants, each trial probed memory for one of the word pairs presented to one of the group members during study. Sequence of word pairs was set to random. On each trial, one of the 108 studied word pairs (e.g., "gift - surprise") was presented together with the corresponding word pair from the distractor set that had not been studied by anyone (e.g., "gift - ribbon"). Subjects were asked to decide which of the two response options per trial referred to a word pair that had been encountered in the initial study phase; alternatively, they could also choose "none of the word pairs" as a third response option. The position of the studied word pair (as response option 1 or 2) was counterbalanced across trials.

Because subjects had only partly studied the same information, we expected that collaboration on this test would prompt social contagion. In the collaborative group condition, subjects in each triad completed the test together and were asked to decide as a group if one of the word pairs on each trial referred to a word pair from the study phase. Subjects were seated in front of the same computer. Before the test began, they were simply asked to complete the test as a group, but were given no further instructions on how to determine group responses. In particular, they were never instructed to try to convince each other or to reach consensus decisions that had to be held by each individual. The test was self-paced and the next trial started once a response was entered. To avoid dominant subjects taking over responding, the experimenter entered all responses for the collaborative groups via the computer keyboard. Collaborative tests were additionally audio recorded.

Subjects in the nominal group condition completed the same test, but did so silently and at their individual computers, without any social interaction. To avoid the confound of individuals completing the test a lot faster than collaborative groups, each trial of the individual version of the test was set to a fixed duration of 8 s (see Abel & Bäuml, 2020). Subjects were asked to provide their responses within this 8-sec window. To avoid missed trials, a countdown was presented on the screen for the last 4 s of each trial. In all other respects, the test was identical to that in the collaborative group condition.

After completing the test, subjects in all conditions were asked to work on another distractor task for 5 min (the d2 test of attention; Brickenkamp & Zillmer, 1998).

2.1.4.4. Final critical individual recognition test. The final phase of the experiment comprised the critical recognition test which was completed individually by subjects in all conditions. Subjects were explicitly reminded that the test probed memory for the study phase at the beginning of the experiment. The format of the test was identical to that of the previous interpolated collaborative vs. individual recognition test. The position of the two word pairs presented on each trial (as response options 1 or 2) was however reversed for half of the word pairs, and the test was now completely self-paced for all participants. Upon completion of the final test, subjects were debriefed and thanked for their participation.

2.2. Results

2.2.1. Individual memory on the final critical test

2.2.1.1. Memory for initially studied information. We first analyzed mean hit rates for word pairs that were initially studied by each single participant (see Fig. 2a). A 2×3 ANOVA with the factors of GROUP CONDITION (nominal, collaborative) and INFORMATION DISTRIBUTION (studied by 1, 2, or 3 subjects) showed no significant main effect of GROUP CONDITION, $F(1, 178) = 0.18$, $MSE = 0.06$, $p = .670$, $\eta_p^2 = .001$, but a significant main effect of INFORMATION DISTRIBUTION, $F(2, 356) = 49.38$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .22$, which was accompanied by a significant interaction between the two factors, $F(1.68, 299.69) = 7.85$, $MSE = 0.01$, $p = .001$, $\eta_p^2 = .04$. This pattern suggests that prior collaboration facilitated later individual memory only selectively, depending on how many participants had initially studied the respective information. Indeed, hit rates were slightly enhanced in the collaborative relative to the nominal group condition, but only for information initially studied by all 3 group members (78.4% vs. 73.3%), $t(178) = 2.31$, $p = .022$, $d = 0.34$. No significant collaborative facilitation was observed for information initially studied by 2 group members (70.8% vs. 69.4%), $t(178) = 0.63$, $p = .531$, $d = 0.09$, or for information initially studied by 1 group member (62.9% vs. 66.7%), $t(178) = 1.31$, $p = .192$, $d = 0.20$.

2.2.1.2. Memory for initially unstudied information. We next analyzed mean false alarms for word pairs that were initially not studied by each subject, but by one or both other group member(s) (see Fig. 2b). A 2×2 ANOVA with the factors of GROUP CONDITION (nominal, collaborative) and INFORMATION DISTRIBUTION (studied by 1 or 2 other group members) showed a significant main effect of GROUP CONDITION, $F(1, 178) = 114.76$, $MSE = 0.05$, $p < .001$, $\eta_p^2 = .39$, a significant main effect of INFORMATION DISTRIBUTION, $F(1, 178) = 11.36$, $MSE = 0.01$, $p = .001$, $\eta_p^2 = .06$, and a significant interaction between the two factors, $F(1, 178) = 22.92$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .11$. In the nominal group condition, false alarms for word pairs initially studied by both or one other group member were relatively low and did not differ from one another (15.2% vs. 16.7%), $t(89) = 1.15$, $p = .252$, $d = 0.12$. In the collaborative group condition, however, word pairs initially studied by both other group members evoked higher false alarm rates than word pairs initially studied by one other group member; 44.1% vs. 35.5%), $t(89) = 5.17$, $p < .001$, $d = 0.54$. False alarm rates were generally enhanced after collaborative vs. nominal group recall, but this social contagion effect was more pronounced for word pairs initially studied by both other group members (44.1% vs. 15.2%), $t(178) = 10.75$, $p < .001$, $d = 1.60$, than for word pairs initially studied by one other group member (35.5% vs. 16.7%), $t(178) = 8.47$, $p < .001$, $d = 1.26$.

2.2.1.3. Discriminability. To address how collaboration affected overall discriminability on the final critical test, we additionally calculated individual d' (as z(hits)-z(false alarms)). Hits were derived from trials in which studied information was present; false alarms were derived from trials in which studied information was not present (only information studied by someone else in the group). On average, the resulting d' was lower for participants who had previously engaged in collaborative remembering, and this was the case irrespective of whether false alarms were only based on the response option that had been studied by other

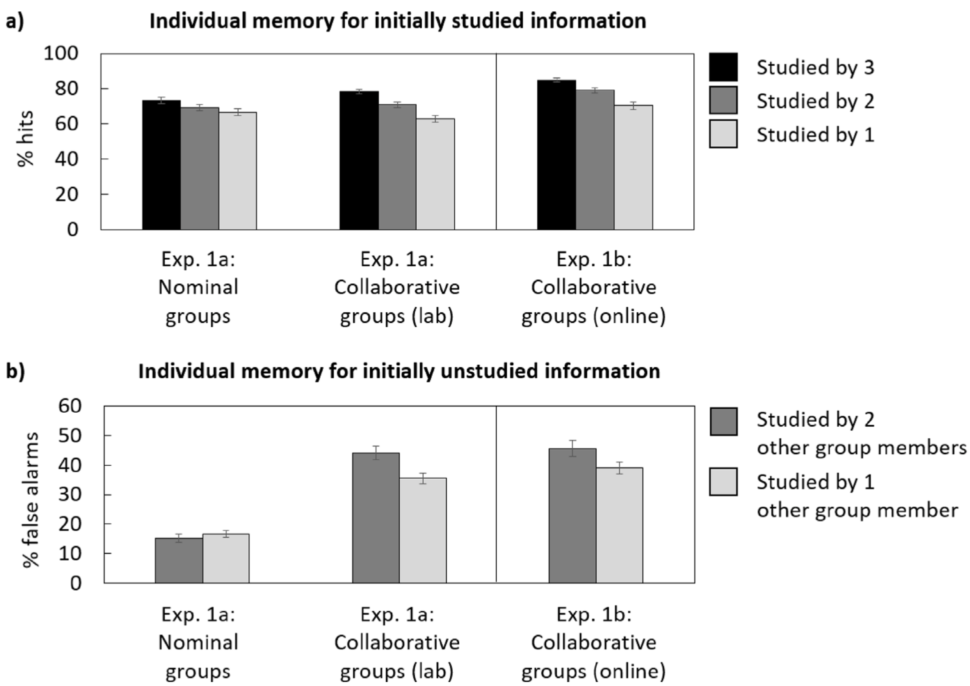

Fig. 2. Individual memory on the final critical test in Experiment 1a and 1b. (a) Hit rates for initially studied information, used to examine collaborative facilitation, and (b) false alarms for initially unstudied information, used to examine social contagion, Error bars ±1 standard errors of the mean.

group members (M = 0.72 vs. M = 1.22, t(168.69) = 7.20, p < .001, d = 1.07) or whether they were based on both unstudied response options per trial (M = 0.41 vs. M = 0.76, t(161.28) = 4.20, p < .001, d = 0.63; see also Appendix). Interpolated collaborative remembering reduced participants' ability to discriminate between initially studied and unstudied contents.

2.2.2. Overlap in remembered contents across group members on the final critical test

Finally, we also examined to what degree social interactions prompted memories for the same contents, held by all three group members (see Fig. 3a). With this dependent variable, a 2 × 3 ANOVA with the factors of GROUP CONDITION (nominal, collaborative) and INFORMATION DISTRIBUTION (studied by 1, 2, or 3 group members) showed a significant main effect of GROUP CONDITION, $F(1, 58) = 36.91$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = .39$, reflecting higher rates of mnemonic overlap in collaborative than in nominal groups (overall: 33.0% vs. 17.5% overlap). There was also a significant main effect of INFORMATION DISTRIBUTION, $F(1.41, 81.80) = 290.16$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .83$, indicating higher rates of mnemonic overlap when information had initially been studied by more group members (studied by 3 group members: 47.1% overlap; studied by 2 group members: 18.9% overlap; studied by 1 group member: 9.7% overlap).[2] There was also a significant interaction between the two factors, however, $F(1.41, 81.80) = 5.63$, $MSE = 0.01$, $p = .011$, $\eta_p^2 = .09$, which suggests that the effect of collaboration on the development of shared memories varied somewhat with information distribution. A larger rate of mnemonic overlap in collaborative groups was observed for information initially studied by all 3 group members (52.8% vs. 41.4%), t(58) = 2.76, p = .008, d = 0.71), and also for information initially studied by 1 group member (16.5% vs. 3.0%), t(58) = 5.74, p < .001, d = 1.48. The effect was however most pronounced for information initially studied by 2 group members (29.7% vs. 8.1%), t(58) = 7.94, p < .001, d = 2.05.

2.3. Discussion

Experiment 1a provides a mix of replications and novel findings. As shown in previous work (see Abel & Bäuml, 2020), collaboration simultaneously enhanced and distorted later individual memory measured on a final critical test. Collaborating with others facilitated later individual memory for information initially studied by all three group members, though not for information studied by single group members. At the same time, collaboration also distorted individual memory. Participants in collaborative groups showed higher rates of false remembering for information that was not initially studied by them, but by other group members instead. This social contagion was most pronounced when the information had initially been studied by both other group members. Experiment 1a thus fully replicated the results by Abel and Bäuml (2020), even though it relied on different types of study materials (weakly associated word pairs instead of single, unrelated items) and recognition tests (2AFC instead of old/new recognition). Moreover, an additional analysis suggested that collaboration reduced participants' ability to discriminate between previously studied and unstudied information.

Most importantly, Experiment 1a also offers new findings on shared remembering at the group level. The opportunity to interact with others enhanced mnemonic overlap on the final critical test, i.e., individuals in collaborative groups were more likely to later remember the same information as their fellow group members. Previous work has documented this effect for information initially studied by all three group members (e.g., Barber et al., 2012; Congleton & Rajaram, 2014), but the present data show that it also occurs for information that was previously only studied by single group members (see also Choi et al., 2017, for some initial data). This finding reveals that collaborative facilitation for initially studied information as well as social contagion with initially unstudied information jointly contribute to the development of shared memories in groups.

[2] This impact of initial information distribution on mnemonic overlap was not only evident in collaborative groups, but also in nominal groups. The chances for information to be remembered by all three group members are highest when it was initially studied by all three group members, and lowest, when it was studied by single group members only. Importantly, this is the case irrespective of whether participants previously engaged in collaborative remembering or not.

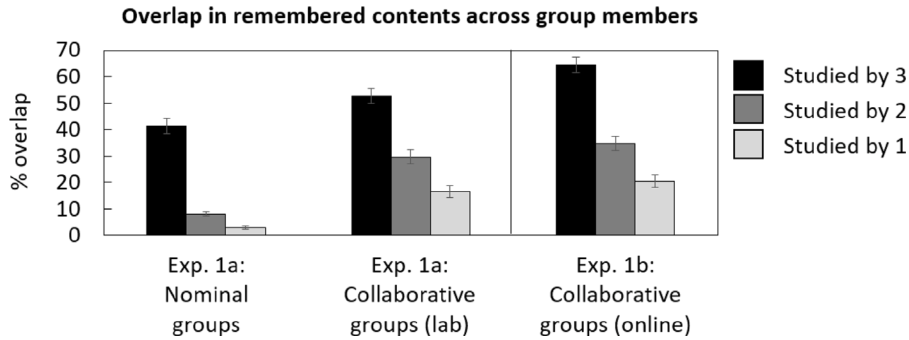

Fig. 3. Group memory on the final critical test in Experiments 1a and 1b. Rates of overlap and remembering of the same contents across all group members. Error bar shows ±1 standard errors of the mean. Note. Rate of overlap can vary between 0%–100% for each item type (initially studied by 3, 2, or 1 participants). Thus, the three bars shown for each group condition do not need to add up to 100%.

3. Experiment 1b

Experiment 1a was run in the lab before the outbreak of the Covid-19 pandemic. The pandemic made it impossible to conduct further small-group studies on social interactions in the lab. As a consequence, we were forced to move our experiments to online testing. In order to keep the experiments as close to lab testing as possible, we decided to try out a variant of the collaborative recognition task via participation in Zoom meetings, resulting in Experiment 1b. The goal of Experiment 1b was to check whether such online testing would result in comparable results for collaborative groups as the lab testing in Experiment 1a. Experiment 1b therefore only comprised a collaborative group, tested online. Three participants were recruited for each Zoom meeting, and were asked to interact and collaborate with the other group members via webcams and microphones.

3.1. Method

3.1.1. Participants

90 subjects were recruited online and received a gift card for an online shop as compensation for participating. Subjects knew that they would participate in groups of three; a total of 30 collaborative triads was tested. Mean age was 23.6 years ($SD = 2.7$); 35 subjects were male, 55 subjects were female. Participants in 10 triads reported not knowing each other at all before the experiment; in 10 triads, two of the three participants knew each other beforehand, and in 10 triads all three participants were acquainted.

3.1.2. Material

Materials were the same as in Experiment 1a.

3.1.3. Design

Experiment 1b by itself had a one-factorial design with the within-subject factor of information distribution, which again concerned the distribution of word pairs across group members during the study phase (see Experiment 1a for details). All participants in Experiment 1b took part in collaborative groups and were tested online. Because the goal of the experiment was to evaluate whether such online testing would create similar results as lab testing, we re-used the data from the collaborative group condition in Experiment 1a (tested in the lab) as a control condition. This creates the additional between-subjects factor of testing environment (in the lab vs. online).

3.1.4. Procedure

The procedure of the study had to be adapted in some ways to be conducted online. Subjects were recruited via the university's subject pool and social media posts. They participated from their homes and received invitations to a joint Zoom meeting via e-mail. The three participants in each triad were guided through the study by three experimenters; i.e., each Zoom meeting was attended by 6 people in total (3 subjects, 3 experimenters). At the beginning, participants received the same information about the study and their rights as participants in Experiment 1a; all subjects provided verbal consent to participate in the study. Subjects were asked to keep their microphones and cameras activated during the Zoom meeting to facilitate communication and social interaction. No video or audio recordings were made to protect subjects' privacy; this aspect was also emphasized to participants.

3.1.4.1. Study phase. The individual study phase was conducted in break-out sessions. Each participant was accompanied to an individual break-out session by one of the experimenters, who provided instructions and presented the study materials via screen-sharing. All other procedural details were the same as in Experiment 1a.

3.1.4.2. Distractor phase. Subsequently, all subjects returned to the main Zoom meeting and were distracted for 20 min. First, subjects provided some demographic information about themselves (2 min) and then moved on to complete decision problems (Tversky & Kahneman, 1974; for about 8 min) as well as standard progressive matrices (Raven, 2000; for about 10 min). Please note that the composition of distractor tasks is a bit different from Experiment 1a, because not all tasks used in Experiment 1a could be adapted for use in an online study.

3.1.4.3. Interpolated collaborative recognition test. The collaborative test on the initially studied materials was also completed together as a group in the main Zoom meeting. One of the experimenters provided instructions, presented the test trials via screen-sharing, and entered the group's responses via key presses (the other two experimenters deactivated their cameras for this part of the experiment). The remaining procedural details were identical to Experiment 1a. Subjects were again asked to complete the self-paced test as a group, but were given no further instructions on how to determine group responses. No audio recording of the collaborative test was made.

After completing the test, the three subjects were again accompanied to individual break-out sessions by the experimenters and completed another distractor task for 5 min (a digit-span test; Miller, 1956).

3.1.4.4. Final critical individual recognition test. Subjects remained in the individual break-out sessions for the final phase of the experiment. The experimenters provided instructions and again reminded participants that the final critical test probed their memory of the study phase at the beginning of the experiment. The format of the self-paced test was identical to Experiment 1a, but participants provided their responses orally and experimenters entered them via key presses. Upon completion of the final test, subjects returned to the main Zoom session for goodbyes and a debriefing. Subjects received gift cards as compensation for participating in the study via e-mail.

3.2. Results

3.2.1. Individual memory on the final critical test

3.2.1.1. Memory for initially studied information. We started by comparing memory for information that was initially studied by each individual participant (used to assess collaborative facilitation in Exp. 1a; see Fig. 2a). A 2 × 3 ANOVA with the factors of TESTING ENVIRONMENT (lab, online) and INFORMATION DISTRIBUTION (initially studied 1, 2, or 3 group members) revealed a significant main effect of TESTING ENVIRONMENT, $F(1,178) = 15.62$, $MSE = 0.05$, $p < .001$, $\eta_p^2 = .08$, reflecting overall higher hit rates with online than lab testing (78.1% vs. 70.7%). There was also a significant main effect of INFORMATION DISTRIBUTION, $F(2,356) = 89.28$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .33$, an expression of hit rates being higher the more group members had initially studied the word pairs. There was however no significant interaction between the two factors, $F(1.70,302.38) = 0.29$, $MSE = 0.01$, $p = .710$, $\eta_p^2 = .002$, which suggests that information distribution affected memory similarly irrespective of whether collaborative groups interacted with each other online or in the lab. Hit rates were higher for information initially studied by 3 rather than by 2 group members, and this held for online testing (84.9% vs. 79.0%, $t(89) = 5.16$, $p < .001$, $d = 0.54$) and lab testing (78.4% vs. 70.8%, $t(89) = 5.85$, $p < .001$, $d = 0.62$). Hit rates were also higher for information initially studied by 2 rather than by 1 group member(s), and this again was the case with both online (79.0% vs. 70.5%, $t(89) = 4.88$, $p < .001$, $d = 0.51$) and lab testing (70.8% vs. 62.9%, $t(89) = 4.35$, $p < .001$, $d = 0.46$).

3.2.1.2. Memory for initially unstudied information. We next compared memory for information that was initially not studied by each individual participant, but by the other group members (see Fig. 2b). A 2 × 2 ANOVA with the factors of TESTING ENVIRONMENT (lab, online) and INFORMATION DISTRIBUTION (initially studied by one or both other group members) only showed a significant main effect of INFORMATION DISTRIBUTION, $F(1,178) = 38.47$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .18$, but no significant main effect of TESTING ENVIRONMENT, $F(1,178) = 0.81$, $MSE = 0.07$, $p = .370$, $\eta_p^2 = .005$, and no significant interaction between the two factors, $F(1,178) = 0.71$, $MSE = 0.01$, $p = .402$, $\eta_p^2 = .004$. False alarm rates for unstudied information were higher if the information had been studied by both rather than only one other group member(s), and this held true irrespective of whether collaborative groups were tested online (45.7% vs. 39.1%, $t(89) = 3.66$, $p < .001$, $d = 0.39$) or in the lab (44.1% vs. 35.5%, $t(89) = 5.17$, $p < .001$, $d = 0.54$).

3.2.2. Overlap in remembered contents across group members on the final critical test

Finally, we also examined rates of mnemonic overlap across the three group members (see Fig. 3). A 2 × 3 ANOVA with the factors of TESTING ENVIRONMENT (lab, online) and INFORMATION DISTRIBUTION (initially studied by 1, 2, or 3 group members) showed a significant main effect of TESTING ENVIRONMENT, $F(1,58) = 4.82$, $MSE = 0.05$, $p = .032$, $\eta_p^2 = .08$, reflecting slightly higher rates of overlap with online than with lab testing (39.9% vs. 33.0%). There was also a significant main effect of INFORMATION DISTRIBUTION, $F(1.64,94.99) = 311.04$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .84$, as well as a significant interaction between the two factors, $F(1.64,94.99) = 3.38$, $MSE = 0.01$, $p = .048$, $\eta_p^2 = .06$, which suggests that the effect of testing environment varied somewhat with information distribution. Rates of mnemonic overlap were higher when information was initially studied by more group members (studied by 3 group members: 58.7% overlap; 2 group members: 32.3% overlap; 1 group member: 18.5% overlap). Online relative to lab testing however only led to higher overlap for information initially studied by all 3 group members (64.6% vs. 52.8%, $t(58) = 2.89$, $p = .005$, $d = 0.75$), not for information studied by 2 group members (34.8% vs. 29.7%, $t(58) = 1.40$, $p = .168$, $d = 0.36$), or 1 group member (20.5% vs. 16.5%, $t(58) = 1.20$, $p = .233$, $d = 0.31$). This was likely the case because online testing relative to lab testing enhanced individual memory for studied information, but not for unstudied information. As a consequence, online testing may also have resulted in higher mnemonic overlap for fully shared information that was initially studied by all participants, but not for partly shared and unshared information, with a substantial part of this information not being studied by all group members.

3.3. Discussion

Experiment 1b suggests that findings on collaborative remembering in the lab may largely transfer to synchronous online testing of small groups via Zoom. Comparing the findings based on collaboration in the lab and online in Figs. 2 and 3, the general patterns are remarkably similar. Even when social interactions occurred via Zoom, the initial distribution of information across group members still had clear effects on later individual memory for initially studied and unstudied information. Moreover, it also continued to affect shared remembering at the group level. We interpret these parallels between the collaborative groups in Experiment 1a and 1b as a positive sign, suggesting that findings from lab-based research on small-group collaboration can generalize to an online setting, at least when cameras and microphones allow relatively normal interactions (but see Ekeocha & Brennan, 2008; Hinds & Payne, 2016, 2018 for further work on other types of digital collaboration). The goal of Experiment 1b was to investigate the viability of online testing via Zoom as a way to continue this line of work during a pandemic that precluded experiments in the lab, and the parallel in findings encouraged us to keep using this approach in Experiment 2.

Nevertheless, participants who were tested online showed higher correct recognition for initially studied information than participants who were tested in the lab. A number of factors could in principle be responsible for this difference. For instance, the boost might be due to the novelty of participating in an experiment via Zoom, or also due to the excitement of social exchange in the middle of a period of social isolation due to the Covid-19 pandemic. In any case, the difference in correct recognition had a cascading effect for the emergence of shared memories at the group level, which may be an interesting finding in itself. Indeed, shared remembering was also enhanced with online testing, though only for information initially studied by all three participants. This restriction was likely observed because shared memories for information initially studied by single group members additionally depends on social contagion, which was found to be comparable across lab and online testing. The finding may thus be an expression of the connection between individual memory and group memory. If individual memory performance is high, this may offer a greater chance for overlap across individuals and promote shared remembering.

4. Experiment 2

Experiments 1a and 1b suggest that, on the basis of collaborative recognition judgments, information can spread across group members rather easily, irrespective of whether collaboration occurs in a face-to-face or an online setting. So far, we have only examined this for additive information, however.

A distinction that is frequently made in the context of research on the misinformation effect (Loftus, 2005; Loftus et al., 1978) is that between additive and contradictory misinformation (see Frost, 2000; Huff & Umanath, 2018; Moore & Lampinen, 2016; Nemeth & Belli, 2006). Additive misinformation refers to information that was not present during encoding, but very well could have been (in addition to what was actually encoded). For example, a witness to a traffic accident might receive the misinformation that a barn was located next to the road, though it was not really there (Loftus, 1975). In contrast, contradictory misinformation refers to information that directly contradicts information that was present during encoding. For example, the witness might receive the misinformation that there was a stop sign at

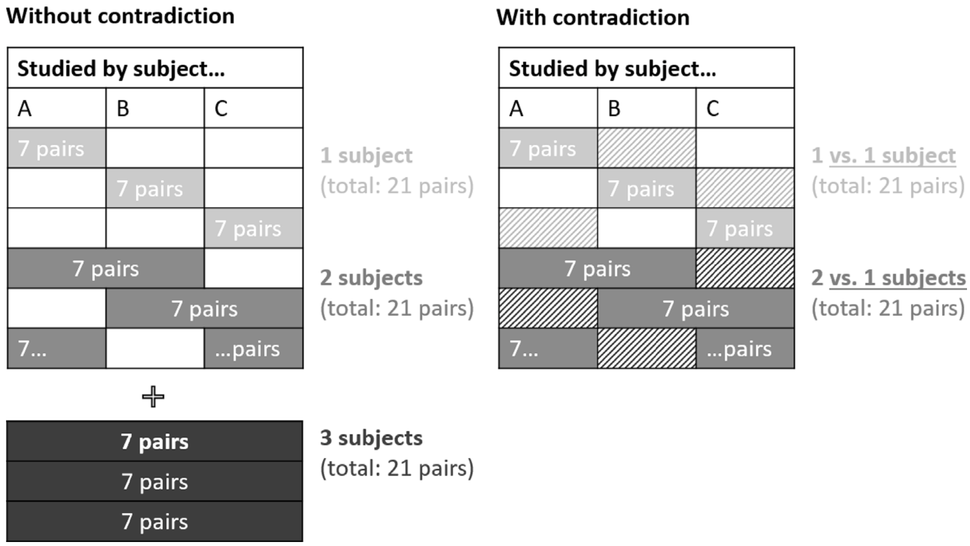

Fig. 4. Manipulation of information distribution in Experiment 2. Word pairs during the study phase were presented to 1, 2 or all 3 subjects in each group. For word pairs during the study by 1 or 2 subjects, we also varied the presence of contradiction across group members (e.g., 1 or 2 subjects might study the word pair "gift - surprise"; with contradiction, another subject in the group might study the word pair "gift - ribbon" instead)

the intersection, although there actually was a yield sign (Loftus et al., 1978). Prior work suggests that people are susceptible to both types of misinformation, but that misinformation effects can be reduced when the misinformation contradicts one's own prior encoding (e.g., Frost, 2000; Huff & Umanath, 2018; Moore & Lampinen, 2016).

To the best of our knowledge, this issue has never been examined in the context of unrestricted social interactions and the spread of information in groups. What happens during collaboration when single group members not only encoded different, additive information, but also directly contradictory information? Does collaboration still result in the spread of this information, such that it affects later remembering at the group level?

Experiment 2 was conducted to address these questions. Subjects again participated in groups of three via joint Zoom meetings. They again encoded information that was either fully shared, partly shared, or unshared with other group members. This time, however, this not only included additive, but also contradictory information. As in Experiment 1a, we manipulated whether participants completed an interpolated test collaboratively or individually. For additive information, we expected to replicate the findings from Experiments 1a and 1b, with collaborative facilitation and social contagion effects in individual memory, and boosts to shared remembering on the basis of collaboration. In addition, for individual memory, we expected lower rates of social contagion with contradictory information, which we assumed would in turn also lower rates of shared remembering at the group level.

4.1. Method

4.1.1. Participants

180 subjects were recruited online and received a gift card for participating in the study via Zoom meetings. Subjects knew that they would participate in groups of three when signing up. A total of 60 triads was tested (30 nominal, 30 collaborative). Mean age was 23.3 years ($SD = 4.0$); 32 subjects were male, 148 subjects were female. Participants in 27 triads reported not knowing each other at all before the experiment; in 16 triads, two of the three participants knew each other beforehand, and in 17 triads all three participants were acquainted.

4.1.2. Material

Materials were the same as in the previous experiments, but the word pairs (and their counterparts, previously only used as distractors) were now differently distributed across the three participants to also create instances in which group members studied contradictory information (see Fig. 4 for an overview). Across each triad, participants studied a total of 105 word pairs. As in the previous experiments, this included word pairs that were studied by all 3 group members (21 word pairs in total), word pairs that were studied by 2 group members only (21 word pairs), and word pairs that were studied by 1 participant only (21 word pairs).

In addition, Experiment 2 now also included word pairs with contradictions across the group. For instance, one or two group members studied the word pair "gift - surprise", but another group member studied the contradicting word pair from the set of distractor materials instead (i.e., "gift - ribbon"). At test, participants would be asked to decide as a group which of the two response options was presented at study, resulting in a contradiction of the studied information. For trials with such contradictions, we also distinguished between word pairs that were initially studied by 2 vs. 1 participants (21 word pairs in total) and word pairs that were initially studied by 1 vs. 1 participants (21 word pairs; see also Fig. 4). As a consequence of these manipulations, each individual participant now encoded a total of 77 word pairs during the study phase.

4.1.3. Design

Depending on the focus of analysis, the experiment had a two- or three-factorial mixed design, respectively. As in Experiment 1a, the factor of group type (nominal vs. collaborative) was manipulated between-subjects. In the nominal group condition, subjects completed all memory tests in the course of the experiment alone; in the collaborative group condition, subjects engaged in the same two tests, but completed the first, interpolated test collaboratively, freely interacting with the other group members.

The second factor of information distribution was again manipulated within-subject and had a total of five levels, which could again be split up into information that was initially studied (three levels: studied by 1, 2 or 3 group members; used to examine collaborative facilitation) or initially unstudied (two levels: studied by 1 or 2 of the other group members; used to examine social contagion). For analyses on the group level, the factor again had only three levels, differentiating between information studied by 1, 2 or 3 group members.

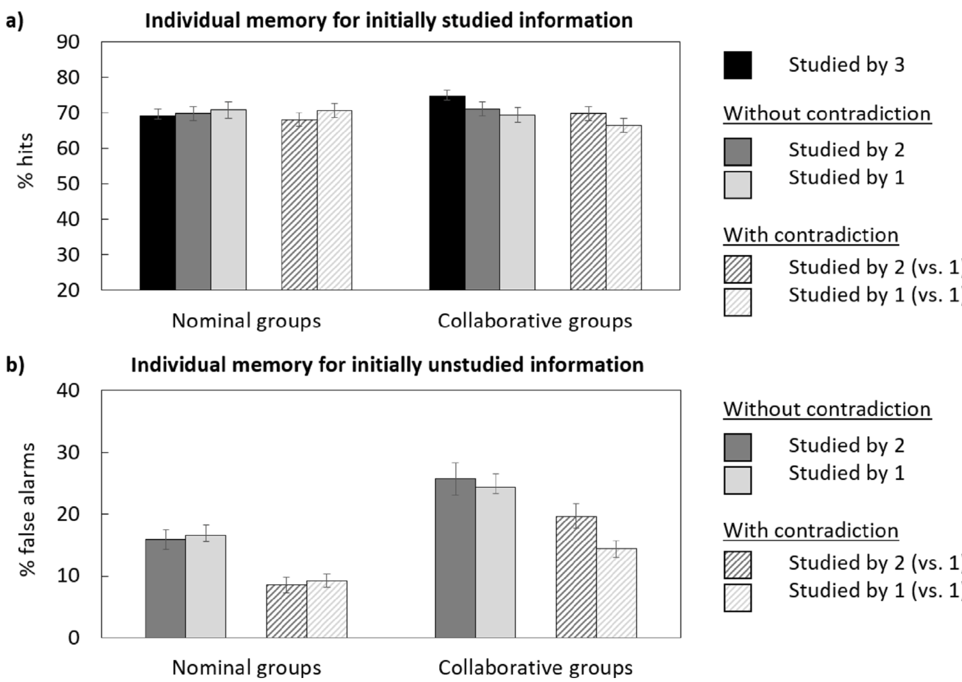

Fig. 5. Individual memory on the final critical test in Experiment 2. (a) Hits for initially studied information, used to examine collaborative facilitation, and (b) false alarms for initially unstudied information, used to examine social contagion. Error bar shows ±1 standard errors of the mean.

Finally, for information that was only studied by 1 or 2 of the group members, Experiment 2 introduced the additional within-subject factor of contradiction, which had two levels. For some word pairs, there was no contradiction, and the distractor materials had not been studied by another group member. For other word pairs, there was contradiction, however, and one of the other group members had initially studied the inconsistent word pair from the set of distractor materials. It should be noted that contradiction could not be manipulated for information that was initially studied by all 3 group members; this level of information distribution could therefore not be included in these analyses.

4.1.4. Procedure

The procedure for collaborative groups was identical to the procedure described in Experiment 1b. For nominal groups, it was of course different in that the interpolated collaborative vs. individual recognition test was not completed as a group, but individually (as in Experiment 1a). In this condition, participants were therefore accompanied to individual break-out sessions by the experimenters right after they completed the 20-min distractor phase. They worked on the individual recognition test by themselves, without interacting with the other group members.

4.2. Results

4.2.1. Individual memory on the final critical test

4.2.1.1. Memory for initially studied information. We first checked for the replicability of previous findings by analyzing hit rates for initially studied additive information without contradiction (see Fig. 5a). A 2 × 3 ANOVA with the factors of GROUP CONDITION (nominal, collaborative) and INFORMATION DISTRIBUTION (initially studied by 1, 2, or 3 group members) showed no significant main effect of GROUP CONDITION, $F(1,178) = 0.52$, $MSE = 0.08$, $p = .473$, $\eta_p^2 = .003$, and no significant main effect of INFORMATION DISTRIBUTION, $F(1.93, 343.59) = 1.10$, $MSE = 0.02$, $p = .332$, $\eta_p^2 = .006$, but a significant interaction between the two factors, $F(1.93, 343.59) = 3.46$, $MSE = 0.02$, $p = .034$, $\eta_p^2 = .02$. Hit rates were slightly enhanced in the collaborative relative to the nominal group condition, but only for information initially studied by all 3 group members (74.6% vs. 69.2%), $t(178) = 2.04$, $p = .043$, $d = 0.30$. No significant difference was observed for information initially studied by 2 group members (71.1% vs. 69.8%), $t(178) = 0.47$, $p = .641$, $d = 0.07$, or for information initially studied by 1 group member (69.4% vs. 70.8%), $t(178) = 0.46$, $p = .647$, $d = 0.07$.

Did the presence of contradictory information in social groups affect individual memory for information that was originally studied? A 2 × 2x2 ANOVA was run to examine this question, with the factors of GROUP CONDITION (nominal, collaborative), INFORMATION DISTRIBUTION (studied by 1 or 2 group members) and CONTRADICTION (absent, present). The ANOVA only revealed a significant two-way interaction between GROUP CONDITION and INFORMATION DISTRIBUTION, $F(1,178) = 5.10$, $MSE = 0.02$, $p = .025$, $\eta_p^2 = .03$, but no further significant main or interaction effects, all $Fs \leq 2.21$, $ps \geq .139$, $\eta_p^2 s \leq .01$. Follow-up tests failed to show significant differences between the collaborative and nominal groups for any of the distinguished word pairs, however (all $ts(178) \leq 1.52$, $ps \geq .131$, $ds \leq 0.23$.). Apparently, the presence of contradictory information in social groups did not substantially affect individual memory for originally studied information.

4.2.1.2. Memory for initially unstudied information. We next turned to memory for information that was initially studied by other group members and assessed the role of contradiction for the spread of this information. In the absence of contradiction, participants had not studied any related information, but in the presence of contradiction, they had encoded a word pair that directly contradicted the potential contagion items studied by the other participants. A 2 × 2 × 2 ANOVA with the factors of GROUP CONDITION (nominal, collaborative), INFORMATION DISTRIBUTION (studied by one or two other group members) and CONTRADICTION (absent, present) revealed a significant main effect of GROUP CONDITION, $F(1,178) = 18.35$, $MSE = 0.07$, $p < .001$, $\eta_p^2 = .09$, reflecting higher false alarm rates in the collaborative vs. the nominal group condition (21.0% vs. 12.6%). There was also a significant two-way interaction between the factors GROUP CONDITION and INFORMATION DISTRIBUTION, $F(1,178) = 5.60$, $MSE = 0.01$, $p = .019$, $\eta_p^2 = .03$. This interaction effect was likely driven by slightly higher false alarms for information initially studied by 2 other group members (overall: 22.7% vs. 12.2%) relative to information studied by 1 other group member (overall: 19.4% vs. 12.9%). The ANOVA also revealed a significant

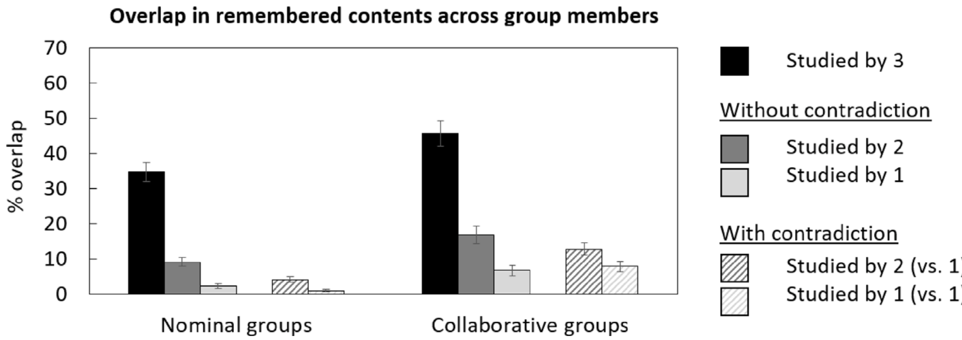

Fig. 6. Group memory on the final critical test in Experiment 2. Rates of overlap and remembering of the same contents across all group members. Error bar shows ±1 standard errors of the mean. Note. Rate of overlap can vary between 0%–100% for each item type (initially studied by 3, 2, or 1 participants; with or without contradiction). Thus the bars shown for each group condition do not need to add up to 100%.

main effect for CONTRADICTION, $F(1,178) = 52.13$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .23$, but no further significant main or interaction effects, all $Fs \leq 2.46$, $ps \geq .118$, $\eta_p^2 s \leq .01$. False alarm rates for initially unstudied information were generally higher if participants had not themselves studied directly contradictory information (20.6% vs. 13.0%). Significantly higher false alarms with prior collaboration (vs. without in the nominal group condition) were however observed in all cases and not further affected by whether contradictory information had been studied (information initially studied by both other group members: 19.7% vs. 8.6%, $t(178) = 4.82$, $p < .001$, $d = 0.72$; information initially studied by one other group member: 14.4% vs. 9.2%, $t(178) = 2.98$, $p = .003$, $d = 0.44$) or not (information initially studied by both other group members: 25.7% vs. 15.9%, $t(178) = 3.18$, $p = .002$, $d = 0.47$; information initially studied by one other group member: 24.4% vs. 16.6%, $t(178) = 2.83$, $p = .005$, $d = 0.42$).[3]

4.2.2. Overlap in remembered contents across group members on the final critical test

Finally, we examined to what degree social interactions prompted mnemonic overlap at the group level. We again first turned to check on the replicability of previously observed patterns when no contradiction was present (see Fig. 6). A 2 × 3 ANOVA with the factors of GROUP CONDITION (nominal, collaborative) and INFORMATION DISTRIBUTION (initially studied by 1, 2, or 3 group members) showed a significant main effect of GROUP CONDITION, $F(1,58) = 13.75$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .19$, reflecting higher rates of overlap in collaborative than in nominal groups (overall: 23.2% vs. 15.5% overlap). There was also a significant main effect of INFORMATION DISTRIBUTION, $F(1.42, 82.32) = 158.26$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .73$, indicating higher rates of mnemonic overlap when information had initially been studied by more group members (studied by 3: 40.2% overlap; studied by 2: 13.1% overlap; studied by 1: 4.6% overlap). There was no significant interaction between the two factors, $F(1.42, 82.32) = 1.21$, $MSE = 0.02$, $p = .292$, $\eta_p^2 = .02$. Collaboration boosted mnemonic overlap irrespective of whether information was initially studied by all 3 group members (45.7% vs. 34.8%), $t(58) = 2.44$, $p = .018$, $d = 0.63$), by 2 group members (17.0% vs. 9.2%), $t(42.55) = 2.78$, $p = .008$, $d = 0.72$, or by 1 group member (6.8% vs. 2.4%), $t(40.92) = 2.77$, $p = .008$, $d = 0.72$.

How did the presence of contradictory information affect mnemonic overlap? A 2 × 2x2 ANOVA with the factors of GROUP CONDITION (nominal, collaborative), INFORMATION DISTRIBUTION (studied by 1 or 2 group members), and CONTRADICTION (absent, present) confirmed significant main effects of GROUP CONDITION, $F(1,58) = 20.64$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .26$, and INFORMATION DISTRIBUTION, $F(1,58) = 58.73$, $MSE = 0.004$, $p < .001$, $\eta_p^2 = .50$. Additionally, it also revealed a significant main effect of CONTRADICTION, $F(1,58) = 10.52$, $MSE = 0.003$, $p = .002$, $\eta_p^2 = .15$, and a significant two-way interaction between CONTRADICTION and INFORMATION DISTRIBUTION, $F(1,58) = 8.19$, $MSE = 0.004$, $p = .006$, $\eta_p^2 = .12$; no further effects reached significance, all $Fs \leq 2.41$, $ps \geq .126$, $\eta_p^2 s \leq .04$. For information initially studied by two participants, mnemonic overlap was reduced by the presence of contradictory information (13.1% vs. 8.6%, $t(59) = 3.57$, $p \leq .001$, $d = 0.46$). For information initially studied by one participant, overlap was not further reduced by the presence of contradictory information, but this result is likely due to a floor effect (4.6% vs. 4.5%, $t(59) = 0.10$, $p = .918$, $d = 0.01$).

4.3. Discussion

Experiment 2 examined the spread of contradictory and additive information in collaborating groups. Adding contradictory information to a collaborative recognition task did not much affect individual memory for initially studied information, but it vastly reduced social contagion with initially unstudied information. Having encoded directly contradictory information, false alarm rates for unstudied information were generally lower than in the absence of such encoding, and this was true for participants in both collaborative and nominal groups. Higher false alarms for initially unstudied information were still observed in collaborative groups, and this social contagion was intact for both additive and contradictory information. Comparing false alarm rates in Experiment 2 to those observed in Experiment 1a, it seems that the introduction of contradictory information may have generally reduced information transmission in collaborating groups. Potentially, contradictions during collaborative recognition based on the encoding of contradictory information made participants more skeptical and cautious to accept information from the other group members.

Importantly, this reduction in social information transmission had downstream effects for the development of shared memories. As in Experiments 1a and 1b, collaboration increased the mnemonic overlap in remembered contents among group members, but this overlap was reduced in the presence of contradiction. Contradiction reduced social contagion, which in turn reduced shared remembering of the same contents. This provides direct evidence for the involvement of social contagion in the development of shared memories.

5. General discussion

Collaborative facilitation and social contagion jointly contribute to the development of shared memories in social groups. Experiments 1a and 1b applied additive information that was unequally distributed across group members, whereas Experiment 2 introduced contradictory information. Although the presence of contradictions within the

[3] An analysis of discriminability as for Experiment 1a was not possible for Experiment 2. Due to the manipulation of contradiction, trials for information initially studied by others now partly also included directly studied information. It was thus not possible to easily derive overarching hit and false alarm rates.

group greatly reduced social information transmission, both experiments found increased rates of mnemonic overlap and shared remembering for all pieces of information (i.e., initially studied by 1, 2, or 3 group members).

5.1. Collaboration and individual memory

Analyses of individual performance on the final critical recognition test showed clear influences of prior collaboration. Collaboration enhanced subsequent remembering of information that was initially studied by each participant — though only for contents that were initially studied by all group members (not for unshared contents, studied by each participant only, or for partly shared contents, studied by each participant plus one other group member). This pattern replicates prior work by Abel and Bäuml (2020), and it is consistent with other demonstrations of collaborative facilitation when participants exclusively studied fully shared information (e.g., Abel & Bäuml, 2017; Bärthel et al., 2017; Blumen & Stern, 2011; Blumen et al., 2014; Weldon & Bellinger, 1997). Social interactions may offer a chance for reexposure with information one would not have remembered on one's own, but such reexposure may be more likely to occur the more group members initially studied the respective information.

Social interactions can however also contaminate and distort individual memories, and importantly, this can happen simultaneously to collaborative facilitation. In the present study, for information that was initially not studied by each participant, but by one or both other group members, collaboration led to social contagion. The final critical test probed individual memory for the initial study phase, and in all experiments, participants systematically indicated to "remember" information from the study phase that had in fact been studied by other group members only. This is consistent with prior work (Roediger et al., 2001; Wright et al., 2000; for a review, see Maswood & Rajaram, 2019), demonstrating that social sources can act as transmitters of new information such that the new information is later (falsely) remembered. Moreover, replicating prior work by Abel and Bäuml (2020), this social contagion was more pronounced when the transmitted information was initially studied by both other group members (rather than by one).

The present experiments extend collaborative facilitation and social contagion in the recognition-based collaboration task to associative study materials and 2AFC recognition tests. Although this can be seen as a first sign for generalization of effects across different stimulus materials and task set-ups, future work is needed to address whether this generalization also holds for more complex and ecologically valid materials. A further variation to note is that Experiments 1b and 2 were conducted online, via Zoom sessions. Since the observed patterns were largely consistent with prior work conducted in the lab, this suggests that synchronous online testing via webcams and microphones enables relatively normal social interactions, leaving the same footprints in our minds as social interactions in face-to-face settings.

Another new contribution of Experiment 2 was the introduction of contradictory information. Memory for initially studied information was not affected much by the presence of contradiction, but initially unstudied information was more likely to be rejected as new. Importantly, this effect of contradiction was not specific to collaborating triads, but occurred as well for participants who had taken an interpolated individual test. False alarm rates for unstudied information were still enhanced in collaborative relative to individual groups and indeed, the size of social contagion effects was roughly the same in the presence and in the absence of contradictory information. Nevertheless, in absolute terms, participants in collaborative groups accepted higher rates of unstudied additive (rather than contradictory) information as old. This findings relates to prior work on the misinformation effect, which also found higher rates of accepted additive (rather than contradictory) misinformation (Frost, 2000; Huff & Umanath, 2018; Moore & Lampinen, 2016; but see Nemeth & Belli, 2006). Thus, the recognition-based collaboration task captures social contagion and produces findings that are consistent with what is currently known about the representation of misinformation in memory.

5.2. Collaboration and the development of shared memories

Participants from collaborating groups showed higher mnemonic overlap in what specific information was later remembered, but importantly a higher degree of overlap was not only observed for information initially studied by all group members, but also for information that was initially only studied by 1 or 2 group members. Collaborative facilitation can account for the higher rates of overlap for shared information, but the higher rates of overlap for initially unshared or partly shared information provide clear evidence that social contagion with originally unstudied information contributes separately to the development of shared memories.

Changes in individual remembering drive the development of shared memories. A comparison of the collaborative groups across Experiments 1a and 1b suggested slightly higher individual remembering for initially studied information, but not for initially unstudied information. This difference was also expressed in higher rates of mnemonic overlap for fully shared information (but not for information that was not shared by the whole group from the outset on). Moreover, the presence of contradictory information in Experiment 2 reduced the absolute rates of social contagion with unstudied information, which in turn led to lower rates of mnemonic overlap for information that was initially only studied by one or two group members. Overall, changes in individual remembering directly translate into changes in shared remembering at the group level.

One caveat to add here is that social contagion may not always persist in the presence of contradictory information. Although we found this to be the case in the present study, across experiments, the data still suggested that the presence of contradiction can reduce effects of social contagion, probably by making subjects more skeptical and cautious. As such, social contagion could also be completely eliminated under other circumstances, for example when blatant contradictions clash with strongly held memories and induce an even higher degree of skepticism, or generally when participants have good reasons to question the accuracy of social sources' memory reports. Under such circumstances, the contribution of social contagion to the development of shared memories would certainly be limited.

5.3. Open questions

One important question that needs to be addressed in future work is to what degree response bias may contribute to the effects observed in the collaborative recognition task. The present work relied on 2AFC recognition tests, which, relative to old/new recognition tests, have been suggested to be less affected by response bias. Nevertheless, the present as well as prior work (Abel & Bäuml, 2020) cannot directly exclude a role of response bias. One way to address this issue would be to collect confidence ratings for each (old/new) recognition judgment in future work. Such confidence ratings allow for the analysis of ROC-curves, and such analysis is more accurate in isolating differences in memory discriminability from differences in response bias (Brady et al., 2022). In addition, confidence ratings would also provide insights into whether social contagion effects in the collaborative recognition task are reflective of strongly held beliefs that information was previously studied (or not).

Another open question is what cognitive mechanisms mediate the effects observed in the collaborative recognition task. Collaborative facilitation has been suggested to arise due to reexposure (Blumen & Stern, 2011; Blumen et al., 2014; Weldon & Bellinger, 1997). The most specific proposal to date attributes the benefits of such collaborative reexposure to enhanced item-specific and relational processing, which may lead to studied information becoming more distinct (Wissman & Rawson, 2015). Social contagion on the other hand has been suggested to arise due to impaired source monitoring, with information from social sources being incorrectly classified as personally encoded (Meade & Roediger, 2002; see also Andrews & Rapp, 2014; Maswood & Rajaram, 2019). Whether the same mechanisms are also at work in the collaborative recognition task has not been investigated yet. Indeed, examining the two effects simultaneously, one can wonder whether they may even have a shared basis. Social interactions provide opportunities for new learning, which can comprise both old (but forgotten) and completely new information. Direct examination of cognitive mechanisms in the collaborative recognition task could thus also help to determine if these mechanisms operate separately for studied and unstudied information, or whether there are places where they intersect.

Social contagion is of high relevance for eyewitness scenarios, because it demonstrates that social interactions can contaminate and distort individual memories (e.g., Gabbert et al., 2004, 2003; Paterson et al., 2011). More broadly, false memories for originally unstudied information have however been conceptualized as by-products of a flexible memory system, potentially also serving adaptive functions (Newman & Lindsay, 2009; see also Howe, 2011; Schacter et al., 2011). The present results are for example consistent with a social function of false memories. Incorporating information from other group members into one's own memory contributes to the development of shared memories. Depending on type of group, type of information, and type of performance pressure (e.g., Andrews-Todd et al., 2021), developing greater mnemonic overlap may help achieve common ground across individuals. Whether social contagion could additionally also serve a directive function and guide future behavior has not been explored yet. For instance, when socially transmitted information is useful for subsequent tasks, it could serve to improve individual behavior. Moreover, to the degree that individuals from collaborative groups show mnemonic overlap, their subsequent behavior could also become more aligned and similar. Future work is needed to explore these functional aspects of collaborative remembering in greater detail.

Understanding how memories become shared across individuals is of great societal importance and a high priority in collective memory research. The present study followed prior work and operationalized shared remembering as mnemonic overlap and the rate with which identical contents were later remembered by all group members (e.g., Barber et al., 2012; Pepe et al., 2021). Only single previous studies went further and provided additional data points on shared remembering. For example, Congleton and Rajaram (2014) analyzed individual free recall data and showed that prior collaboration enhanced mnemonic overlap not just in terms of recalled contents, but also in terms of recall organization (i.e., output sequence). This suggests that collaboration may not only affect the *what*, but also the *how* of later remembering. By collecting additional measures (e.g., confidence or source memory measures) future work can also increase our understanding of what exactly becomes shared across individuals after joint remembering.

CRediT authorship contribution statement

Magdalena Abel: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Karl-Heinz T. Bäuml:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors have no competing interests to declare.

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Data availability

The data and materials for all experiments are available on the Open Science Framework (https://osf.io/mkzfn/).

Appendix. Breakdown of responses across all response options on the final critical test

On each trial of the final critical test, participants were presented with two different word pairs and asked to indicate if they remembered seeing one of the word pairs during the study phase. In Experiment 1a, each trial contained a word pair that was initially studied by themselves or by other group members (studied) as well as a word pair that was initially not studied by anyone in the group (distractor). In addition, participants also had the option to respond with "none of the word pairs" (neither). The analyses in the main text focused on hits for word pairs studied by each participants as well as on false alarms for word pairs initially studied by other group members only. Here, we provide an additional breakdown of responses across all three response options.

Experiment 1a

Table A.1 focuses on trials for initially studied information in Experiment 1a and shows mean percentage of responses across response options. As reported in the main text, participants from collaborative groups showed slightly higher hit rates for information that was initially studied by all three group members (78.4% vs. 73.3%), $t(178) = 2.31$, $p = .022$, $d = 0.34$. In addition, for information studied by all three group members, participants from nominal groups were slightly more likely to choose the "neither" response option (22.1% vs. 17.4%), $t(178) = -2.30$, $p = .022$, $d = -0.34$. There were no further significant differences between collaborative and nominal groups.

Table A.2 focuses on trials for information that was not initially studied by each participant, but by the other group members instead. As reported in the main text, false alarm rates for word pairs initially studied by other group members were enhanced after engaging in collaboration. This social contagion effect was most pronounced for word pairs initially studied by both other group members (44.1% vs. 15.2%), $t(178) = 10.75$, $p < .001$, $d = 1.60$, but it was also present for word pairs initially studied by one other group member (35.5% vs. 16.7%), $t(178) = 8.47$, $p < .001$, $d = 1.26$. Participants from nominal groups were in contrast more likely to choose the "neither" response option; both for information initially studied by both other group members (67.3% vs. 41.5%), $t(178) = -7.00$, $p < .001$, $d = -1.04$, and for information initially studied by one other group member, (64.4% vs. 48.1%), $t(178) = -4.99$, $p < .001$, $d = -0.74$. There were no significant differences between collaborative and nominal groups for endorsement of the distractor response options, $ts(178) \leq -1.43$, $ps \geq .155$, $ds \leq -0.21$.

Experiment 2

Table A.3 focuses on trials for initially studied information in Experiment 2. As reported in the main text, participants from collaborative groups again showed slightly higher hit rates for information that was initially studied by all three group members (74.6% vs. 69.2%), $t(178) = 2.04$, $p = .043$, $d = 0.30$. There were no significant differences between collaborative and nominal groups for endorsement of the "neither" response option, $ts(178) < 1.0$, $ps \geq .393$, $ds \leq 0.13$. In the absence of contradictions, participants from nominal groups were slightly more likely to choose the distractor response option that had not been studied by anyone (for word pairs studied by 3: 10.9% vs. 5.2%, $t(153.69) = -4.18$, $p < .001$, $d = -0.62$; for word pairs studied by 2: 11.0% vs. 7.6%, $t(171.45) = -2.25$, $p = .026$, $d = -0.34$). Yet, in the presence of contradictions, participants from collaborative groups were slightly more likely to endorse the distractor response option; this was however only the case for trials that probed memory for targets initially studied by 1 participant (14.4% vs. 9.2%, $t(178) = 2.93$, $p = .004$, $d = 0.44$).

Table A.4 focuses on trials for information that was not initially studied by each participant, but by the other group members instead. As reported in the main text, false alarm rates for word pairs initially

Table A.1
Mean percentage of responses (plus standard deviations) across all response options on the final test in Experiment 1a for trials probing memory for initially studied word pairs.

	Studied by 3			Studied by 2			Studied by 1		
	Studied	Distractor	Neither	Studied	Distractor	Neither	Studied	Distractor	Neither
Nominal groups	73.3 (15.5)	4.5 (6.5)	22.1 (14.6)	69.4 (16.7)	9.8 (8.4)	20.8 (15.4)	66.7 (20.3)	13.1 (13.9)	20.3 (16.9)
Collaborative groups	78.4 (13.7)	4.2 (4.0)	17.4 (12.7)	70.8 (14.3)	8.9 (7.0)	20.3 (11.8)	62.9 (18.2)	13.8 (13.1)	23.3 (16.2)

Table A.2
Mean percentage of responses (plus standard deviations) across all response options on the final test in Experiment 1a for trials probing memory for word pairs initially studied by other group members only.

	Studied by 2 other group members			Studied by 1 other group member		
	Studied	Distractor	Neither	Studied	Distractor	Neither
Nominal groups	15.2 (13.6)	17.5 (17.0)	67.3 (25.2)	16.7 (12.5)	18.9 (14.1)	64.4 (23.6)
Collaborative groups	44.1 (21.6)	14.4 (11.5)	41.5 (24.3)	35.5 (16.9)	16.5 (10.4)	48.1 (20.1)

Table A.3
Mean percentage of responses (plus standard deviations) across all response options on the final test in Experiment 2 for trials probing memory for initially studied word pairs.

	Studied by 3			Studied by 2			Studied by 1		
	Studied	Distractor	Neither	Studied	Distractor	Neither	Studied	Distractor	Neither
Without contradiction									
Nominal groups	69.2 (17.5)	10.9 (10.9)	19.9 (13.9)	69.8 (19.2)	11.0 (11.1)	19.2 (15.3)	70.8 (21.8)	9.4 (14.2)	19.8 (19.7)
Collaborative groups	74.6 (17.9)	5.2 (7.1)	20.2 (17.5)	71.1 (19.5)	7.6 (9.1)	21.3 (17.0)	69.4 (19.9)	8.7 (12.3)	21.9 (18.7)
With contradiction									
Nominal groups				68.1 (17.7)	11.5 (11.7)	20.4 (15.8)	70.7 (18.6)	9.2 (10.6)	20.1 (16.2)
Collaborative groups				69.7 (18.8)	11.6 (10.1)	18.7 (16.3)	66.4 (19.3)	14.4 (12.9)	19.2 (15.6)

Table A.4
Mean percentage of responses (plus standard deviations) across all response options on the final test in Experiment 2 for trials probing memory for word pairs initially studied by other group members only.

	Studied by 2 other group members			Studied by 1 other group member		
	Studied	Distractor	Neither	Studied	Distractor	Neither
Without contradiction						
Nominal groups	15.9 (15.7)	19.7 (23.3)	64.4 (30.8)	16.6 (16.1)	17.2 (16.6)	66.2 (28.8)
Collaborative groups	25.7 (24.8)	12.7 (17.1)	61.6 (32.8)	24.4 (20.5)	13.0 (14.1)	62.6 (28.1)
With contradiction						
Nominal groups	8.6 (11.9)	70.5 (20.6)	21.0 (17.8)	9.2 (10.1)	70.7 (18.3)	20.1 (16.2)
Collaborative groups	19.7 (18.4)	59.1 (24.3)	21.3 (20.9)	14.4 (12.9)	66.7 (19.2)	19.0 (15.3)

studied by other group members were generally enhanced after collaborative vs. nominal group recall, $ts(178) \geq 2.83$, $ps \leq .005$, $ds \geq 0.42$. There were no significant differences between collaborative and nominal groups for endorsement of the "neither" response option, $ts(178) < 1.0$, $ps \geq .401$, $ds \leq 0.13$. Participants from nominal groups were more likely to choose the distractor response option; the corresponding comparisons were however only significant for trials for word pairs initially studied by 2 other participants (without contradiction: 19.7% vs. 12.7%, $t(163.04) = -2.29$, $p = .023$, $d = -0.34$; with contradiction: 70.5% vs. 59.1%, $t(178) = -3.40$, $p < .001$, $d = -0.51$). The high rise in endorsement of the distractor response option with contradictions (relative to without contradictions) is caused by participants having directly studied the contradictory (distractor) word pair.

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