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Learning with friends and strangers: partner familiarity does not improve collaborative learning performance in younger and older adults

Catherine J. Crompton ^{a,b}, Maria K. Wolters^b and Sarah E. MacPherson ^a

^aHuman Cognitive Neuroscience, Department of Psychology, University of Edinburgh, Edinburgh, UK; ^bSchool of Informatics, University of Edinburgh, Edinburgh, UK

ABSTRACT

Collaborative learning with a familiar partner can reduce age-related differences in learning and memory compared to learning alone. This study compares younger and older adults' learning with familiar and unfamiliar partners to determine whether familiarity is beneficial for collaborative learning. Twenty-four younger adults aged 18–28 years and 24 older adults aged 60–80 years participated in familiar and unfamiliar pairs. Participants were asked to arrange abstract tangram shapes in a specific order on a grid over multiple trials; the directors' tangram cards were arranged in a specific order on the grid and this order was communicated to the matcher. Older adults initially took longer to complete the task, using more words to correctly arrange the tangrams. Over multiple trials, a learning effect was observed in both groups, although older adults did not perform with similar efficiency to younger adults. Familiarity had no effect on performance. These findings suggest that the familiarity of a partner does not affect learning outcomes in younger or older adults when learning in a social context. Collaborative learning may be beneficial for older adults, even if they do not know their learning partner, which may have implications for adult education and lifelong learning.

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Aging; social interaction; learning; memory; collaborative learning



The literature on aging has typically considered memory as an independent, solitary phenomenon, where participants learn and are assessed individually (Mahr & Csibra, 2018; Rönnlund et al., 2005; Strough & Margrett, 2002). However, this does not reflect many real-world learning opportunities, where new information and skills are often learned with other people within a social context. Investigating how older adults interact and learn with their close social partners such as spouses and friends, as well as strangers, has important implications for our understanding of memory in everyday life. Exploring cognition in a social context, rather than on an individual, isolated basis, may lead to an improved understanding of cognition across the lifespan (Strough & Margrett, 2002). With an aging population, greater investigation and understanding of collaborative learning in older adults has become increasingly pertinent (Martin & Wight, 2008).

Collaborative learning refers to the specific process of learning a skill or task in collaboration with another person typically within the context of an in-person interaction (Derksen et al., 2015). It involves multiple processes such as comprehending, processing and storing information (Gorman et al., 2013), and in research, is typically

assessed in a controlled lab setting, where recall is examined individually, with the collaborative partner, or not at all (van der Linden et al., 2000). While older adults consistently show a decline in memory performance when assessed individually (Hultsch et al., 1998; Zelinski & Burright, 1997), learning collaboratively may ameliorate age-related differences in learning and memory (Derksen et al., 2015).

Theoretical basis of collaborative learning benefits

A possible explanation for the benefits of collaborative learning is that memory is enhanced for information that is self-relevant and social compared with neutral and non-social information (Cassidy & Gutchess, 2012; May et al., 2005; Yang et al., 2012). By learning collaboratively, and interacting with a partner throughout the learning process, the information learned becomes placed in the wider context of a social interaction. The encoding of self-relevant or social information is prioritised. This aligns with the scaffolding theory of aging and cognition; scaffolding is a process that occurs during healthy aging

CONTACT Catherine J. Crompton  catherine.crompton@ed.ac.uk  Centre for Clinical Brain Sciences, University of Edinburgh, Kennedy Tower, Royal Edinburgh Hospital, Morningside Terrace, Edinburgh EH10 5HF, UK

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where alternative, complementary neural systems develop to achieve a cognitive goal (Park & Reuter-Lorenz, 2009). Thus, while the age-related decline in memory performance is common, in certain recall contexts such as those scaffolded by social interaction with another person, older adults can ameliorate reductions in memory performance and perform at a higher level (Blumen et al., 2013; Park & Reuter-Lorenz, 2009).

Other mechanisms purported to underlie successful collaborative memory are re-exposure, which occurs during collaborative learning (Blumen et al., 2013; Blumen & Rajaram, 2008; Weldon & Bellinger, 1997), and cross-cueing, which occurs during collaborative recall (Blumen et al., 2013; Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Meudell, 1996; Meudell et al., 1995, 1992). While learning new information, collaborative partners provide opportunities to be “re-exposed” to the learning material, which would not have occurred if learning alone. For example, Person A may not remember what they had eaten at a family meal the previous week, though Person B may remember. When these individuals recall collaboratively, Person A is re-exposed to this information and is subsequently more likely to recall this information later; thus collaboration provides an opportunity to re-learn information provided by their partner which they would not have recalled alone (Blumen et al., 2013). Cross-cueing occurs during collaborative recall, and involves a collaborator providing information that acts as a retrieval cue, prompting the other participant to recall information that they would not have remembered if recalling on their own (Blumen et al., 2013). For example, when trying to recall what was eaten at a family meal, Person B may recall and mention that the family had used a new set of hand-painted plates. This may then cue the Person A’s memory to recall what they had eaten, a trigger that would not have been available without the retrieval cue (Blumen et al., 2013). Thus, during collaboration, re-exposure provides additional opportunities to learn the information, and cross-cueing provides additional prompts and recall opportunities (Blumen et al., 2013).

Collaborative learning and familiarity

Relatively little is known about the role of familiarity in collaborative learning and whether people learn more effectively with familiar friends, family, or partners with whom they converse frequently, compared to unfamiliar strangers. Early theories of collaboration such as the transactive memory theory (Wegner, 1987; Wegner et al., 1985) propose that collaborative partners depend on an existing understanding of their partner’s knowledge, which allows participants to focus on encoding information that relates only to their individual knowledge. Partners who know each other very well can develop an implicit understanding of each other’s knowledge, which allows them to jointly solve memory tasks, with the couple’s transactive memory being superior to their individual memories.

Couples are likely to have good knowledge of one another’s cognitive skills as well as practice in many kinds of collaborative situations (Dixon & Gould, 1998). Additionally, Clark and Brennan’s (1991) concept of communicative “grounding” suggests that mutual knowledge, beliefs, and assumptions are essential for communication between two people; thus it may be assumed that familiar partners would have more success on collaborative learning tasks compared with strangers.

However, experimental studies comparing learning in familiar and unfamiliar pairs have yielded mixed findings: some suggest familiarity is beneficial (Fussell & Krauss, 1989) and some do not (Gould et al., 2002). This inconsistency in findings may be due in part to the conflicting methodologies used when experimentally assessing collaborative learning. Multiple tasks are used, for example, story recall (Gould et al., 2002), collaborative referencing (Duff et al., 2013), and list recall (Basden et al., 1997); all of which include tasks of differing lengths and difficulty. These factors could play a potential role in the success of learning collaboratively, and the between-studies differences in methodologies make interpreting the body of literature as a whole problematic. Investigating whether familiarity plays a role in collaborative learning is an important question; to explore whether a familiar partner provides the optimal context for collaborative learning, or whether it is merely the act of collaborating that improves memory performance (Strough & Margrett, 2002).

Familiarity in older and younger adult collaborative learning

While studies have examined younger and older adults’ collaborative learning with familiar (e.g., Derksen et al., 2015) and unfamiliar partners (e.g., Blumen & Stern, 2011; Meade et al., 2009) and have found positive effects in both conditions, few studies have compared familiarity and age within a single paradigm, directly examining the effect of both familiarity and age on collaborative learning outcomes. Gould et al. (2002) found that both younger and older participants performed similarly on story recall, word recall, and a referential labelling task when paired with their spouse and with a stranger. In contrast, Gagnon and Dixon (2008) found older familiar dyads recalled more information about a story than older unfamiliar dyads, suggesting that older adults are more successful when learning collaboratively with a familiar partner compared with a stranger. In the current study, we examine younger and older adults’ performance on an ecologically valid collaborative learning task, and investigate whether familiarity enhances the effect of collaboration on older and younger adults’ memory performance.

The current study

The current study uses an adapted version of the Barrier Task paradigm (Derksen et al., 2015). This is a learning

task where pairs of participants collaborate to create and learn referential labels for tangram shapes, and then use these labels to arrange the tangrams in a specific order on a grid over multiple trials. The social aspect of the task is emphasised by its game-like nature, and participants interact in the naturalistic setting of a social interaction and joint problem-solving. The “learning” component of this task involves participants developing abbreviated labels for each of the shapes and building a mutual understanding of these labels, so that over time, participants can complete the task in an increasingly fast manner. Unlike many experimental tasks used in the collaborative learning literature which involve participants memorising abstract or arbitrary information, the Barrier Task reflects real-world interaction, and centres on a goal-oriented activity with participants jointly engaged in a problem-solving task (Derksen et al., 2015; Duff et al., 2006). Our reason for selecting the Barrier Task was its uniquely meaningful and engaging method of assessing collaborative memory: it is differentiated from standard experimental memory tasks due to its ecological validity and meaningful way of assessing learning collaboratively (Derksen et al., 2015). Performance is measured by how efficiently participants complete the Barrier Task, using three dependent variables: time to complete the task, number of words used, and number of interactive turns taken (Derksen et al., 2015; Duff et al., 2006, 2008).

Alongside completing the collaborative Barrier Task, participants completed individual assessments of memory, IQ, and executive function. As success on the Barrier Task depends on both learning new information and switching between tangram labels, it may be expected that a robust relationship between individual memory and executive function performance and Barrier Task performance would be found, for both younger and older adults. The original Barrier Task study included assessments of these domains, and found that performance on an anterograde visual memory task was associated with Barrier Task performance in older adults only, that IQ was associated with Barrier Task performance in younger adults only, and executive function was not associated with Barrier Task performance in either younger or older adults (Derksen et al., 2015). We included these to examine whether these effects replicate in a new sample.

This study makes a unique contribution to the literature by examining three components of collaborative learning within a single paradigm: the role of familiarity (familiar/unfamiliar), aging (younger/older), and individual cognitive performance (on memory, executive function, and IQ measures). This allows us to examine the role of these three factors on collaborative learning performance using the Barrier Task paradigm. Additionally, in our analyses, we use linear mixed-effects models alongside Bayesian ANOVA, to probe differences between familiar and unfamiliar groups more comprehensively than previous research. While linear mixed models (LMMs) can provide evidence that two groups do not significantly differ in

terms of their performance on the tests as illustrated by non-significant *t*-values, this does not provide direct support for the hypothesis that the two groups perform similarly. Bayesian analysis allows comparisons of the strength of the evidence supporting either the experimental (i.e., familiar and unfamiliar pairs learn with different efficiency) or null hypothesis (i.e., familiar and unfamiliar pairs learn with similar efficiency), and provide quantifiable support for the evidence for these hypotheses (Bayarri et al., 2016). Thus, we can, for the first time in the collaborative learning literature, directly test the (null) hypothesis that familiar and unfamiliar pairs learn with similar efficiency, which has not been addressed by previous research. Additionally, Bayesian analyses are more robust to small sample sizes (McNeish, 2016).

To extend and replicate findings from previous studies, we examine three hypotheses within a single paradigm. Our hypotheses include (H1) Older adults would be less efficient (use fewer words, less time and fewer turns) compared to younger adults during initial trials due to their poorer memory abilities but would become more efficient in subsequent trials (as in Derksen et al., 2015); (H2) Familiarity would improve performance (how efficiently the Barrier Task is completed in terms of words, time and turns) in younger and older pairs (as in Fussell & Krauss, 1989; Gagnon & Dixon, 2008); and (H3) Performance on individual cognitive memory assessments would be related to Barrier Task performance (as in Derksen et al., 2015).

Method

Experimental procedures were reviewed and approved by the University of Edinburgh Psychology Research Ethics Committee, and all participants provided written informed consent prior to participating in the study. Participants were remunerated for their time.

Study design

This study used a 2×2 mixed design, with a between-subjects condition of age group (younger/older), and a within-subjects condition of familiarity (familiar/unfamiliar).

Participants

A total of 48 adult volunteers participated, with 24 adults in each of the younger and older groups. All participants were native speakers of English, aged between 18–30 years in the younger group and 60–80 years in the older group, and were screened for neurological or medical conditions using the Wechsler Memory Scale-III exclusion criteria (WMS-III; Wechsler, 1997). Participants were recruited through a participant database, community advertisements, and mailing lists. Participants were recruited in “familiar pairs”, which constituted of two people who were friends, relatives, or romantic partners

who had known one another for at least two years, spoke at least once a week, and were in the same age group. The pairs could be the same or mixed gender. Two same-age pairs attended each session, where participants completed the task once in their familiar pair, and once with a participant from another pair, producing two unfamiliar pairs in a counter-balanced order (see Figure 1).

Thus, the final sample was 24 younger (16 female, aged 18–28 years) and 24 older (16 female, aged 60–80 years) adults. All participants were native speakers of English and were screened for neurological or medical conditions using the Wechsler Memory Scale-III (WMS-III; Wechsler, 1997) exclusion criteria.

Materials and procedure

The Barrier Task

The Barrier Task was administered according to Duff et al. (2008) and Derksen et al. (2015). The task involved two participants: one assigned the role of Director; and the other of Matcher. Once assigned a role of Director or Matcher, the participant remained in this role for all trials. The Director and Matcher sat opposite one another at a table separated by a 9-inch barrier in the middle of the table. Each participant had a 6×2 grid in front of them with 12 numbered spaces and a set of 12 cards that all featured a black tangram shape (approx. 2×3 inches) on a white background (approx. 3.5×5.5 inches) (see Figure 2). The participants' view of the other person's grid and cards was

obscured but not their view of the other person's face or gestures.

The Director's tangram cards were arranged in a predetermined order on their grid. The Director was required to communicate this order to the Matcher by describing the card in each numbered space starting with the first tangram, and then subsequent tangrams in ascending order. The Matcher's role was to recreate the Director's card order on their own grid. Participant pairs were told that they could communicate with one another in any way they liked, but they could not show each other the tangram cards. They were told that they would not be timed and that they had as much time as they needed to complete each trial. They were also told to treat the task as a game and to have fun. Once the Matcher had recreated the Director's card order, the researcher rearranged the Director's cards in a second predetermined order, and the procedure was repeated. Each complete reordering of the 12 tangram cards was defined as one trial. Participants were asked to complete nine trials of the Barrier Task in a single session. All trials were video recorded and transcribed using the methodology outlined by Duff et al. (2008). Half of the participants completed nine trials using one set of tangram cards with a familiar partner, before completing an additional nine trials using a different set of cards and an unfamiliar partner. The other half completed nine trials firstly with an unfamiliar partner and then nine trials with a familiar partner. The card set used was also counterbalanced across

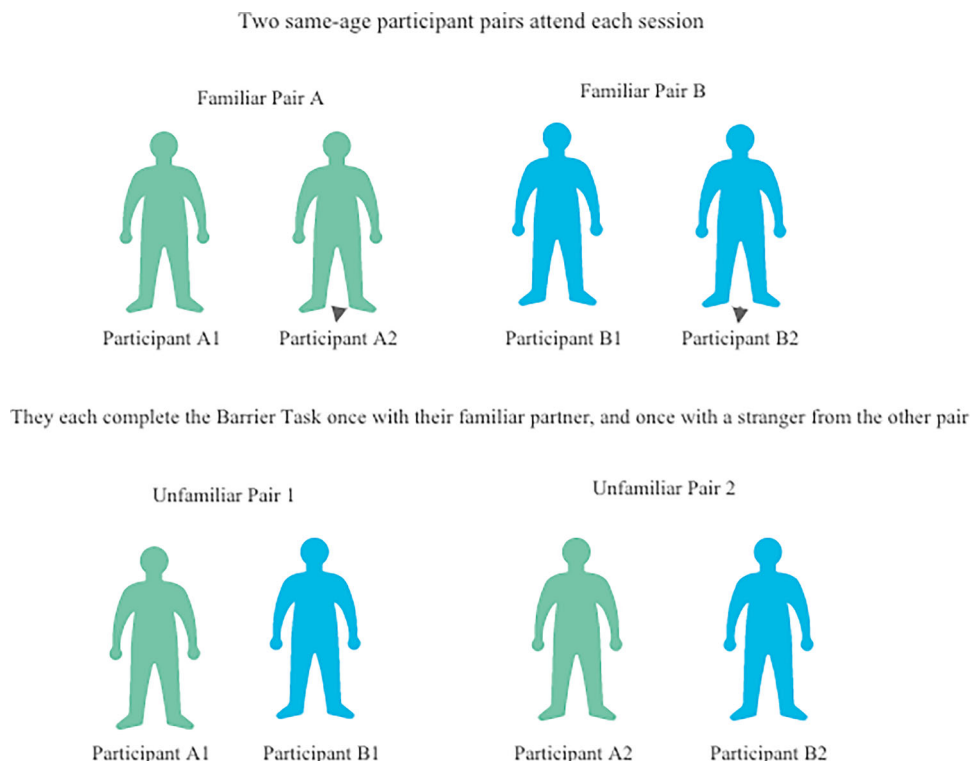


Figure 1. Procedure for collecting data for two familiar and two unfamiliar partners at each participant session.

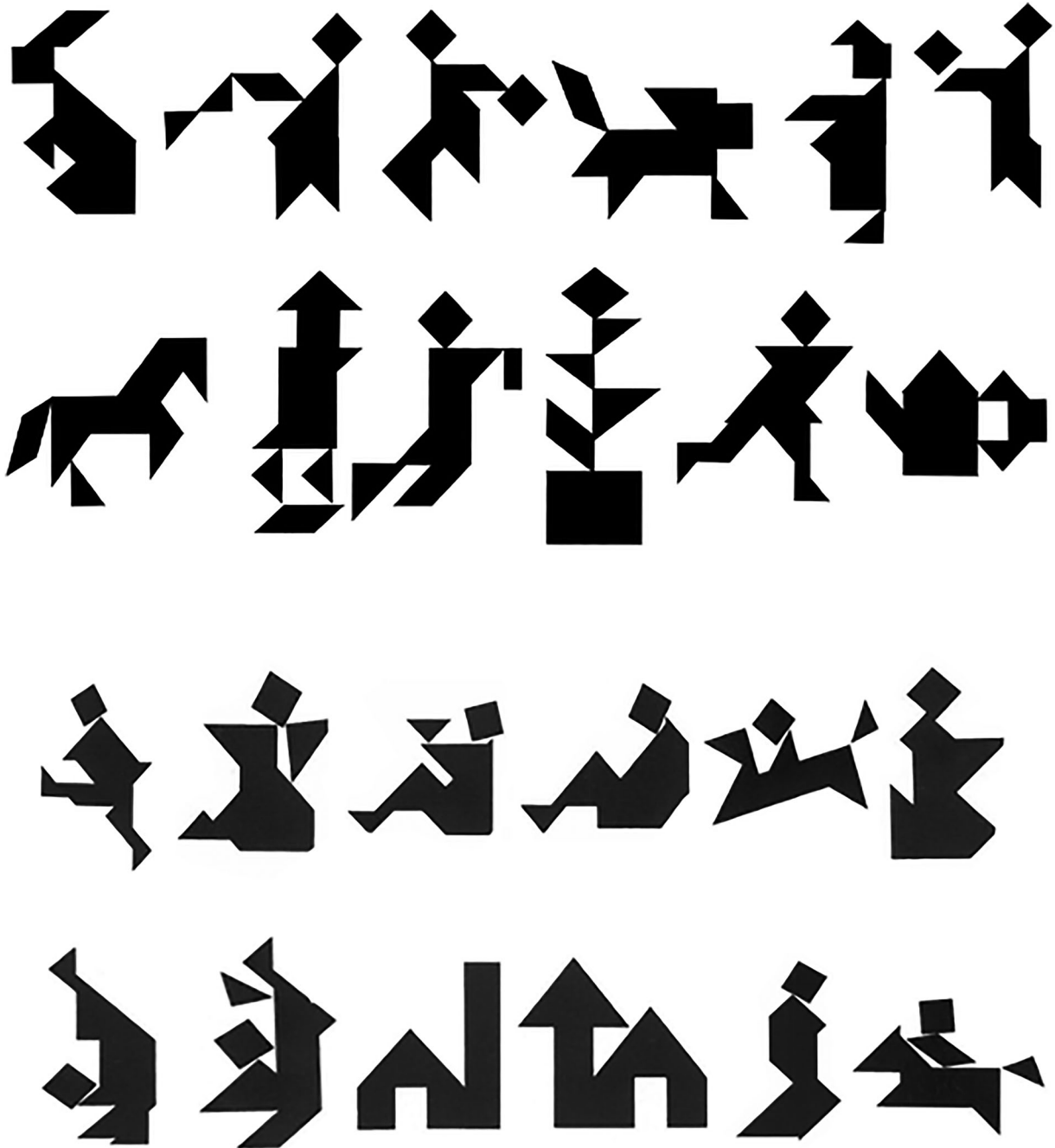


Figure 2. Tangram card set 1, as used in Derksen et al. 2015 (upper) and tangram card set 2, created for this study (lower).

participants, and each of the participants played the role of Director either with a familiar or unfamiliar partner and Matcher either with a familiar or unfamiliar partner. Participants completed the Barrier Task in a single session and returned individually to complete the neuropsychological test session later that week.

The Barrier Task includes three dependent variables: time to complete the task, number of words used, and number of interactive turns taken (Derksen et al., 2015; Duff et al., 2006, 2008). Together, these variables provide an objective measure of the efficiency with which

participants complete each task trial, reflecting their success in learning and applying labels to each tangram. Time to complete is defined as the amount of time participants take to complete each trial, measured in seconds. The number of words is the total number of words including filled pauses such as “um” and “ah”. Contractions such as “don’t” count as one word; for example “I can’t find the one that looks like a hat” would be counted as 10 words. A turn was defined as a participant’s utterance, with the end of the turn defined by a change in speaker; for example, the following would be considered three turns:

Director: It's the one that looks kind of like a tree

Matcher: Do you mean the like a man with a lopsided hat?

Director: I suppose, I suppose yes it does look like that

If participants spoke simultaneously, each of the participants' utterances were included as a turn. The independent variables in this study were age group (younger/older) and familiarity (familiar/unfamiliar).

Previous research using the Barrier Task has specifically focused on interactive measures when the participant was in the Director role (Derksen et al., 2015). As successful performance on the Barrier Task depends on the learning of both the Director and Matcher, the current study considers the Director and Matcher's time and number of turns taken together in the same interaction (i.e., a single trial), but considers the number of words separately for both Directors and Matchers.

The Barrier Task was administered first. On finishing the Barrier task, participants individually completed the following neuropsychological assessments, administered by a researcher in the following order. The Rey Osterreith Complex Figure Test (Bernstein & Waber, 1996) was administered to assess visuospatial memory, and the Test of Premorbid Functioning (Wechsler, 2009) was administered to provide a measure of full-scale IQ. Executive functions were assessed using the Plus-Minus task (Hull et al., 2008; Jersild, 1927); and the Self-Ordered Pointing Task (MacPherson et al., 2002; Petrides & Milner, 1982). Finally, the Digit Span subtest from the WAIS-IV (Wechsler, 2008) was administered, which assessed working memory. These measures were included to allow for examination of the relationships between individual task performance and collaborative Barrier Task performance (see Hypothesis 3).

Results

Demographic and neuropsychological data. The younger and older groups' demographic characteristics and performance on the background measures are demonstrated in Table 1. The two groups were compared on demographic and cognitive variables using independent samples *t*-tests, if the data were normally distributed, or Mann-Whitney-Wilcoxon tests, if the data were non-normally distributed. The older group were more highly educated than the younger adults, had a significantly higher IQ, and had known their familiar partner for a longer period of time. While older adults performed significantly more poorly than younger adults on both the Rey Osterreith Complex Figure Test and Self-Ordered Pointing Task, the two age groups did not differ on digit span or plus-minus task performance.

The Barrier Task. In line with previous Barrier Task studies (Derksen et al., 2015; Duff et al., 2008), the nine trials were collapsed into three trial bins to minimise inter-trial noise. This was done by calculating the mean

Table 1. Demographic and cognitive characteristics and comparisons of younger and older groups.

		Younger (<i>n</i> = 24)	Older (<i>n</i> = 24)	<i>p</i>
Age (years)	M	21.25	66.88	<0.0001
	SD	2.69	7.19	
Gender	M/F	8/16	8/16	
Handedness	L/R	1/23	1/23	
Relationship length (years)	M	4.67	37.08	<0.0001
	SD	6.14	17.59	
Relationship type	Spouse/ Partners	0	16	
	Siblings	2	4	
	Friends/ Flatmates	22	4	
Education (years)	M	15.17	16.02	<0.0001
	SD	1.49	2.29	
ToPF Full Scale IQ (max = 127)	M	105.61	115.12	<0.0001
	SD	6.13	6.67	
ROCF Immediate Recall (max = 36)	M	26.46	20.10	<0.001
	SD	4.10	6.41	
ROCF Delayed Recall (max = 36)	M	25.83	18.29	<0.0001
	SD	3.82	6.07	
WAIS-IV Digit Span Forwards Score (max = 16)	M	11.50	11.63	=0.87
	SD	2.40	2.16	
WAIS-IV Digit Span Backwards Score (max = 16)	M	9.17	10.00	=0.27
	SD	2.79	2.81	
Plus Minus Task (max = 100)	M	72.18	66.56	=0.11
	SD	8.31	14.71	
Self-Ordered Pointing Task (max = 36)	M	31.42	29.29	<0.05
	SD	2.98	3.92	

ToPF: Test of Premorbid Functioning; ROCF: Rey Osterreith Complex Figure Test; WAIS-IV: Wechsler Adult Intelligence Scale-IV.

of each variable during trials 1–3 ("Bin 1"), trials 4–6 ("Bin 2") and trials 7–9 ("Bin 3"). To test Hypotheses 1 and 2, and examine the effects of age group, familiarity condition and trial number on the number of words used, number of turns taken, and time taken to complete, LMMs were used, since this allows distinguishing between participant-level and trial bin-level predictors, and can be applied to non-normal data. LMMs were implemented using the "lme" function of the lme4 package, version 1.1–8 (Bates et al., 2014) in R 3.2.2 (R Core Team, 2015). The threshold for statistical significance for the linear mixed effect analyses of time, turns and words used was $|t| > 2$.

A forward stepwise approach was used to select factors for the final model using likelihood ratio tests to compare models. The random-effects structure was reduced to trial bin by participant to avoid model over-specification. All best-fitting models included the main effects and interaction between age group (younger or older) and trial (1, 2, or 3) and a main effect of familiarity condition (familiar or unfamiliar). Including familiarity as an interaction did not significantly improve model fit, and so this interaction was not included in the final models run (see Table 2). For time taken to complete and number of turns taken, the models included random slopes and intercepts for trial bin and familiarity condition by participant. Familiarity was removed as a random effect as it did not significantly influence model fit in other models.

Table 2. Model comparisons for time, turns, director words and matcher words of linear mixed effects models by REML, with best fitting model shown in bold.

M	Fixed effects	Random effects	Df	AIC	BIC	logLik	Deviance	χ^2	X DF	$p(\chi^2)$
Time to complete										
1	None (1)	1 + (Familiarity + Bin) Participant	12	3025.6	3069.6	-1500.8	3001.6			
2	Age	1 + (Familiarity + Bin) Participant	13	3025.2	3072.9	-1499.6	2999.2	2.38	1	0.12
3	Age + Familiarity	1 + (Familiarity + Bin) Participant	14	3026.3	9077.5	-1499.1	2999.3	0.98	1	0.32
4	Age * Familiarity	1 + (Familiarity + Bin) Participant	15	3026.6	3081.5	-1498.3	2996.6	1.67	1	0.20
5	Age + Familiarity + Bin	1 + (Familiarity + Bin) Participant	16	2947.8	3006.4	-1457.9	2915.8	82.43	2	<0.0001***
6	Age * Bin + Familiarity	1 + (Familiarity + Bin) Participant	18	2908.7	2974.6	-1436.3	2872.7	43.13	2	<0.0001***
7	Age * Bin * Familiarity	1 + (Familiarity + Bin) Participant	23	2914.6	2998.9	-1434.3	2868.6	4.08	5	0.54
Turns taken										
1	None (1)	1 + (Familiarity + Bin) Participant	12	1611.0	1655.0	-793.52	1587.0			
2	Age	1 + (Familiarity + Bin) Participant	13	1608.9	1656.5	-791.45	1582.9	4.13	1	0.04*
3	Age + Familiarity	1 + (Familiarity + Bin) Participant	14	1610.6	1661.8	-791.28	1582.6	0.34	1	0.56
4	Age * Familiarity	1 + (Familiarity + Bin) Participant	15	1612.0	1667.0	-791.01	1582.0	0.55	1	0.46
5	Age + Familiarity + Bin	1 + (Familiarity + Bin) Participant	16	1521.1	1579.7	-744.55	1489.1	93.48	2	<0.0001***
6	Age * Bin + Familiarity	1 + (Familiarity + Bin) Participant	18	1503.2	1569.1	-733.58	1467.2	21.93	2	<0.0001***
7	Age * Bin * Familiarity	1 + (Familiarity + Bin) Participant	23	1510.2	1594.4	-732.07	1464.2	3.01	5	0.70
Director words										
1	None (1)	1 + (Bin) Participant	5	1819.4	1834.3	-904.71	1809.4			
2	Age	1 + (Bin) Participant	6	1805.3	1823.1	-896.64	1793.3	16.13	1	<0.0001***
3	Age + Familiarity	1 + (Bin) Participant	7	1804.6	1825.4	-895.30	1790.6	2.69	1	0.10
4	Age * Familiarity	1 + (Bin) Participant	8	1806.1	1829.5	-895.04	1790.1	0.52	1	0.47
5	Age + Familiarity + Bin	1 + (Bin) Participant	9	1658.4	1685.1	-820.18	1640.4	150.23	2	<0.0001***
6	Age * Bin + Familiarity	1 + (Bin) Participant	11	1639.9	1672.5	-808.93	1617.9	22.50	2	<0.0001***
7	Age * Bin * Familiarity	1 + (Bin) Participant	16	1638.5	1665.2	-810.24	1620.5	2.60	5	0.2718
Matcher words										
1	None (1)	1 + (Bin) Participant	5	1549.7	1564.5	-769.86	1539.7			
2	Age	1 + (Bin) Participant	6	1539.0	1556.8	-763.50	1527.0	12.72	1	<0.001**
3	Age + Familiarity	1 + (Bin) Participant	7	1541.0	1561.7	-763.50	1527.0	0.006	1	0.93
4	Age * Familiarity	1 + (Bin) Participant	8	1542.9	1556.6	-763.44	1526.9	0.12	1	0.73
5	Age + Familiarity + Bin	1 + (Bin) Participant	9	1415.8	1442.5	-698.92	1397.8	129.25	2	<0.0001***
6	Age * Bin + Familiarity	1 + (Bin) Participant	11	1394.2	1426.8	-686.11	1372.2	25.64	2	<0.0001***
7	Age * Bin * Familiarity	1 + (Bin) Participant	16	1403.8	1421.2	-685.92	1371.8	0.37	5	0.99

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

In general, all three dependent variables on the Barrier Task showed a similar pattern; participants took more time, turns, and words to complete the initial, early trials, but by later trials, participants took less time, turns and words to complete. While older adults were less efficient than the younger participants in terms of time, turns and words, this age difference reduced across trials.

Figures 3–6 illustrate time to complete, number of words used, and number of turns taken for each age

group across each condition. Each of the analyses revealed a main effect of age group, trial bin, and an age group \times trial bin interaction (see Tables 3–6). For number of words used by both Directors and Matchers, the interaction between age group and trial bin was only significant across trial bins 1–2 (Director words $B = -74.15$, $SE = 22.89$, $t = -3.24$; Matcher words $B = -36.32$, $SE = 10.52$, $t = -3.45$) and not bins 2–3 (Director words $B = -36.60$, $SE = 22.88$, $t = 1.60$; Matcher words $B = -19.08$, $SE = 10.45$,

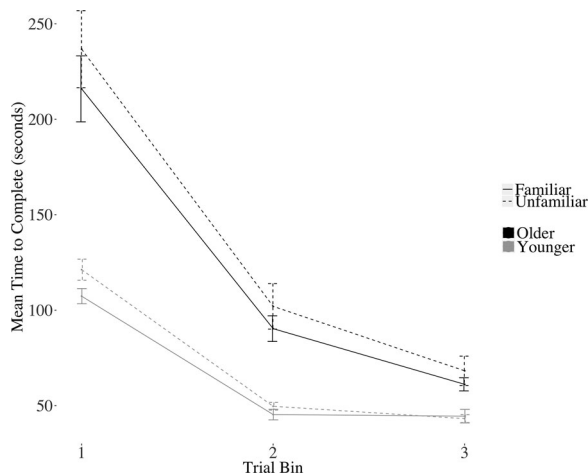


Figure 3. Mean and standard error of the mean for time to complete the Barrier Task by trial bin, age group, and familiarity condition.

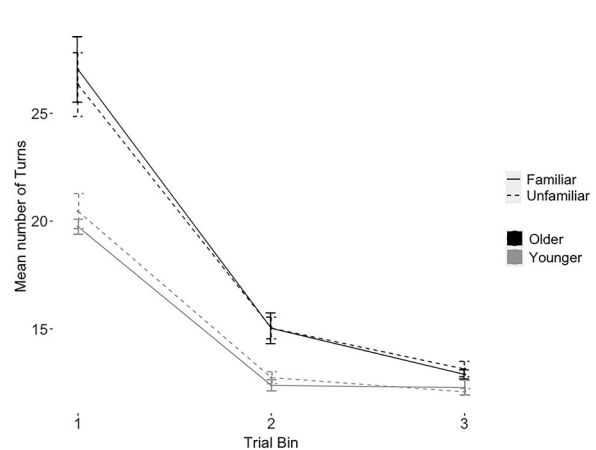


Figure 4. Mean and standard error of the mean for number of turns taken to complete the Barrier Task by trial bin, age group, and familiarity condition.

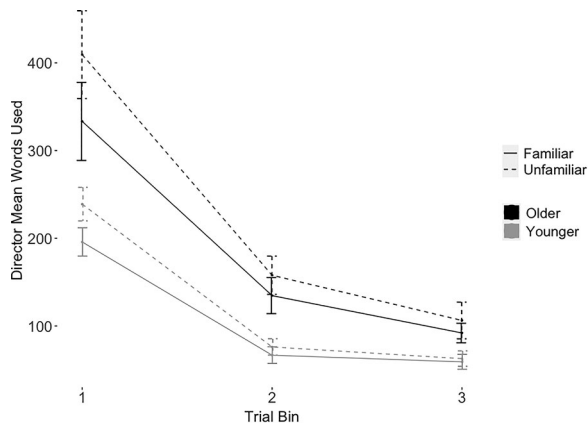


Figure 5. Mean and standard error of the mean for number of words used by directors to complete the Barrier Task by trial bin, age group, and familiarity condition.

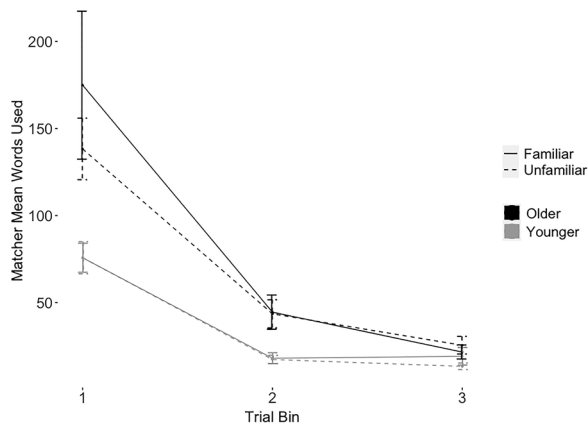


Figure 6. Mean and standard error of the mean for number of words used by matchers to complete the Barrier Task by trial bin, age group, and familiarity condition.

$t = -1.82$), indicating that the older and younger adults were using a similar number of words in mid and later trials (see Table 7).

Learning performance in bin 3. Younger and older adults' performance in trial bin 3 was compared to

explore whether collaborative learning using this paradigm resulted in younger and older adults performing with similar efficiency. As familiarity had no effect on performance, familiarity was not included in these contrasts. The analyses indicated that younger adults were still significantly faster than older adults by the final trials, using significantly fewer turns and words (see Table 7), although the difference between the older and younger groups appeared to lessen in the later trials, as indicated by non-significant interactions between age group and trial bin for Director and Matcher words (see Tables 5 and 6).

Power analysis

Effect size was calculated using the “cohensD” command from the “lsr” R package (Navarro, 2015) A power analysis was calculated using the “pwr.2p.test” from the “pwr” R package (Champely, 2017), and was calculated by bin as in Derksen et al. (2015). Table 8 shows the means for older and younger adults on each of the dependent variables, along with the effect sizes and power.

Bayesian analysis

To further address Hypothesis 2, Bayesian ANOVAs were conducted with dependent variables of age group and familiarity condition to provide further support for our finding that familiar and unfamiliar pairs completed the Barrier Task with similar efficiency. Bayesian analysis can address the issue of uncertainty in smaller sample sizes with non-significant effects (Bayarri et al., 2016). While linear models provide evidence that participants did not significantly differ in terms of their efficiency on the Barrier Task as illustrated by non-significant t -values, this does not provide direct support for the interpretation that participants in both conditions learn with similar efficiency. Bayesian analysis allows comparisons of the strength of the evidence supporting either the experimental (i.e., familiar and unfamiliar pairs learn with different efficiency) or null hypothesis (i.e., familiar and unfamiliar

Table 3. Time to complete: beta, standard errors, and t values for fixed effects and variance and residual for random effects, model fit by REML.

Effects			
Fixed effects	β	S.E.	t
Intercept	170.30	6.97	24.42**
Age group (older)	109.52	13.19	8.35**
Bin 1–2	–98.49	5.02	–19.64**
Bin 2–3	–17.56	3.98	–4.41**
Familiarity (unfamiliar)	9.41	7.02	1.33
Age (older) * bin 1–2	–62.05	9.72	–6.39**
Age (older) * bin 2–3	–27.37	7.92	–3.46**
Random effects		Variance	Standard deviation
Participant	Intercept	1660.18	40.75
–	Familiarity (U)	1897.61	43.56
–	Bin 1–2	506.50	22.51
–	Bin 2–3	59.75	7.73
Residual	–	701.15	26.48

Table 4. Turns taken: beta, standard errors, and *t* values for fixed effects and variance and residual for random effects, model fit by REML.

Effects			
<i>Fixed effects</i>	β	S.E.	<i>t</i>
Intercept	23.39	0.59	39.88**
Age group (older)	6.62	1.16	5.67**
Bin 1–2	–9.59	0.50	–19.09**
Bin 2–3	–1.32	0.38	–3.47**
Familiarity (unfamiliar)	0.16	0.48	0.34
Age (older) * bin 1–2	–4.15	0.99	–4.17**
Age (older) * bin 2–3	–1.89	0.76	–2.48*
<i>Random effects</i>		Variance	Standard deviation
Participant	Intercept	13.41	3.66
	Familiarity (U)	6.75	2.59
–	Bin 1–2	5.93	2.44
–	Bin 2–3	0.77	0.876
Residuals	–	6.19	2.49

Table 5. Director words: beta, standard errors, and *t* values for fixed effects and variance and residual for random effects, model fit by REML.

Effects			
<i>Fixed effects</i>	β	S.E.	<i>t</i>
Intercept	291.87	10.90	26.78**
Age group (older)	144.34	21.08	6.86**
Bin 1–2	–183.02	11.45	–15.99**
Bin 2–3	–28.77	11.45	–2.51*
Familiarity (unfamiliar)	23.30	17.33	1.52
Age (older) * bin 1–2	–74.15	22.89	–3.24**
Age (older) * bin 2–3	–36.60	22.88	–1.60
<i>Random effects</i>		Variance	Standard deviation
Participant	Intercept	2176	46.65
	Familiarity (U)	1519	38.98
Residuals	–	3144	56.07

Table 6. Matcher words: beta, standard errors, and *t* values for fixed effects and variance and residual for random effects, model fit by REML.

Effects			
<i>Fixed effects</i>	β	S.E.	<i>t</i>
Intercept	106.89	4.63	23.08**
Age group (older)	62.71	9.26	6.77**
Bin 1–2	–76.88	5.23	–14.47**
Bin 2–3	–10.88	5.22	–2.08*
Familiarity (unfamiliar)	–0.67	6.93	–0.09
Age (older) * bin 1–2	–36.32	10.52	–3.45**
Age (older) * bin 2–3	–19.08	10.45	–1.82
<i>Random effects</i>		Variance	Standard deviation
Participant	Intercept	248.0	15.75
	Familiarity(U)	432.0	20.78
Residuals	–	655.5	25.60

pairs learn with similar efficiency), and provide quantifiable support for the evidence or these hypotheses (Bayarri et al., 2016). Evidence is quantified using Bayes Factors (BF01), which provides a likelihood ratio of the probability of the data occurring under the null hypothesis over the probability of the data occurring under the experimental hypothesis. For example, a BF01 of 5 indicates that the observed data are five times more likely to have occurred given the null hypothesis than the experimental hypothesis. Bayes Factors above 3 are considered “moderate” evidence, those above 10 are considered “strong” evidence, and those above 30 are “very strong” evidence (Lee &

Wagenmakers, 2014). Bayesian analysis was carried out using JASP (JASP Team, 2018), and used the default null of $P(M) = 0.2$.

Table 7. Mann–Whitney–Wilcoxon U comparisons with FDR corrections for bin three variables of performance comparing younger and older adult groups.

Variables	Comparison
Time	$W = 1754, p < 0.0001$
Turns	$W = 1540.5, p = 0.008$
Director words	$W = 412, p = 0.02$
Matcher words	$W = 394, p = 0.03$

Table 8. Mean group performance and mean group difference on the Barrier Task, with effect size calculated as Cohen's *d*, and statistical power calculated with a group size of 24, and a significant level of $p < 0.05$.

	Bin 1	Bin 2	Bin 3
<i>Time to complete</i>			
Younger	114.26	47.47	43.82
Older	226.33	96.15	64.68
Difference	112.07	48.68	20.86
Effect size	1.67	1.41	0.91
Power	0.99	0.99	0.88
<i>Turns taken</i>			
Younger	20.10	12.56	12.18
Older	26.68	15.03	12.76
Difference	6.58	2.48	0.58
Effect size	1.18	1.07	0.41
Power	0.98	0.96	0.29
<i>Director words</i>			
Younger	217.37	71.43	60.96
Older	156.58	44.04	23.56
Difference	80.80	26.36	7.28
Effect size	1.33	1.33	0.84
Power	0.99	0.99	0.83
<i>Matcher words</i>			
Younger	75.78	17.68	16.28
Older	156.58	44.04	23.56
Difference	80.80	26.36	7.28
Effect size	0.98	1.17	0.51
Power	0.92	0.98	0.43

As illustrated in Table 9, the Bayes Factors for each variable at each time point ranged between 3.069 and 4.659; indicating moderate evidence for the hypothesis that familiar and unfamiliar pairs perform the task with similar efficiency during every trial bin; and for every variable.

Relationship with neuropsychological test performance. Spearman's correlational analyses with a False Discovery Rate (FDR; Benjamini & Hochberg, 1995) correction for multiple comparisons explored relationships between the three Barrier Task variables (time to complete, number of words, number of turns), age, and cognitive test performance in younger and older participants (see Tables 10 and 11), addressing Hypothesis 3. In the younger adult group, executive function as measured by the plus-minus task was related to time taken to complete ($r = -0.30, p < 0.05$) and number of turns taken ($r = -0.33, p < 0.05$); no other relationships were found. In the older group, there was only one significant association: performance on the Rey Osterreith Complex Figure was related to the number of turns taken ($r = -0.30, p < 0.05$).

Discussion

The current study examined the effects of aging and familiarity on collaborative learning using an ecologically valid paradigm. Our first hypothesis, that older adults would be less efficient compared to younger adults using initial trials, but would become more efficient in subsequent trials, was supported. Older adults performed less efficiently than younger adults at the start of the Barrier Task, using more words and taking more time and turns to complete the task. By the end of the trials, the older group was still significantly less efficient than younger group, although the difference between the two groups was

Table 9. Bayesian ANOVA illustrating the effect of age group and familiarity condition on time, turns and words in each trial bin.

	Model	$P(M)$	$P(M data)$	BF_M	BF 01	% error
<i>Bin 1</i>						
Time	Null model	0.20	<0.0001	<0.0001	1.000	
	Age	0.20	0.64	7.12	<0.0001	<0.0001
	Familiarity	0.20	<0.0001	<0.0001	3.07*	<0.0001
Turns	Null model	0.20	<0.0001	<0.0001	1.000	
	Age	0.20	0.78	14.55	<0.0001	<0.0001
	Familiarity	0.20	<0.0001	<0.0001	4.66*	0.03
Words	Null model	0.20	<0.005	<0.01	1.000	
	Age	0.20	0.69	9.01	<0.005	<0.0001
	Familiarity	0.20	<0.0001	<0.005	3.11*	0.03
<i>Bin 2</i>						
Time	Null model	0.20	<0.0001	<0.0001	<0.0001	
	Age	0.20	0.68	8.37	<0.0001	<0.0001
	Familiarity	0.20	<0.0001	<0.0001	3.18*	0.03
Turns	Null model	0.20	<0.0001	<0.0001	1.000	
	Age	0.20	0.78	13.96	<0.0001	<0.0001
	Familiarity	0.20	<0.0001	<0.0001	4.41*	0.03
Words	Null model	0.20	<0.005	<0.01	1.000	
	Age	0.20	0.75	12.11	<0.005	<0.0001
	Familiarity	0.20	<0.0001	<0.005	4.00*	0.03
<i>Bin 3</i>						
Time	Null model	0.20	<0.0001	<0.005	1.00	
	Age	0.20	0.74	11.46	<0.001	<0.0001
	Familiarity	0.20	<0.0001	<0.0001	4.05	0.03
Turns	Null model	0.20	0.28	1.56	1.00	
	Age	0.20	0.38	2.49	0.73	<0.0001
	Familiarity	0.20	0.09	0.40	3.09*	0.03
Words	Null model	0.20	0.20	1.02	1.00	
	Age	0.20	0.57	5.36	0.35	<0.0001
	Familiarity	0.20	0.05	0.19	4.31*	0.03

*BF01 > 3 indicating moderate evidence for the null hypothesis.

Table 10. Spearman's correlations between younger adults' Barrier Task performance and performance on individual cognitive assessments.

	1	2	3	4	5	6	7	8	9	10
1. Time	1									
2. Words	0.41**	1								
3. Turns	0.83***	0.45**	1							
4. ToPF full scale IQ	-0.14	-0.11	0.03	1						
5. ROCF immediate recall	0.06	0.10	0.10	-0.16	1					
6. ROCF delayed recall	0.01	0.05	0.10	-0.04	0.91***	1				
7. WAIS-IV DSF	0.16	0.1	0.19	0.27	-0.08	0.02	1			
8. WAIS-IV DSB	-0.14	-0.14	-0.08	0.49**	-0.03	0.21	0.46	1		
9. Plus minus task	-0.30*	-0.21	-0.33*	-0.24	0.18	0.17	-0.43**	0.09	1	
10. Self-ordered pointing task	0.04	0.06	0.07	-0.18	-0.08	-0.18	-0.11	-0.34*	-0.30*	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

ToPF: Test of Premorbid Functioning; ROCF: Rey Osterreith Complex Figure Test; WAIS-IV: Wechsler Adult Intelligence Scale-IV; DSF: Digit Span Forward; DSB: Digit Span Backward.

Table 11. Spearman's correlations between older adults' Barrier Task performance and performance on individual cognitive assessments.

	1	2	3	4	5	6	7	8	9	10
1. Time	-									
2. Words	0.51**	-								
3. Turns	0.72**	0.55**	1							
4. ToPF Full Scale IQ	-0.17	-0.04	-0.18	1						
5. ROCF Immediate Recall	-0.21	-0.15	-0.27	0.22	1					
6. ROCF Delayed Recall	-0.21	-0.16	-0.30*	0.19	0.91	1				
7. WAIS-IV DSF	0.1	0.06	0.08	0.29	-0.23	-0.28	1			
8. WAIS-IV DSB	-0.05	0.04	-0.14	0.36*	0.15	0.14	0.41**	1		
9. Plus Minus Task	0	0.04	0.01	0.29*	0.25	0.24	0.25	0.32	1	
10. Self-Ordered Pointing Task	0.02	-0.11	-0.14	-0.22	-0.17	-0.17	-0.40**	-0.38**	-0.58***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

ToPF: Test of Premorbid Functioning; ROCF: Rey Osterreith Complex Figure Test; WAIS-IV: Wechsler Adult Intelligence Scale-IV; DSF: Digit Span Forward; DSB: Digit Span Backward.

considerably less, and the difference between the two groups reduced over trials. However, unlike previous collaborative learning research (e.g., Derksen et al., 2015), our older adults were still not performing as efficiently as our younger adults by the end of the nine trials. It is possible that with a higher number of trials (as in Derksen et al., 2015), the two age groups may have become statistically indistinguishable.

Our second hypothesis, that familiarity would improve Barrier Task performance in younger and older pairs, was not supported. Familiarity did not affect collaborative learning: participants showed similar improvements in learning efficiency with a close friend or partner as they did with a stranger, suggesting that collaboration alone may be sufficient to result in successful learning. Our additional inclusion of Bayesian analysis allowed us to test the strength of support for the null hypothesis, that familiar and unfamiliar pairs performed similarly, and found moderate support for this. This, for the first time, provides evidence not just of a lack of significant difference between familiar and unfamiliar pairs, but that there is evidence that performance is similar between the two conditions.

Our third hypothesis, that performance on individual cognitive memory assessments will be related to Barrier Task performance, yielded unclear results. Individual memory ability was not entirely related to Barrier Task efficiency: older adults' individual visuospatial memory performance was correlated with turns taken during the

Barrier Task, but no relationship was found between the two tasks in the younger group. This echoes Derksen et al.'s (2015) findings that performance on the Barrier Task and individual anterograde visual memory tasks (using the Visual Representation Task from the Wechsler Memory Scale-III, Wechsler, 1997) are correlated in older, but not younger adults. However, in the current study, this relationship was only found when inferring efficiency from turns taken, and not words or time. This may be because participants in the final trials are continuing to provide verbose answers, therefore using more words and time, though with less back and forth, resulting in fewer turns. These results indicate that collaborative memory ability may be at least in part be independent of individual memory ability, which supports studies of amnesic patients who showed robust learning through collaboration at a rate equal to non-amnesic comparative controls, despite marked inability to learn arbitrary relations in paired-associate learning (Duff et al., 2006, 2008).

Theoretical basis for findings

The lack of a strong relationship between individual memory performance and collaborative learning performance is aligned with the theory that memory performance is enhanced for information that is self-relevant and learned within a social context (Cassidy & Gutchess, 2012; May et al., 2005; Yang et al., 2012). These findings

also support the scaffolding theory of aging, and suggest that learning new information within the context of a social interaction may “scaffold” this learning process and help reduce age-related memory differences (Park & Reuter-Lorenz, 2009).

Our finding that familiar and unfamiliar pairs do not differ in their collaborative learning success echo previous findings from studies of socially shared cognition that indicate that collaborators act as external memory aids, providing additional learning opportunities and cues for recall, similar to cross-cueing and re-exposure theories (Blumen et al., 2013; Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Meudell et al., 1992; Meudell et al., 1995; Weldon & Bellinger, 1997). Our findings support the theory that cross-cueing and re-exposure do not rely on participants being familiar to one another when learning, and should both apply when learning with friends and strangers.

Implications

Our findings that there are no differences in collaborative learning with familiar and unfamiliar partners have both useful and practical implications. Older adults learn new information from a number of people that they may not know: doctors, people in the community, and through lifelong education projects. Collaborative learning is also one of the cornerstones of lifelong learning, which is increasingly important in today’s society (Fischer, 2000). Our study suggests that even if older adults do not know the people involved, they should not feel deterred from learning new things in a collaborative setting, and lifelong learning providers may consider including collaborative learning activities regardless of participant age.

Additionally, our results indicated that there is not a clear or robust relationship between individual memory performance and collaborative learning performance. This indicates that older adults may benefit from learning new information within the context of a social interaction or collaboration rather than individual rote learning, though replications and extensions of this work are needed to provide greater detail on the most beneficial learning environments and task types that collaborative learning may support.

Limitations and future directions

Our study has some limitations; firstly, relationship length differed considerably across the two groups, with older adults having a significantly longer relationship with their familiar partner than the younger pairs, although, arguably, this was beneficial for older adults. Secondly, the sample size was moderate for a study of this complexity, though post-hoc power calculations showed large effect sizes and high statistical power for early trials and smaller effect sizes and lower statistical power for later trials. To further address the issue of uncertainty given our modest sample size and apparent lack of effect of familiarity on

performance, Bayesian post-hoc analyses were conducted, which are more robust to small sample sizes. These post-hoc analyses provided further evidence that familiarity did not affect learning performance. Thirdly, as collaborative learning involves a social interaction with another person, performance may be affected by social cognitive functioning. While we examined the relationship between Barrier Task performance and individual measures of memory and executive function, we did not include measures of social cognition. Future work may examine whether a relationship between the two exists. Finally, the measures of words, turns and time are useful to measure efficiency but do not allow us to understand the underlying communications between participants, and how these may vary by age or familiarity. Future work may examine more closely the linguistic content of these interactions to enhance our understanding of the underlying components of successful collaboration, and whether there are differences in interactive content between familiar and unfamiliar, and younger and older pairs. This may also provide opportunities to analyse incidences of cross-cueing and re-exposure across age groups and familiarity conditions (Blumen et al., 2013; Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Meudell, 1996; Meudell et al., 1995; Meudell et al., 1992; Weldon & Bellinger, 1997).

Additionally, the Barrier Task is not thought to incorporate or rely upon participants’ prior knowledge, nor is the task set within a wider social context. However, many real-world collaborations involve aspects of previous shared experience and knowledge. Future work may involve more complex tasks that incorporate previously learned skills to investigate whether collaboration alone is sufficient to improve learning performance regardless of whether the pairs are familiar with one another or not. It may also be beneficial for future studies to analyse the content of collaborative learning interactions to examine the impact of non-task-related social talk or meta comment. This type of work will be valuable when translating the lab-based findings from this paper to, for example, the types of environments studied in Computer-Supported Collaborative Work and Collaborative Learning communities, where tasks tend to be far more natural.

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ORCID

Catherine J. Crompton  <http://orcid.org/0000-0001-5280-1596>
Sarah E. MacPherson  <http://orcid.org/0000-0001-8676-6514>

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