THE EFFECTS OF SELF-REFERENCE ON RELATIONAL MEMORY IN YOUNG AND OLDER ADULTS

by

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ABSTRACT

Prior studies suggest that older adults show age-related impairments in relational memory, which may be attributed to decreased ability in basic memory and executive functions. The two studies presented in this dissertation investigated the effectiveness of self-reference, an encoding strategy, on different subtypes of relational memory in young and older adults, and the extent to which the effect varies as a function of individual differences in basic memory and executive functioning. Study 1 investigated the influence of self-reference on two kinds of relational memory, internal source memory and associative memory, in young and older adults. Forty young and 40 older adults encoded object-location word pairs using the strategies of imagination and sentence generation, either with reference to themselves or to a famous other (i.e., George Clooney or Oprah Winfrey). Both young and older adults showed better memory performance in the self-referential conditions compared to other-referential conditions on both tests, and the self-referential effects in older adults were not limited by low memory or executive functioning. Study 2 investigated the effectiveness of self-reference on memory for multi-element events. Thirty-six young and 36 older adults imagined person-object-location events with reference to themselves, George Clooney or Oprah Winfrey, and were later assessed on their memory for the events via multiple, cued, forced-choice recognition tasks. Self-reference was found to increase memory for the multi-element events in both young and older adults, and the benefit of self-reference was not correlated with memory functioning in either group. Further, self-reference did not increase memory coherence—the extent to which the retrieval outcomes of different pairwise associations within the imagined events were dependent on one another. These findings are discussed in terms of

the potentially different binding mechanisms involved in self-related and non-self-related memories. The results of these studies also suggest that self-reference can benefit relational memory in older adults relatively independently of basic memory and executive functions, and may be a viable strategy to improve relational memory in individuals with different levels of neuropsychological functioning.

LITERATURE REVIEW

1. Age-related changes in relational memory

Relational memory concerns associations among multiple-elements that enable our recollective experiences to be holistic and with rich details. In the laboratory setting, relational memory has usually been studied using one of two paradigms: a source memory task in which many items are studied in the context of one of two sources (e.g., many words in one of two voices, a many-to-one mapping between items and voices), or an associative memory task in which unique pairs of items are presented (e.g., word-word pairs, in a one-to-one mapping). According to the source monitoring framework (Johnson, Hashtroudi, & Lindsay, 1993), source memory can be further divided into internal source monitoring (differentiation between two internally generated sources, such as say vs. think), external source monitoring (differentiation between two externally presented sources, such as the color of blue vs. red) and reality source monitoring (differentiation between an internally generated source and an externally presented source, such as say vs. listen). Older adults typically show deficits in both source and associative memory tasks, highlighting the scope of difficulty with such memory demands.

Age-related changes in source memory have been widely investigated with external sources, such as voices, colors, list membership and spatial locations, and older adults have been found to show impaired performance compared to young adults (Kausler & Puckett, 1981; Swick, Senkfor, & Van Petten, 2006; Park, Puglisi, & Lutz, 1982; Johnson et al, 1993 for review). For instance, in the study of Park and colleagues (1982), after learning pictures of items on the left or right side of index cards, older adults exhibited more errors than young adults in reporting the locations of the items at test. Also, Swick and colleagues (2006) found age-related decrements in deciding whether studied words were spoken in female or male voices.

Although less investigated, age-related deficits in internal source memory have also been found. For instance, in a study by Hashtroudi, Johnson and Chrosniak (1989), young and older adults were presented with words and were asked either to repeat them aloud or to imaging themselves repeating them aloud. Compared to young adults, older adults had more difficulty differentiating between the two internal sources (say vs. think). In another study, Hashtroudi, Johnson, Vnek and Ferguson (1994) had young and older adults participating in a short play, in which lines from a script were either said aloud or just thought about. In a later test, older adults were less able than young adults to remember whether they actually spoke a line from the script or just thought about it.

Age-related changes are also observed in associative tasks. For instance, in four experiments, Naveh-Benjamin (2000) found older adults showed lower performance than young adults in remembering word-nonword pairs, word-word pairs, and word-font pairs; however, the age effect disappeared when the stimuli were semantically-related word pairs. In later studies, the age-related deficits were also evident in studies with pairs such as pictures of objects, name-face pairs, and people-action pairs (Naveh-Benjamin, Hussain, Guez, & Baron, 2003; Naveh-Benjamin, Guez, Klib, & Reedy, 2004; Old & Naveh-Benjamin, 2008a; Old & Naveh-Benjamin, 2008b for review). For instance, in Old and Naveh-Benjamin (2008a), both young and older adults viewed a series of video clips about different people performing different everyday actions. After study, the participants took three recognition tests: a test for actions, a test for people and a test for people-action pairs. Age-related deficits were found only in the recognition of people-action pairs.

The majority of research on relational memory, as noted above, has focused on memory for pairwise associations. However, events in daily life are more complex and may contain multiple elements such as persons, objects and locations. Studies of memory for multiple contextual features or multi-element events suggest that older adults also show deficits in remembering such complex events (Chalfonte & Johnson, 1996; Kessels, Hobbel, & Postma, 2007; Plancher, Gyselinck, Nicolas, & Piolino, 2010; Sumida et al., 2016; Addis, Giovanello, Vu & Schacter, 2014). For example, in the study of Kessels and colleagues (2007), young and older adults were shown pictures of different objects one at a time in different cells of a grid on the computer screen. They then took five memory tests: for the items (objects), the contexts (positions), combinations of item and context (object-position, object-order), and context-context pairings (position-order). It was found that older adults performed worse than young adults in all of the tests, indicating an age-related impairment in multi-feature memories. In another study (Sumida et al., 2016), where young and older adults were required to remember a sequence of pictures of different faces in different locations, older adults were found to remember fewer face-location pairs in the correct order than young adults. Further, Addis and colleagues (2014) varied the amount of semantic associations (i.e., zero, one or two links) within the to-be-encoded word triplets, and observed age-related deficits in memory for all trial types.

Based on the findings of age-related deficits in relational memory, Naveh-Benjamin (2000) proposed that older adults have a specific deficit in forming and retrieving links among different pieces of information, relative to their ability to remember the individual items—what he called the associative deficit hypothesis. Two possible factors have been considered to contribute to the associative deficits in older adults (Giovanello & Dew, 2015): 1) deficits in executive functions mediated by prefrontal cortex (PFC) (Moscovitch & Winocur, 1995), which are associated with decreased ability to initiate encoding strategies and monitor memory output at retrieval, and 2) deficits in binding, mediated by structures in the medial temporal lobes particularly the hippocampus (MTL/H; Ryan, Leung, Turk-Browne, & Hasher, 2007), which lead to an inability to integrate multiple elements into coherent events. Evidence for both factors has been found in behavioral studies (e.g., Craik, Morris, Morris, & Loewen, 1990; Glisky & Kong, 2008; Glisky, Polster, & Routhieaux, 1995; Glisky, Rubin, & Davidson, 2001; Henkel, Johnson, & De Leonardis, 1998; Siedlecki, Salthouse, & Berish, 2005). For example, Glisky and colleagues (2001) found that older adults with low executive functioning were impaired on source memory. In this study, older adults were grouped based on composite measures of executive function dependent on the frontal lobes (FL) and memory function based on the medial temporal lobes (MTL). Participants viewed multiple pictures of chairs (items) paired with one of two rooms (sources) at study, and were asked how comfortable each chair was. On the subsequent source memory test in which they had to remember in which room each chair had appeared, older adults with low FL scores performed worse than young adults, while older adults with high FL scores did not differ from young adults. Performance on the source test was not related to their memory scores. On the other hand, Henkel and colleagues (1998) observed a correlation between memory scores and source memory performance in older adults after delays of 15 minutes and 2 days, although scores from their frontal battery were also correlated with older adults' performance after the delay of 2 days.

Consistent with the behavioral results, functional neuroimaging studies of relational memory suggest there are age-related changes in both PFC and hippocampal activity, which are assumed to underlie the executive and binding functions, respectively (Addis et al., 2014; Dennis et al., 2008; Dulas & Duarte, 2011, 2014; Giovanello & Schacter, 2012; Kim & Giovanello, 2011; Leshikar, Gutchess, Hebrank, Sutton, & Park, 2010). Focusing on source memory, Dulas and Duarte (2011) asked young and older adults to study words and pictures and decide whether the items were living or bigger than a shoebox. In later tests participants were instructed to indicate the tasks (sources) they used when studying the items. Compared to young adults, older adults showed smaller activation differences at encoding between later remembered and later forgotten sources (i.e., subsequent memory effects) in dorsolateral prefrontal cortex (DLPFC). In a later study, using objects as items and colors as sources, Dulas and Duarte (2014) again showed that older adults under-recruited lateral PFC during encoding of source, but also found weaker activations in the hippocampus at retrieval compared to young adults. Similarly, in an associative memory paradigm, Dennis and colleagues (2008) found that when encoding face-scene pairs that were subsequently remembered, older adults showed less activation in hippocampus and bilateral DLPFC than young adults. In another study, Giovanello & Schacter (2012) compared the neural activity during the retrieval of item information and relational information of noun pairs in young and older adults. While young adults exhibited enhanced activity in the left posterior VLPFC and bilateral hippocampus in the relational memory condition compared to the item memory condition, activity in these regions was equivalent across conditions in older adults, suggesting that aging is related to reduced specificity of VLPFC and hippocampal activity during relational memory retrieval. Leshikar and colleagues (2010) found equal hippocampal recruitment between young and older adults in encoding pairs of line-drawing images, but compared to young adults, older adults showed reduced functional connectivity between hippocampus and the posterior occipital regions, suggesting less efficient use of perceptual processes to bind visual information (Dennis et al., 2008).

Age-related changes in PFC and hippocampus have also been observed in memory for multi-element events. In the study mentioned earlier by Addis and colleagues (2014), it was found that at encoding, young adults showed greater activation of ventrolateral prefrontal cortex (VLPFC) in the low-association trials (i.e., no semantic association among the triplets) relative to the high-association trials. This up-regulation of VLPFC, however, which might help with organization of the stimuli, was not observed in older adults. Moreover, compared to young adults who exhibited positive modulations by number of associations in the right hippocampus, older adults showed bilateral hippocampal modulation effects. There is also evidence for age-related changes in hippocampal connectivity during the encoding of multi-featural events, even when behavioral performance is matched between young and older adults (Foster et al., 2016). In this study, young and older adults encoded words presented in one of four colors and in one of four locations on the screen, and then received a test for the color and location associated with each recognized cue word. Although performance was purposely made to be equivalent between the two groups (e.g., using a study-test delay in young adults but not in older adults), at encoding, older adults showed greater hippocampal functional connectivity in the default mode network regions than young adults, which was not related to memory performance. Although these findings are not entirely consistent, possibly because of the use of different materials and different paradigms, overall they suggest that changes in neural correlates of executive and binding functions are related to reduced relational memory in older adults. Compared to young people, older adults' executive functions mediated by PFC and binding functions mediated by hippocampus seem to be less efficient or under-recruited.

Most studies on multi-element events focus on the contribution of hippocampally-mediated binding to memory accuracy. Some studies, however have suggested further that this binding function enables the retrieval of coherent events, in which the retrieval outcomes of the pairwise associations within the same event are statistically dependent (Horner & Burgess, 2013, 2014; Horner, Bisby, Bush, Lin, & Burgess, 2015; Uncapher, Otten, & Rugg, 2006). For example, in a series of experiments, Horner and Burgess found that the retrieval outcomes of several pairwise associations within the same event were dependent on one another. In one study (Horner & Burgess, 2013), participants vividly imagined person-object-location events, and then performed a cued-recall task (Experiment 1) or a forced-choice recognition task (Experiment 2 and 3) at retrieval, where all the pairwise associations (e.g., person cueing location, person cuing object etc.) within the same events were tested across trials. It was found that performance in retrieving different elements was significantly related, such that if participants could retrieve one pair (e.g., person-object), they were more likely to retrieve another pair (e.g., person-location) from the same event. In a follow-up study with fMRI (Horner et al., 2015), the hippocampal activity at encoding was shown to predict subsequent memory for complex events, the retrieval of which was also observed to be coherent, indicating that the hippocampus was involved in binding different elements of complex events. Although not previously investigated, it is likely that older adults would have difficulty in memory for the kind of complex events investigated by Horner and Burgess (2013), given that older adults perform worse behaviorally than young adults, and show age-related changes in hippocampal activity in memory for multi-featural and multi-element events.

Despite the multiple potential contributors to age-related memory decline, it has also been shown that providing associative memory strategies can enhance relational memory in older adults. Moreover, such environmental support is especially beneficial to individuals with low executive functions, who fail to initiate effective strategies. For example, Naveh-Benjamin and colleagues (2007) found that compared to an intentional encoding condition, older adults showed better associative memory performance in conditions where they were instructed to use a semantically-derived relational strategy (i.e., generating sentences of the to-be-remembered word pairs) during encoding and reminded to think back to the sentences they had generated earlier at retrieval. Similarly, in the previously mentioned study of Glisky and colleagues (2001), when participants were given an orienting task that related the pictures of chairs with the appropriate room (the sources), older adults with low executive functioning performed as well as young adults and older adults with high executive functioning on the source memory test. However, although low executive functioning may not limit the effectiveness of associative strategies, poor binding mechanisms might pose further difficulties. It is noteworthy that although Naveh-Benjamin and colleagues (2007) found that the age-related deficit in associative memory was substantially reduced by the use of a semantically-derived strategy at encoding and retrieval, it was not eliminated. This finding suggests that even in the face of good associative strategies, some older adults may have problems linking together aspects of content and context because of deficits in the binding function that is mediated by the MTL/H.

2. Self-reference and relational memory

In addition to semantically-derived strategies, some recent studies suggest that self-reference, an associative strategy whereby people encode to-be-remembered information with reference to themselves (Rogers, Kuiper, & Kirker, 1977), also can enhance relational memory in older adults. For example, in the study of external source memory by Leshikar and Duarte (2014), participants viewed multiple pictures of objects, each shown with one of three pictures of natural scenes, and made judgments about whether the object-scene pairs were pleasant either for themselves or for Queen Elizabeth II. At test, they were shown the objects and asked to select the related scenes. Both young and older adults showed better source memory in the self-referential condition than in the other-referential condition. Also, Rosa and Gutchess (2011) tested reality source memory for actions after young and older adults either placed different items in a suitcase or observed others (a stranger and a close other) performing the same actions. Both young and older adults were found to remember their own actions better than those performed by other people.

In some studies on internal sources (self-referential sources vs self-external sources), both young and older adults remember the self-referential sources better (Dulas, Newsome, & Duarte, 2011; Leshikar, Dulas, & Duarte, 2015; Hamami, Serbun, & Gutchess, 2011). For instance, in the study of Leshikar et al (2015), young and older adults encoded adjectives in two conditions: in the self-referential condition, they decided whether the adjectives described them and in the self-external condition, they decided whether the words were commonly used based on their own standards. At test, the participants took a remember/familiar/new recognition test, and for each word, they were also required to decide the sources (the task of self-descriptiveness or commonness). Both young and older adults showed higher subjective recollection and source accuracy for the self-referenced words. However, Kalenzaga and colleagues (2015) failed to observe the self-referential effect on internal source memory in older adults. In this study, young and older adults were instructed to engage in two tasks: 1) mentally recall personal events based on the cue word, and 2) complete sentences with words that first came to mind and imagine the event described by the sentences at the North Pole. Then they were asked to recall the cue words and indicate their related subjective feelings (remember, knowing and guessing) and the source (self or imagery) for each recalled word. The results showed that although self-reference enhanced the response rates of remembering in both groups, it did not improve the source memory of older adults compared to the imagery condition.

In contrast to source memory, only one study of older adults has investigated the effect of self-reference on associative memory (Cassidy & Gutchess, 2012). In this study, participants were asked to view pairs of faces and behaviors (described by a sentence), to form an impression about each behavior, and to make one of the following judgments: 1) whether the sentence describing the behavior contained any three-syllable words, 2) whether the behavior was common, or 3) whether they themselves ever did this behavior. It was found that both young and older adults remembered comparable face-impression pairs after deciding whether the behaviors described by the sentences were self-related and whether the behaviors were common. These two encoding conditions both yielded better performance than the condition where they decided whether the sentences contained three syllables. However, memory for the stimuli used in this study (face-impression associations) was not sensitive to aging or hippocampal damage (see Todorov & Olson, 2008 for evidence on patients with brain damage), suggesting that associative memory for such stimuli may be less MTL/H based than associative memory investigated in studies mentioned earlier.

Compared to studies on pairwise associations, very few studies have focused on the influence of self-reference on multi-element events. To our knowledge, only one study has investigated the effects of self-reference on multi-featural source memory in young adults (Leshikar & Duarte, 2012). In this study, participants encoded different objects paired with one of two scenes either self-referentially or self-externally. In the self-reference condition, the instruction was to judge whether the object-scene pairs were pleasant, and in the self-external condition people judged whether the object and scene in each pair shared a similar color. At retrieval, the task was to make item recognition judgments for the presented objects, and then to decide the related task sources (i.e., pleasantness or color judgments) and scene sources. It was found that source memory accuracy was greater when both sources were retrieved than when only one source was retrieved (e.g., higher accuracy for retrieving the task given that the scene was correctly retrieved, compared to retrieving the task given that the scene was not correctly retrieved), indicating memory dependency between the two sources. Furthermore, compared to self-external encoding, self-referential encoding increased the likelihood that both sources would be retrieved. However, given the emphasis on item-source associations and the intentional retrieval tasks in this study, it is hard to tell whether self-reference enhanced memory overall for complete events. Moreover, it remains unclear if self-reference can enhance memory for such complex events in older adults.

3. Self-reference and prior knowledge

A few studies have suggested that self-referenced memory can be modulated by congruency between incoming information and self-knowledge or a self-schema (Glisky & Marquine, 2009; Durbin, Mitchell, & Johnson, 2017; Grilli & Glisky, 2013). For example, in the study of Glisky & Marquine (2009), young and older adults encoded positive and negative trait words and made yes/no responses in the self-reference (SR), semantic and structural conditions. In the SR condition, participants judged whether the traits described themselves, in the semantic condition, they decided whether the traits were positive, and in the structural condition, participants were asked if the words were presented in upper case letters. Performance on a recognition test suggested that participants remembered more traits endorsed as ‘’yes” in both SR and semantic conditions, despite the equivalent advantage of self-reference over sematic processing for both responses. Notably, the age difference was eliminated for “yes” responses compared to “no” responses, indicating that self-congruency (as well as semantic congruency) may be especially beneficial for older adults. Similar yes/no effects were observed in Grilli & Glisky (2013), where both patients with memory deficits and healthy controls remembered more self-descriptive trait words compared to non-self-descriptive traits in a free recall test.

Relevantly, studies focused on more general knowledge also suggest that prior knowledge can facilitate memory in both young and older adults (Liu, Grady, & Moscovitch, 2016, 2018; Robin & Moscovitch, 2018; Smyth & Naveh-Benjamin, 2018; Castel, 2005; Amer, Giovanello, Grady & Hasher, 2018; Bonasia et al., 2018). For example, Liu and colleagues (2016) found that, compared to nonfamous face-house pairs, young adults remembered more face-house pairs when the faces were famous, presumably because famous faces elicited more prior knowledge. In another study, Robin & Moscovitch (2018) asked young and older adults to perform tasks including scene reconstruction, autobiographical retrieval and future imagination about real-world locations with which they were familiar and visited often. Although young adults showed better performance than older adults overall, both groups reported increased internal details (i.e., information that was directly associated with the events described, such as time, people and sensory perceptions) for locations that they considered to be more familiar. In some situations, as suggested by Smyth & Naveh-Benjamin (2018), prior knowledge may be especially beneficial for older adults (see also Glisky & Marquine, 2009 as noted above). In this study, the researchers compared associative memory for noun-noun, adjective-noun, and noun-adjective word pairs in both young and older adults. The age-related memory deficits were observed for noun-noun and noun-adjective word pairs but not for adjective-noun word pairs, which were in a linguistic structure more familiar in daily life. Furthermore, only older adults showed the benefits from the adjective-noun format. Although these findings suggest that information consistent with either self-knowledge or general non-self-knowledge is more memorable, it is less known if the congruence with self-knowledge would be more effective than general knowledge in facilitating memory.

4. The self-referential effects and neuropsychological functioning

One intriguing feature of self-reference strategies is that, in contrast to semantically-derived strategies, they might be less dependent on MTL/H binding functions. A few studies have explored the relation between self-reference and neuropsychological functioning, and the findings suggest that the self-reference effect (SRE, i.e., the difference between self-related performance and self-external or non-self-related performance) is relatively independent of executive and memory functioning (Glisky & Marquine, 2009; Grilli & Glisky, 2010, 2011; Grilli & McFarland, 2011). For example, in a study on associative memory (Grilli & Glisky, 2011), brain-injured patients with memory impairments studied object-location word pairs in four conditions: forming visual images, generating sentences, imagining oneself with the object in the location, and imagining another person with the object in the location. In the later cued-recall test, participants showed higher performance for the self-imagined word pairs than for those in other conditions. Correlational analyses showed that the self-imagination effect was not related to performance on executive functions, and there was a trend for brain-injured patients with lower memory ability (indicated by their General Memory Index scores from the WAIS-III; Wechsler, 1997) to show a larger SRE. In an earlier study on item memory in an aging population (Glisky & Marquine, 2009), older adults benefited from self-reference (compared to a semantic orienting task) to a similar level as young adults, and the SRE did not differ as a function of executive or memory functioning.

One possible reason for the null relation between the performance in the self-referential conditions and executive functioning, according to Glisky and Marquine (2009), is that the self-referential instructions given to participants are specific strategies, which can compensate for the inability of people with low executive functioning who may fail to initiate strategies at encoding. Self-reference, similar to other strategies (self-external strategies such as other-reference), may allow people with different levels of executive functioning to process information similarly.

In contrast, the self-referential conditions seems to recruit both basic memory and self-referential processes, which appear to be dissociable. As reviewed, although self-reference has been found to benefit both young and older adults equivalently, the age differences generally persist in the self-referential conditions (e.g., Leshikar & Duarte, 2014; Glisky & Marquine, 2009), suggesting that there are still age-related deficits attributable to basic memory processes. Further, older adults with high memory functioning also show higher levels of performance in the self-referential condition than those with low memory functioning, but equivalent self-reference effects (Glisky & Marquine, 2009). Thus, self-reference, compared to self-external processing, seems to bring add-on benefits to different groups.

Consistent with the findings that SRE is relatively independent from executive or memory functioning, studies with neuroimaging techniques suggest that self-reference is related to activities in cortical midline regions including medial PFC (mPFC) (e.g. Gutchess, Kensinger, & Schacter, 2007; Leshikar & Duarte, 2012, 2014), an area that is relatively unaffected by aging (Salat et al., 2004), and has been assumed to serve as a hub that integrates different kinds of information (Nieuwenhuis & Takashima, 2011, Liu, Grady, & Moscovitch, 2016). In studies on source memory, mPFC was found to mediate self-referential encoding in source memory, whereas the involvement of the hippocampus was observed less consistently (Leshikar & Duarte, 2012, 2014; Kalenzaga et al., 2015). For instance, Leshikar and Duarte (2012) found that for the self-referential condition, both mPFC and hippocampus were more activated for later successfully retrieved trials than those that were later forgotten. Further, Kalenzaga et al (2015) found that although both mPFC and hippocampus were more activated in the self-referential encoding, the activation of mPFC rather than hippocampus modulated later source accuracy. In another study (Leshikar & Duarte, 2014), the self-related subsequent source memory effect was found in mPFC but not hippocampus.

Relevantly, the self has been recently referred to as the “integrative glue”, which binds cognitive processes and different kinds of information together (Sui & Humphrey, 2015, 2016). Thus, it is possible that self-related processing may undertake some binding function that can work with the basic memory functioning mediated by MTL/H, and thereby enhance memory performance. However, it remains unclear if this hypothesized, self-related binding function is similar to the binding mediated by the hippocampus.

Given the reviewed findings from both behavioral and imaging studies, it is possible that self-reference can benefit older adults with different levels of executive or memory functioning in relational memory. However, investigation of the relation between self-referential effects on relational memory and neuropsychological functioning in older adults is lacking.

PURPOSE OF THE PRESENT RESEARCH

The following two studies were designed to provide further insight into issues related to the influence of self-reference on relational memory.

Study 1 investigated the influence of self-reference on internal source memory (i.e., two different encoding tasks) and associative memory (i.e., unique object-location pairs) in young and older adults. Given that investigation of the relation between self-referential effects on relational memory and neuropsychological functioning in older adults is lacking, we included a study sample in which comprehensive neuropsychological data were available, to assess whether the benefits of self-reference in older adults were related to memory or executive function.

Study 2 investigated the influence of self-reference on memory for multi-element events in young and older adults. This is the first study to our knowledge that sought to understand the effectiveness of self-reference on memory for complex events in older adults. Given the prior findings about the facilitation effects of prior knowledge on both self-related and non-self-related memory, we also considered the congruency between the events and prior knowledge, and compared the effectiveness of self-knowledge to more general, non-self-knowledge. To understand whether self-reference can benefit individuals with different memory functioning in young and older adults, we measured their performance in two additional memory tests (i.e., verbal test, visual test) as a proxy for memory ability. To understand the cognitive mechanisms of self-reference, especially whether self-related processing can undertake a binding function that is similar to that of the hippocampus, we compared memory coherence in self-related events and other-related events.

STUDY 1: THE EFFECT OF SELF-REFERENCE ON INTERNAL SOURCE MEMORY AND ASSOCIATIVE MEMORY IN YOUNG AND OLDER ADULTS

This study has been published in *Aging, Neuropsychology and Cognition*. For details, see APPENDIX A.

STUDY 2: THE EFFECT OF SELF-REFERENCE ON MEMORY FOR MULTI-ELEMENT EVENTS IN YOUNG AND OLDER ADULTS

1. Introduction

Building on the results from Study 1, Study 2 was designed to investigate the influence of self-reference on memory for multi-element events in young and older adults.

Compared to memory for pairwise associations, memory in our daily life is more complicated and may contain multiple elements. Although age-related deficits are also evident in memory for events with multiple features or elements (Chalfonte & Johnson, 1996; Kessels et al., 2007; Plancher et al., 2010; Sumida et al., 2016; Addis et al., 2014), strategies to enhance memory for such complex events have been less investigated. Findings from Study 1 imply that self-reference may benefit older adults in memory for multi-elements, given that both young and older adults showed improved memories for both the encoding tasks (i.e. imagination, sentence generation) and the locations related to the objects in self-referenced events compared to other-referenced events. However, since we focused only on one aspect (either the encoding task or the paired location) of each event, it is hard to tell if self-reference would have improved memory for the complete events. Therefore, Study 2 investigated the effectiveness of self-reference on memory for person-object-location events by measuring performance for the complete events, in addition to the within-event pairwise associations.

Some studies on self-reference suggest that the congruency between the encoded information and self-knowledge can modulate performance for self-referenced memory. For example, Glisky & Marquine (2009; also Grilli & Glisky, 2013) found that memory for self-descriptive trait words was better than memory for the non-self-descriptive trait words. Studies on more general knowledge also suggest information that is congruent with prior knowledge is more memorable (Liu et al., 2016, 2018; Robin & Moscovitch, 2018; Smyth & Naveh-Benjamin, 2018; Castel, 2005; Amer et al., 2018; Bonasia et al., 2018). It remains unclear, however, if congruence with self-knowledge would be more effective than general knowledge in facilitating memory. In Study 2, we included a measure of congruency between the encoded events and prior knowledge, including self-knowledge as well as non-self-knowledge, to understand the influence of prior knowledge on memory for multi-element events.

In Study 1, we observed that the benefits of self-reference in memory for pairwise associations were not limited by low executive or memory functioning in older adults. Considering the lack of correlation between memory performance and executive functions, we considered that the encoding tasks given to the participants constituted effective encoding strategies which eliminated the need for individuals with low executive functioning to initiate strategies spontaneously (Glisky & Maquine, 2009). With similar encoding tasks (i.e., self-imagination, other-imagination), in Study 2 we therefore focused on the relation between SRE and memory functioning in young and older adults, to understand whether self-reference can benefit individuals with different levels of memory ability in memory for more complex, multi-element events. Performance in each of two additional memory tasks was measured as a proxy for memory ability.

In addition, Study 2 sought to further understand the cognitive mechanisms of self-reference, particularly the possible binding function of self-referential processing. In

Study 1, we suggested that self-related processes may work with the binding processes mediated by MTL/H to enhance memory. However, the specific role of self-reference in relational memory remains unclear. A recent proposal about self-reference is that it binds different kinds of information and cognitive processes together (Sui & Humphrey, 2015, 2016). Relevantly, studies with neuroimaging measures indicate that mPFC, an area supposed to serve as a hub to integrate different kinds of information (Liu et al., 2016; Nieuwenhuis & Takashima, 2011), is also involved in the formation of self-referenced source memory. Together with the results from Study 1, these findings suggest that self-reference may provide a binding function in self-referenced relational memory. However, it is not clear if self-related binding is similar to the binding mediated by the hippocampus. In some recent studies on memory for multi-element events, the binding function of the hippocampus has been implicated in enabling the retrieval of coherent events, in which the retrieval outcomes of pairwise associations are statistically dependent (Horner & Burgess, 2013, 2014; Horner et al., 2015). To test whether self-reference increases memory coherence, Study 2 also compared memory coherence between self-referenced events and other-referenced events.

To address the aims mentioned above, in Study 2 we asked participants to imagine either themselves or one of two famous others (i.e., George Clooney or Oprah Winfrey) interacting with different objects in difference locations, and to decide the likelihood that each imagined event would happen, a measure of prior knowledge that is similar to those used in prior studies (e.g., Bonasia et al., 2018). We assumed that events judged as likely to happen would be more congruent with participants' knowledge about the persons they imagined. At the incidental retrieval phase in which links among elements within the same events were tested, we predicted that, for both young and older adults: 1) self-reference would enhance memory for pairwise associations as well as memory for complete events, 2) memory performance for events judged as likely to happen would be better than events judged as unlikely to happen, and 3) the SRE would be unrelated to memory functioning. Whether self-reference would increase memory coherence was an empirical question: If self-reference is involved in a binding function that is similar to the one mediated by the hippocampus, a higher level of memory coherence in the self-referential condition would be expected.

2. Methods

2.1. Participants

Participants included 36 young adults recruited from the research participant pool at the University of Arizona and 36 older adults from the community participated in the present study. Data from one additional older adult were excluded from analyses due to low performance (overall accuracy < .26). All participants signed the written consent forms approved by the University of Arizona Institutional Review Board.

Prior to the start of the experiment, participants received two tests of memory ability, one verbal and one visual. The verbal memory task consisted of 15 cue-target word pairs, 3 semantically related (e.g., rain-snow) and 12 unrelated (e.g., paint-ask). Each word pair was presented for 2.5 s at study, followed by a cued recall test. This study-test procedure was repeated for 3 trials. Word pairs and cues appeared in different random orders across trials. The visual memory test also consisted of 3 study-test trials. Participants studied 10 cue-target pairs of kaleidoscope patterns for 2.5 s, followed by a two-alternative forced-choice recognition test. At test, the cue kaleidoscope was presented along with two alternatives, one of which was the target kaleidoscope, and the other a previously unseen foil. Order of presentation was random and a different foil appeared with each target across trials. Participants also completed the Shipley Vocabulary test at the end of the experiment (Shipley, 1986).

Demographic information and performance on the vocabulary and memory tests are shown in Table 1. Older adults had more education, $t(70) = 11.20$, $p < .001$, $d = 2.64$, and higher vocabulary scores, $t(70) = 13.24$, $p < .001$, $d = 3.12$, than young adults. A 2 (Age: young, older) x 2 (Test: verbal, visual) mixed ANOVA on total memory scores across the three trials indicated that performance was better for young adults ($M = .61$) than older adults ($M = .54$), $F(1, 70) = 6.58$, $p = .012$, partial $\eta^2 = .09$, and for visual memory ($M = .67$) than for verbal memory ($M = .47$), $F(1, 70) = 69.50$, $p < .001$, partial $\eta^2 = .50$. The Age x Test interaction was not significant, $F < 1$ (See supplemental information for memory comparison among different trials).

Table 1. Demographics and performance on verbal and visual memory tests for young and older adults (standard deviation).

	Young	Older
n	36	36
Age	18.53 (.91)	79.19 (5.15)
Gender	21 F, 15 M	25 F, 11 M
Education	12.75 (.81)	17.25 (2.27)
Shipley Vocabulary	27.28 (4.06)	37.11 (1.83)
Verbal Memory Test	.51 (.18)	.44 (.16)
Visual Memory Test	.71 (.14)	.64 (.12)

2.2. Stimuli

Stimuli for the experimental task were 54 randomly-formed object-location word pairs. The object words were selected from the MRC Psycholinguistic Database (Coltheart, 1981), and the location words were selected from the SUN database (Xiao, Hays, Ehinger, Oliva, & Torralba, 2010), from Grilli and Glisky (2011), and from names of locations found online. The object words were rated as highly imageable (M=600.48) and concrete (M=603.56). The object-location word pairs were separated into 3 lists with matched imageability and concreteness based on ratings of the object words. These lists were rotated across three imagination conditions: reference to the self, George Clooney, or Oprah Winfrey. This combination created unique person-object-location triplets (e.g., Self-pencil-basement, George-cane-attic, Oprah-glove-campus).

2.3. Procedure

The imagination memory task consisted of an encoding phase, a delay, and an incidental memory test phase. At encoding, participants viewed 54 person-object-location word triplets, 18 for each referent: self, George and Oprah. Triplets were presented in six blocks of nine trials, blocked by the reference person. Presentation order of the 6 blocks was pseudo-randomized so that blocks from the same referent did not occur consecutively. Before each block, there was a short 8 s instruction indicating the reference person for that block. Each word triplet was shown for 7 s, during which participants were asked to close their eyes and imagine the person (i.e. self, George or Oprah) interacting with the object at the location, as vividly as possible until they heard a beep. They then saw a question, for example, "How likely is it that this event would happen to you (George/Oprah)?" along with four choices: "1 = highly unlikely, 2 =

somewhat unlikely, 3 = somewhat likely, 4 = highly likely”. Participants were required to press a key corresponding to one of the choices within 5s. After that, there was an interval of 1 s with a blank screen. Across participants, the sequence of person, object, location within the triplets was counterbalanced, and triplets in each block were shown in different randomized orders.

After encoding, there was a 10-min filled delay during which participants were engaged in a test of mental rotation that was not relevant to the experiment. Participants then read the instructions for the test phase and took practice trials.

The test phase included six blocks, across which the 54 imagined events were tested six times for a total of 324 trials. In each block, each triplet was tested once for one of six cue-target pairs: person cuing location, person cuing object, object cuing person, object cuing location, location cuing person, and location cuing object. Also, within each block, the six cue-target pair types occurred equally often (i.e., 9 times, 3 times for each reference condition). For each trial, participants were shown a cue word (e.g., pencil) at the top of the screen, and three choices (e.g., 1. basement 2. attic 3. campus) at the bottom of the screen, and were required to choose the related target word and press the corresponding key within 5 s. The two distractors had each been studied previously in different pairings in different referential conditions. The intertrial interval after each trial was 200 ms with a blank screen. The order of cue-target pairs for each event was counterbalanced across participants. Within each test block, the trial order was pseudo-randomized so that no more than three trials with the same cue-target type occurred consecutively.

2.4. Analysis of memory for complete events

Successful retrieval of complete events is defined as the situation in which each element successfully cues the other two elements, or when an element is successfully cued by the other two elements within the same event. For example, retrieval of a complete event is accomplished when a person cues both the related object and location, or when a person is successfully cued by the related object and location. There are therefore six possible conditions for each event to be retrieved: person as the cue, person as the target, object as the cue, object as the target, location as the cue and location as the target. Memory performance for complete events was calculated as the mean proportion of events in which retrieval was successful across all six conditions.

2.5. Analysis of memory coherence

Following prior studies (Horner & Burgess, 2013, 2014), we also calculated the statistical dependency in the data. Six 2 x 2 contingency tables were created in each reference condition for each participant. Each table represented the retrieval outcome for one element cueing the other two associated elements in the same event or the retrieval outcome when one element was cued by the other two associated elements. We calculated the proportion of events where both associations were correctly retrieved or incorrectly retrieved, and took the average proportion across the six tables (with two tables for each element) in each reference condition for each participant, as the final measure of dependency in the data (*D*). We also created the same number of contingency tables for an independent model, which predicts that the retrieval outcomes of associations within the same events are independent. Dependency in the independent model (*Di*) was calculated based on the mean accuracy for different types of associations across events (for an example, see Table 2). The presence of memory coherence is indicated if the dependency in the data is higher than dependency in the independent model.

Table 2. Contingency table for the independent model with element A cueing B and C

Retrieval of element C	Retrieval of element B	
	Correct (P_{AB})	Incorrect ($1- P_{AB}$)
Correct (P_{AC})	$\sum_{i=1}^{N} P_{AB} \times P_{AC}$	$\sum_{i=1}^{N} (1 - P_{AB}) \times P_{AC}$
Incorrect (1 - P_{AC})	$\sum_{i=1}^{N} P_{AB} \times (1 - P_{AC})$	$\sum_{i=1}^{N} (1 - P_{AB}) \times (1 - P_{AC})$

3. Results

The reference conditions for George and Oprah were combined as an Other-reference condition, since they did not differ significantly in any analysis of interest (ps > .122).

3.1. Memory for pairwise associations within events

Across the six memory tests for each event, we analyzed the memory performance for different pairs within events (i.e. person-object, object-location, person-location), collapsed across cue direction (e.g., person-object and object-person). Performance for the pairwise associations is shown in Table 3. (See supplemental information for performance split by the type of cue and target, and results about testing direction).

A mixed Age (2: young, older) x Reference (2: self, other) x Pair (3: person-object, person-location, object-location) ANOVA was conducted. Overall, young adults (M = .84) showed better performance than older adults (M = .64), $F(1, 70) = 43.95$, p <.001, partial η^2 = .39. Performance for pairs within the self-referenced events (M = .75) was better than those in the other-referenced events (*M* = .73), $F(1, 70) = 9.50$, $p = .003$, partial $\eta^2 = .12$. Also, there was a significant main effect of Pair, $F(2, 140) = 53.68$, $p < .001$, partial $\eta^2 = .43$. Pairwise comparisons showed that accuracy for the object-location pairs (*M* = .79) was higher than the person-object pairs (*M* = .72, $p < .001$) and the person-location pairs (*M* = .71, $p < .001$), which did not differ ($p = .793$). In addition, the three-way interaction of Age x Reference x Pair was marginally significant, $F(2, 140) = 2.99$, $p = .054$, partial $\eta^2 = .04$. We therefore conducted a Reference (2: self, other) x Pair (3: person-object, person-location, object-location) ANOVA for young and older adults, respectively.

For young adults, performance was better for pairs in the self-referenced events (*M* = .86) than the other-referenced events (*M* = .83), $F(1, 35) = 12.64$, $p = .001$, partial $\eta^2 = .27$. Also there was a main effect of Pair, $F(2, 70) = 36.52$, $p < .001$, partial $\eta^2 = .51$, with better performance for the object-location pairs (*M* = .90) than the person-object pairs (*M* = .81, $p < .001$) and the person-location pairs (*M* = .81, $p < .001$), which did not differ ($p = 1.000$). The Reference x Pair interaction was not significant, $F < 1$. Thus, memory was best for object-location pairs, but the self-reference effect was evident for all pair types.

For older adults, as in young, the main effect of Pair was significant, $F(2, 70) = 20.45$, $p < .001$, partial $\eta^2 = .37$, and performance was better for the object-location pairs (*M* = .69) than the person-object pairs (*M* = .62, $p = .001$) and the person-location pairs (*M* = .61, $p < .001$), which did not differ ($p = .520$). However, unlike young adults, there was no main effect of Reference, but a marginally significant Reference x Pair interaction, $F(2, 70) = 2.68$, $p = .076$, partial $\eta^2 = .07$, suggesting a self-reference effect only for the object-location pairs ($M_{self} = .71$ and $M_{other} = .66$, $p = .01$).

Table 3. Memory performance for pairwise associations (standard deviation).

		Young adults	Older adults
Self	Person-Object	.83 (.13)	.62 (.17)
	Person-Location	.83 (.13)	.61 (.17)
	Object-Location	.91 (.10)	.71 (.16)
Other	Person-Object	.80 (.14)	.62 (.16)
	Person-Location	.80 (.14)	.60 (.14)
	Object-Location	.89 (.11)	.66 (.17)

3.2. Memory for pairwise associations as a function of likelihood

We then considered whether memory performance was influenced by the likelihood that the imagined events would occur. In this analysis, the original four likelihood ratings were combined into two categories: high-L (ratings of highly likely and somewhat likely) and low-L (ratings of somewhat unlikely and highly unlikely).

An initial analysis indicated that there were no differences in likelihood responses as a function of age or reference, *F*s <1 (see Table 4). However, there was a significant main effect of Likelihood, $F(1, 70) = 8.13$, $p = .006$, partial $\eta^2 = .10$. Fewer events were endorsed as high-L ($M = .46$) than low-L ($M = .54$). We then looked at the possible effects of likelihood ratings on performance in our imagination memory task.

Table 4. Proportion of events rated as having high or low likelihood of occurring (standard deviation).

	Young		Older	
	High-L	Low-L	High-L	Low-L
Self	.48(.16)	.52(.16)	.45(.16)	.55(.16)
Other	.46(.12)	.54(.12)	.45(.10)	.55(.10)

Memory performance for pairwise associations for each likelihood rating is shown in Table 5. A follow-up mixed Age (2: young, older) x Reference (2: self, other) x Pair (3: person-object, person-location, object-location) x Likelihood (2: high-L, low-L) ANOVA confirmed all the main effects and interactions noted in the previous 3-factor analysis, but further suggested that these effects were only evident in high-L events. This analysis revealed a significant main effect of Likelihood, $F(1, 70) = 45.88$, $p < .001$, partial $\eta^2 = .40$, with overall higher performance for high-L pairs ($M = .77$) than low-L pairs ($M = .71$), and a significant three-way interaction of Likelihood x Reference x Pair, $F(2, 140) = 5.82$, $p = .004$, partial $\eta^2 = .08$. In addition, there was a marginally significant, four way interaction of Age x Reference x Likelihood x Pair, $F(2, 140) = 2.62$, $p = .077$, partial $\eta^2 = .04$.

To further understand the influence of likelihood on the self-reference effects, we focused on the Reference x Likelihood x Pair interaction in each age group.

For both groups, the self-reference effect (i.e., SRE) was evident only in the high-L events, although with different patterns. For young adults, the SRE was observed across all pair types (self: $M = .89$; other: $M = .84$, $p < .001$); for older adults, the SRE was significant only for the object-location pairs (self: $M = .77$; other: $M = .69$, $p = .007$), but not for person-object (for self, $M = .70$; for other, $M = .65$, p = .071), or person-location pairs (*p* = .213). No SRE was found in the low-L events for either group (*p*s > .182). (See supplemental information for complete results for each group).

These results thus suggest that self-reference can enhance memory for pair-wise associations within events that are rated as highly likely to occur in both young and older adults, although with different patterns: Young adults showed SRE in all pair types, older adults, however, only showed benefits for the object-location pairs.

Table 5. Memory performance for pairwise associations for each likelihood category (standard deviation).

		Young adults		Older adults	
		High-L	Low-L	High-L	Low-L
Self	Person-Object	.88 (.11)	.78 (.19)	.70 (.21)	.56 (.21)
	Person-Location	.85 (.11)	.78 (.18)	.62 (.22)	.59 (.19)
	Object-Location	.93 (.09)	.87 (.15)	.77 (.17)	.66 (.20)
Other	Person-Object	.80 (.14)	.79 (.15)	.65 (.18)	.58 (.18)
	Person-Location	.82 (.15)	.78 (.17)	.66 (.17)	.56 (.14)
	Object-Location	.89 (.11)	.87 (.14)	.69 (.19)	.63 (.19)

3.3. Memory for complete events

To understand if self-reference enhances memory for complete multi-element events (i.e., all six cue-target associations were retrieved for an event), we further compared memory performance for complete person-object-location events in the self-reference condition to the other-reference condition. Performance for each group and condition is shown in Table 6.

An Age (2: young, older) x Reference (2: self, other) x Likelihood (2: high-L, low-L) ANOVA was conducted on memory for complete events. We observed a main effect of Age, $F(1, 70) = 42.71$, $p < .001$, partial $\eta^2 = .38$, with young adults ($M = .73$) performing better than older adults ($M = .45$); of Reference, $F(1, 70) = 8.34$, $p = .005$, partial $\eta^2 = .11$, with better performance for the self-referenced events ($M = .61$) than the other-referenced events ($M = .57$), and of Likelihood, $F(1, 70) = 51.92$, $p < .001$, partial $\eta^2 = .43$, with better performance for the high-L events ($M = .63$) than low-L events ($M = .55$). There was a significant Age x Likelihood interaction, $F(1, 70) = 4.43$, $p = .039$, partial $\eta^2 = .06$, indicating that the difference between high-L and low-L events was larger in older adults ($M_{diff} = .11$, $p < .001$) compared to young adults ($M_{diff} = .06$, $p = .001$). Also, there was a Reference x Likelihood interaction approaching significance, $F(1, 70) = 3.55$, $p = .064$, partial $\eta^2 = .05$. Further analyses suggested that the SRE was evident for high-L events ($M_{diff} = .056$, $p = .001$) but not low-L events ($M_{diff} = .014$, $p = .386$). There was no 3-way interaction.

These results suggest self-reference enhances memory for complete, multi-element events that are likely to happen in both groups. Further, compared to young adults, older adults benefitted more than young adults when events were rated as likely to happen.

Table 6. Memory performance on complete events (standard deviation).

	Young			Older		
	Overall	High-L	Low-L	Overall	High-L	Low-L
Self	.75 (.17)	.80 (.14)	.70 (.21)	.46 (.20)	.52 (.23)	.41 (.22)
Other	.71 (.19)	.72 (.18)	.70 (.20)	.43 (.19)	.49 (.22)	.39 (.19)

3.4. Correlation between the self-reference effect and verbal and visual memory functioning

We calculated the self-reference effect (i.e. SRE) on memory for the complete events by subtracting performance in the other-reference condition from performance in the self-reference condition, and correlated this effect with the memory scores in both young and older adults. Since we observed a SRE in total events as well as specifically in high-L events, the correlational analyses were conducted separately.

Correlational results between memory performance for all events in different conditions and memory tests are shown in Table 7. SRE was not correlated with performance in either verbal or visual memory test in young and older adults. Across groups and referential conditions, memory performance was correlated with performance in the verbal memory test but not the visual memory test. Follow-up Steiger's z test indicated that the correlations between self-reference and verbal memory and other-reference and verbal memory did not differ in either young or older adults, *p*s > .488. Further, performance on the verbal memory and visual memory tests was not correlated in either young adults ($r = .25$, $p = .151$), or older adults ($r = .01$, $p = .972$).

Table 7. Correlations between performance for all complete events and memory score.

	Memory score	
	Verbal memory	Visual memory
Young (N = 36)		
SRE	-.17 (*p* = .319)	.11 (*p* = .510)
Self	.38 (*p* = .022)	.31 (*p* = .070)
Other	.43 (*p* = .009)	.24 (*p* = .168)
Older (N = 36)		
SRE	.13 (*p* = .453)	-.17 (*p* = .335)
Self	.63 (*p* < .001)	.12 (*p* = .477)
Other	.58 (*p* < .001)	.22 (*p* = .197)

We found similar results when only the high-L events were considered. For young adults, SRE was not correlated with verbal memory ($r = -.19$, $p = .279$) or visual memory ($r = .07$, $p = .667$). For older adults, SRE was not correlated with verbal memory ($r = .05$, $p = .764$) or visual memory ($r = -.20$, $p = .243$). Memory performance across conditions was correlated with performance in the verbal memory test but not the visual memory test in both young and older adults.

Thus, SRE was not related to memory functioning measured by either a verbal or visual memory test.

3.5. Memory coherence

We also investigated memory coherence for the multi-element events. Following the methods used in Horner and Burgess (2013, 2014), we calculated the dependency in the data (*D*) and the dependency (*Di*) in an independent model, where successful retrieval of individual pairs within events is assumed to be independent (see Methods). Coherent retrieval is indicated by higher dependency in the data than in the independent model (*D* > *Di*).

An Age (2: young, older) x Reference (2: self, other) x Measure (2: data, independent model) was conducted on the dependencies for the complete events regardless of likelihood (See Table 8). There was a main effect of Measure, $F(1, 70) = 79.30$, $p < .001$, partial $\eta^2 = .53$, indicating overall *D* ($M = .70$) higher than *Di* ($M = .67$), along with a main effect of Age, $F(1, 70) = 41.34$, $p < .001$, partial $\eta^2 = .37$ and Reference, $F(1, 70) = 7.42$, $p = .008$, partial $\eta^2 = .10$. The only significant interaction was Age x Measure, $F(1, 70) = 11.38$, $p = .001$, partial $\eta^2 = .14$ (For all others, *p*s > .245).

Further analyses suggested that the although *D* was higher than *Di* for both young ($M_{diff} = .02$, $p < .001$) and older adults ($M_{diff} = .04$, $p < .001$), the difference (*D* - *Di*) was larger for older adults than young adults, $t(70) = 3.37$, $p = .001$. However, it is possible that the difference was limited by the high performance in young adults, since *Di*, the baseline in the coherence analysis, scales with accuracy (An extreme example would occur if performance was perfect, making both *D* and *Di* equal to1, with a difference of 0). To control for the baseline dependency, we split each age group into two subgroups (i.e., high-*Di* vs. low-*Di*) based on the median overall *Di* (with self and other conditions collapsed). *Di* of older adults in the high-*Di* subgroup ($M = .65$) was roughly equal to *Di* of young adults in the low-*Di* subgroup ($M = .66$), $t(34) = .30$, $p = .763$, $d = .10$. A direct comparison of dependency difference (*D* - *Di*) suggested these two groups did not differ (for young adults, $M = .03$; for older adults, $M = .04$), $t(34) = .82$, $p = .417$, $d = .28$.

Table 8. Memory dependency for the data (D) and the independent model (Di) for each reference condition (standard deviation).

	Young adults		Older adults	
	D	*Di*	*D*	*Di*
Self	.79 (.12)	.77 (.13)	.63 (.11)	.58 (.11)
Other	.76 (.13)	.74 (.13)	.61 (.10)	.58 (.10)

When we took likelihood into consideration, results from Age (2: young, older) x Reference (2: self, other) x Likelihood (2: high-L, low-L) x Measure (2: data, independent model) ANOVA showed a similar pattern as above (See Table 9). The overall D (M = .70) was higher than *Di* (M = .68) across Age groups, reference conditions as well as likelihood. None of the interactions with Measure was significant, *p*s > .391, except an Age x Measure interaction that approached significance, $F(1, 70) = 3.55$, $p = .064$, partial $\eta^2 = .05$, indicating that although *D* was higher than *Di* for both young ($M_{\text{diff}} = .019$, $p < .001$) and older adults ($M_{\text{diff}} = .031$, $p < .001$), the difference (*D* - *Di*) tended to be bigger in older adults. However, when we controlled for the overall performance level, the dependency difference (*D* - *Di*) did not differ between young and older adults. (See supplemental information for results of full analyses on memory coherence split by likelihood).

Table 9. Memory dependency for the data (D) and the independent model (Di) for each reference condition and likelihood category (standard deviation).

		Young adults		Older adults	
		D	*Di*	*D*	*Di*
Self	High-L	.83 (.10)	.81 (.12)	.65 (.14)	.62 (.14)
	Low-L	.76 (.14)	.75 (.15)	.60 (.12)	.57 (.11)
Other	High-L	.77 (.13)	.75 (.14)	.65 (.14)	.61 (.13)
	Low-L	.76 (.13)	.73 (.14)	.59 (.09)	.56 (.09)

Thus, consistent with prior findings, our results suggest that memory for multiple elements within imagined events are dependent, regardless of the reference condition or likelihood category. When controlling for overall performance, young and older adults showed similar levels of coherence.

4. Discussion

In the present study, we investigated the effectiveness of self-reference on memory for person-object-location events in young and older adults. We found that self-reference increased memory for pairwise associations as well as complete three-element events in both groups. When likelihood of occurrence of the imagined events was taken into consideration, the self-reference effects were observed exclusively for the events rated as likely to occur. There was also an overall memory advantage for the higher-likelihood events, which was greater in older adults. Further, the observed self-reference effects were not correlated with memory functioning in either young or older adults. Retrieval of within-event associations showed a significant level of dependency, which did not differ as a function of age, reference condition, or likelihood category.

4.1. SRE in memory for multi-element events

We observed that self-reference enhanced memory for pairwise associations within the imagined events, but with different patterns for young and older adults. Although the benefits were evident for all associations (i.e., person-object, person-location, and object-location) in young adults, in older adults, the SRE was only observed for the object-location pairs. We consider these findings to be consistent with prior studies showing SRE in pairwise relational memory in young and older adults (Hou et al., 2017; Leshikar & Duarte, 2014; Rosa & Gutchess, 2011). However, we also note that self-reference does not necessarily benefit older adults in all situations. In our study, the persons (i.e., self and two others) were imagined repeatedly across events whereas the objects and locations were unique, making the associations of person-object and person-location less distinctive than the object-location association. Indeed, there was a consistent pattern of lower performance for person-object and person-location pairs than object-location pairs, across reference conditions and age groups. There may also have been interference from the imagination task. Since the encoding task we used involved imagining a scene, participants may have personalized the location even when George or Oprah were involved, making it more difficult to differentiate the person involved at retrieval. Interference from both sources may particularly reduce the self-reference effect in older adults, since prior research suggests that compared to young adults, older adults are more affected by increasing interference (Radvansky, Zacks, & Hasher, 1996).

As noted earlier, older adults show age-related changes in multi-element memory at both the behavioral and neural level (Addis et al., 2014; Foster et al., 2016). Although SRE has been evident in studies on item memory and relational memory, it is less known if self-reference can benefit older adults in multi-element memory tasks. Our findings fill in the gap and suggest that self-reference can enhance memory for person-object-location events via imagination in both young and older adults. Consistent with the prior study in young adults where self-reference was found to increase the retrieval of two source features (Leshikar & Duarte, 2012), our study further indicates that the effectiveness can extend to a more general situation, where all the associations within an event, not just the item-source associations, are considered. Taken together, our findings suggest that self-reference can facilitate memory for different associations and enable greater memory integrity in young and older adults.

4.2. Self-reference and prior knowledge

Across reference conditions, both young and older adults showed better performance for the events that were rated as likely to happen (i.e., high-L) compared to those rated as unlikely to happen (i.e., low-L), and this effect was greater in older adults in memory for complete events.

Our findings highlight the role of prior knowledge, including self-knowledge and more general knowledge, in modulating memory for incoming information. Studies on self-reference often include orienting questions to guide the participants to associate the to-be-remembered information with themselves (e.g., does this trait word describe you?), but only a few have investigated the memory difference between information endorsed as self-descriptive versus non-self-descriptive (Grilli & Glisky, 2013; Glisky & Marquine, 2009), where better performance has been observed for self-descriptive items. Together with these prior findings, our results suggest that congruency with self-knowledge can influence self-referenced memory and thus potentially contribute to the SRE. On the other hand, the memory advantage for the high-L events observed in the other-reference condition is consistent with observations in the literature on prior knowledge effects (e.g., Liu, Grady & Moscovitch, 2016; Smyth & Naveh-Benjamin, 2018; Bonasia et al., 2018), where the facilitation effect on memory has been observed for information that is congruent with existing general knowledge structures.

Consistent with our findings, a few studies have found that prior knowledge is especially beneficial to older adults (Badham, Hay, Foxon, Kaur & Maylor, 2016; Amer et al., 2018; Smyth & Naveh-Benjamin, 2018). For example, Badhan and colleagues (2016) found that the benefit of prior knowledge on memory for sentences describing person-consistent actions (e.g., “The pilot landed the aeroplane safely”) compared to person-neutral actions (e.g., “The teacher caught the train to London”), was greater in older adults than in young adults. These results indicate that older adults have relatively intact access to their knowledge base, and may be more reliant on existing knowledge when processing incoming information (Dennis, Kim & Cabeza, 2007). As a result, memory is supported for information that is consistent with existing knowledge, but may be hindered for information that is inconsistent with existing knowledge (Umanath & Marsh, 2014), leading to a bigger effect in older adults. Another related possibility is that the imagination task in our study enabled older adults to flexibly add distinct, plausible information to imagined scenarios, which later provided effective cues at retrieval. Indeed, when provided additional conceptual information to support memory for semantically-related word pairs, Badham et al. (2016) found that older adults benefitted more than young adults from information that was unique to each to-be-remembered pair relative to information shared by multiple pairs.

Although similar memory enhancement was observed in self- and other-reference conditions for the high-L events compared to the low-L events, extra benefit was associated with self-reference in memory for the high-L events. These findings reflect the higher effectiveness of self-knowledge over non-self-knowledge, and may indicate that the self is related to a richer knowledge base than general knowledge and is thus more powerful in supporting memory. Alternatively, the self may activate special memory processes, which might be dissociated from general knowledge-related memory processes. To our knowledge, no study has directly compared the neural mechanisms underlying self-reference and prior knowledge, although in separate studies, brain areas, such as mPFC and PCC, have been found to be relevant for both, (e.g., Leshikar and Duarte, 2014; Bonasia et al., 2018). However, different patterns of brain activation or connectivity might be observed through a direct comparison of the two conditions. Our paradigm might be helpful for future studies with behavioral and neural imaging measures to further understand the relation between processes associated specifically with the self and those linked more broadly to prior knowledge.

4.3. SRE and memory functioning

As reviewed before, the basic binding processes mediated by the hippocampus enable the formation of multi-element events, and thus contribute to the retrieval of the complete events as well as the within-event pairwise associations, which show dependent outcomes (Horner et al., 2015). However, we found that although higher performance for the complete events was observed in the self-reference condition, the magnitude of the SRE was not correlated with performance on verbal or visual memory tests in young or older adults. These results are consistent with our prior study on pairwise relational memory, suggesting that self-referential processing is independent of the basic memory functioning mediated by MTL/H, and thus can similarly benefit individuals with different levels of memory ability in the both young and older populations.

Despite the fact that the SRE has been found in many studies, the cognitive mechanisms underlying the SRE in memory remain unclear. A recent proposal is that the self can enhance binding of different stimuli, perhaps by acting as a glue to link external stimuli together (Sui & Humphreys, 2015, 2017; Sui, 2016). In Study 1, we also proposed that self-related processes may work with MTL/H, to strengthen the bonds among various aspects of information related to the self (Hou et al., 2017). However, whether the self is involved in a binding function similar to the one mediated by the hippocampus remains an untested possibility. Findings about memory coherence in the present study failed to support this idea. We reasoned that if the self-related processes supporting the observed SRE in memory for complete events were similar to the binding processes engaged by the hippocampus, we would see an enhanced memory dependency for the self-referenced events. However, we found a significant and equivalent level of dependency in self and other-reference conditions. Thus, self-related processing did not increase memory coherence. In addition, memory coherence in the two reference conditions may have arisen from the common binding processes mediated by the hippocampus, given that performance for the multi-element events in both conditions was similarly correlated with our verbal memory test, which is associative in nature and presumably hippocampal-dependent. This suggests that the hippocampus was similarly involved in the two conditions. The lack of correlation between memory for the multi-element events and the visual memory test may reflect the lack of meaningful associations between pairs of kaleidoscopes. It is possible on this test that performance was based more on item memory which may rely on MTL areas outside the hippocampus.

Taken together, these findings provide further support for the conclusion that self-referential processes are relatively independent of the basic memory processes mediated by MTL/H. Instead, the self-related enhancements in relational memory observed in prior studies and our present study, suggest that the self may be involved in a binding function that is dissociable from the one that contributes to memory coherence and is mediated by the hippocampus. Our findings are also consistent with neuroimaging studies in which mPFC has been identified during the formation of self-referenced relational memory (Leshikar & Duarte, 2012, 2014; Kalenzaga et al., 2015). Further, our results with regard to memory coherence provide indirect support for a recent proposal differentiating the binding mediated by mPFC and hippocampus (Moscovitch, Cabeza, Winocur & Nadel, 2016), which argues that the mPFC binds general information that is congruent with schemas (including self- and non-self-knowledge schemas), and is thus common to many similar events, while the hippocampus binds detailed information specific to a particular event. In this vein, self-related processing may be responsible for the binding of information that is consistent with self-knowledge generalized from similar self-experienced events, given that the SREs were only observed for the high-L events. In contrast, the hippocampus may bind the specific person-object-location events, and thus contribute to the coherence of the within-event elements. Future studies with neuroimaging measures are needed to understand how the hypothesized differential binding processes mediated by mPFC and hippocampus work together in supporting self-referenced memory.

In conclusion, we provide new evidence that self-reference can enhance memory for multi-element events rated as likely to happen in both young and older adults, and the benefits are not related to their memory ability. However, self-reference did not increase memory coherence. These findings highlight the importance of self-reference as a memory strategy in improving relational memory, and imply a self-related binding function that is different from the one mediated by the hippocampus.

GENERAL SUMMARY

The research presented in this dissertation suggests that self-reference can enhance relational memory in both young and older adults. Compared to other-reference, self-reference improved internal source memory and associative memory (Study 1) and memory for multi-element events (Study 2) in both age groups. Also, the benefit of self-reference was not limited by the low executive functions in older adults (Study 1) or memory ability in young and older adults (Study 1 and 2), indicating that self-reference is a viable strategy to improve relational memory in individuals with different levels of neuropsychological functioning.

The research contributes to understanding of the cognitive mechanism of self-reference. The lack of positive correlation between the observed SRE and memory functioning suggests that self-referential processing relies on a different mechanism than that associated with regions in the MTL/H, which mediates basic memory functioning. However, self-specific processing may work together with MTL/H to facilitate the binding processes and enhance relational memory, consistent with a recent proposal stressing the role of self-reference in binding. The hypothesized self-related binding, however, appeared to be functionally different from the hippocampally-mediated binding, given that compared to other-reference, self-reference did not increase memory coherence, a function previously associated with the hippocampus (Horner et al., 2015).

The research also suggests some boundaries on the effectiveness of self-reference. In Study 2, self-reference did not benefit older adults in remembering information under conditions of high interference. In addition, the self-reference effect was not observed for events that were incongruent with prior knowledge. More investigations on the mechanisms of self-reference would be helpful to determine in what situations self-reference is most likely to be beneficial.

LIMITATIONS AND FUTURE DIRECTIONS

One limitation of the presented studies is that the delays between encoding and subsequent memory tests were relatively brief (i.e., 2 minutes in Study 1, 10 minutes in Study 2). It is thus unclear if the SREs in relational memory would hold across longer intervals. In addition, although findings from Study 2 suggest that the effectiveness of self-reference may be affected by interference and congruence with self-knowledge, the potentially influential factors were not systematically investigated. Future studies should explore the duration of the SRE, and examine the factors that could influence the self-referenced memory to guide the application of this promising strategy.

Although the findings about SRE in this research converge with prior findings in neuroimaging studies, and support the idea that self-specific processes work with MTL/H in binding, the related brain activity was not measured. Further, given that this research provided preliminary evidence for differential binding functions mediated by the self-related areas of the brain and hippocampus, future studies with functional neuroimaging measures would be helpful to understand the respective roles of these regions, as well as their interactions in supporting the self-referenced relational memory.

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APPENDIX A: STUDY 1

Self-Reference Enhances Relational Memory in Young and Older Adults

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Abstract

The present study investigated the influence of self-reference on two kinds of relational memory, internal source memory and associative memory, in young and older adults. Participants encoded object-location word pairs using the strategies of imagination and sentence generation, either with reference to themselves or to a famous other (i.e., George Clooney or Oprah Winfrey). Both young and older adults showed memory benefits in the self-reference conditions compared to other-reference conditions on both tests, and the self-referential effects in older adults were not limited by low memory or executive functioning. These results suggest that self-reference can benefit relational memory in older adults relatively independently of basic memory and executive functions.

Key words: self-reference, aging, relational memory, source memory, associative memory

One challenge to older adults in daily life is to remember contextual information about certain events (e.g., "where did I put my keys?"), a type of memory known as relational memory. In the laboratory setting, relational memory has usually been studied using one of two paradigms: a source memory task in which many items are studied in the context of one of two sources (e.g., many words in one of two voices, a many-to-one mapping between items and voices), or an associative memory task in which unique pairs of items are presented (e.g., word-word pairs, in a one-to-one mapping). Older adults typically show deficits in both kinds of tasks (Hashtroudi, Johnson, & Chrosniak, 1989; Hashtroudi, Johnson, Vnek, & Ferguson, 1994; Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Old & Naveh-Benjamin, 2008a, 2008b for review; Swick, Senkfor, & Van Petten, 2006), highlighting the scope of difficulty with such memory demands.

Based on these and similar findings, Naveh-Benjamin (2000) proposed that older adults have a specific deficit in forming and retrieving links among different pieces of information, relative to their ability to remember the individual items—what he called the associative deficit hypothesis. Two possible factors have been considered to contribute to the associative deficits in older adults (Giovanello & Dew, 2015): 1) deficits in executive functions mediated by prefrontal cortex (PFC) (Moscovitch & Winocur, 1995), which are associated with decreased ability to initiate encoding strategies and monitor memory output at retrieval, and 2) deficits in binding, mediated by structures in the medial temporal lobes particularly the hippocampus (MTL/H; Ryan, Leung, Turk-Browne, & Hasher, 2007), which lead to an inability to integrate multiple elements into coherent events. Evidence for both factors has been found in behavioral studies (e.g., Craik, Morris, Morris, & Loewen, 1990; Glisky & Kong, 2008; Glisky, Polster, & Routhieaux, 1995; Glisky, Rubin, & Davidson, 2001; Henkel, Johnson, & De Leonardis, 1998; Siedlecki, Salthouse, & Berish, 2005). For example, Glisky and colleagues (2001) found that older adults with low executive functioning were impaired on source memory. In this study, older adults were grouped based on composite measures of executive function dependent on the frontal lobes (FL) and memory function based on the medial temporal lobes (MTL). Participants viewed multiple pictures of chairs (items) paired with one of two rooms (sources) at study, and were asked how comfortable each chair was. On the subsequent source memory test in which they had to remember in which room each chair had appeared, older adults with low FL scores performed worse than young adults, while older adults with high FL scores did not differ from young adults. Performance on the source test was not related to their memory scores. On the other hand, Henkel and colleagues (1998) observed a correlation between memory scores and source memory performance in older adults after delays of 15 minutes and 2 days, although scores from their frontal battery were also correlated with older adults' performance after the delay of 2 days.

Consistent with the behavioral results, functional neuroimaging studies of relational memory suggest there are age-related changes in both PFC and hippocampal activity, which are assumed to underlie the executive and binding functions, respectively (Addis, Giovanello, Vu, & Schacter, 2014; Dennis et al., 2008; Dulas & Duarte, 2011, 2014; Giovanello & Schacter, 2012; Kim & Giovanello, 2011). Focusing on source memory, Dulas and Duarte (2011) asked young and older adults to study words and pictures and decide whether the items were living or bigger than a shoebox. In later tests participants were instructed to indicate the tasks (sources) they used when studying the items. Compared to young adults, older adults showed smaller activation differences at encoding between later remembered and later forgotten sources (i.e., subsequent memory effects) in dorsolateral prefrontal cortex (DLPFC). In a later study, using objects as items and colors as sources, Dulas and Duarte (2014) again showed that older adults under-recruited lateral PFC during encoding of source, but also found weaker activations in the hippocampus at retrieval compared to young adults. Similarly, in an associative memory paradigm, Dennis and colleagues (2008) found that when encoding face-scene pairs that were subsequently remembered, older adults showed less activation in hippocampus and bilateral DLPFC than young adults. In a somewhat different paradigm, Addis and colleagues (2014) manipulated the semantic associations among to-be-encoded word triplets, and found that at encoding, young adults showed greater activation of ventrolateral prefrontal cortex (VLPFC) in the low-association trials (i.e., no semantic association among the triplets) relative to the high-association trials. This up-regulation of VLPFC, however, which might help with organization of the stimuli, was not observed in older adults. Although these findings are not entirely consistent, possibly because of the use of different materials and different paradigms, overall they suggest that changes in neural correlates of executive and binding functions are related to reduced relational memory in older adults. Compared to young people, older adults' executive functions mediated by PFC and binding functions mediated by hippocampus seem to be less efficient or under-recruited.

Despite the multiple potential contributors to this age-related memory decline, it has also been shown that providing associative memory strategies can enhance relational memory in older adults. Moreover, such environmental support is especially beneficial to individuals with low executive functions, who fail to initiate effective strategies. For example, Naveh-Benjamin, Bray, and Levy (2007) found that compared to an intentional encoding condition, older adults showed better associative memory performance in conditions where they were instructed to use a semantically-derived relational strategy (i.e., generating sentences of the to-be-remembered word pairs) during encoding and reminded to think back to the sentences they had generated earlier at retrieval. Similarly, in the previously mentioned study of Glisky and colleagues (2001), when participants were given an orienting task that related the pictures of chairs with the appropriate room (the sources), older adults with low executive functioning performed as well as young adults and older adults with high executive functioning in the source memory test. However, although low executive functioning may not limit the effectiveness of associative strategies, poor binding mechanisms might pose further difficulties. It is noteworthy that although Naveh-Benjamin and colleagues (2007) found that the age-related deficit in associative memory was substantially reduced by the use of a semantically-derived strategy at encoding and retrieval, it was not eliminated. This finding suggests that even in the face of good associative strategies, some older adults may have problems linking together aspects of content and context because of deficits in the binding function that is mediated by the MTL/H.

In addition to semantically-derived strategies, some recent studies suggest that self-reference, an associative strategy whereby people encode to-be-remembered information with reference to themselves (Rogers, Kuiper, & Kirker, 1977), also can enhance relational memory in older adults. For example, in the study of source memory by Leshikar and Duarte (2014), participants viewed multiple pictures of objects, each shown with one of three pictures of natural scenes, and made judgments about whether the object-scene pairs were pleasant either for themselves or for Queen Elizabeth II. At test, they were shown the objects and asked to select the related scenes. Both young and older adults showed better source memory in the self-referential condition than in the other-referential condition. Also, Rosa and Gutchess (2011) tested source memory for actions after young and older adults either placed different items in a suitcase or observed others (a stranger and a close other) performing the same actions. Both young and older adults were found to remember their own actions better than those performed by other people.

One intriguing feature of self-reference strategies is that, in contrast to semantically-derived strategies, they might be less dependent on MTL/H binding functions. A few studies have explored the relation between self-reference and neuropsychological functioning, and the findings suggest that the self-reference effect (SRE, i.e., the difference between self-related performance and self-external performance) is relatively independent of executive and memory functioning (Glisky & Marquine, 2009; Grilli & Glisky, 2010, 2011; Grilli & McFarland, 2011). For example, in a study on associative memory (Grilli & Glisky, 2011), brain-injured patients with memory impairments studied object-location word pairs in four conditions: forming visual images, generating sentences, imagining oneself with the object in the location, and imagining another person with the object in the location. In the later cued-recall test, participants showed higher performance for the self-imagined word pairs than for those in other conditions. Correlational analyses showed that the self-imagination effect was not related to performance on executive functions, and there was a trend for brain-injured patients with lower memory ability (indicated by their General Memory Index scores from the WAIS-III; Wechsler, 1997) to show a larger SRE. In an earlier study on item memory in an aging population (Glisky & Marquine, 2009), older adults benefited from self-reference (compared to a semantic orienting task) to a similar level as young adults, and the SRE did not differ as a function of executive or memory functioning. A handful of studies have investigated the SRE in older adults with mild cognitive impairment or dementia secondary to Alzheimer's disease. Here, the results have been mixed, with evidence both for (Leblond et al., 2016; Rosa, Deason, Budson, & Gutchess, 2016) and against (Rosa, Deason, Budson, & Gutchess, 2015; Rosa et al., 2016) an SRE in individuals with mild cognitive impairment. Moreover, the SRE appears to be less robust in individuals with Alzheimer's dementia (Genon et al., 2014; Hussey et al., 2012; Lalanne, Rozenberg, Grolleau, & Piolino, 2013, but also see Kalenzaga & Clarys, 2013). These findings may indicate that multi-domain cognitive impairment, including loss of semantic knowledge, may be necessary to compromise the effectiveness of self-reference.

Despite the insights gained from recent research on self-reference strategies, gaps still remain in our understanding of the effectiveness of such strategies in relational memory. Indeed, only one study of older adults has investigated the effect of self-reference on associative memory, a core subtype of relational memory (Cassidy & Gutchess, 2012). However, memory for the stimuli used in this study (face-impression associations) was not sensitive to aging or hippocampal damage (see Todorov & Olson, 2008 for evidence on patients with brain damage), suggesting that associative memory for such stimuli may be less MTL/H based than associative memory investigated in studies mentioned earlier. Moreover, according to the source monitoring framework (Johnson, Hashtroudi, & Lindsay, 1993), source memory can be divided into internal source monitoring (i.e., differentiation between two internally generated sources, such as saying vs. thinking), external source monitoring (i.e., differentiation between two externally presented sources, such as blue vs. red) and reality source monitoring (i.e., differentiation between an internally generated source and an externally presented source, such as saying vs. listening). Although self-reference has been found to benefit external and reality source memory, the influence of self-reference on internal source memory, however, remains less clear. In some studies, both young and older adults remember the self-referential sources better (Dulas, Newsome, & Duarte, 2011; Hamami, Serbun, & Gutchess, 2011; Leshikar, Dulas, & Duarte, 2015), whereas in others (e.g., Kalenzaga et al., 2015) older adults do not show the self-reference advantage.

In the current study, we sought to investigate the influence of self-reference on internal source memory (i.e., two different encoding tasks) and associative memory (i.e., unique object-location pairs) in young and older adults. Specifically, we made the source/associative distinction on the basis of the mapping (many-to-one mapping between object words and encoding tasks vs. one-to-one mapping between object words and location words), keeping the study materials constant (Van Petten, Luka, Rubin, & Ryan, 2002). Moreover, given that investigation of the relation between self-referential effects on relational memory and neuropsychological functioning in older adults is lacking, we included a study sample in which comprehensive neuropsychological data of executive and memory functioning were available. The hypotheses were: 1) both young and older adults would benefit from self-reference in internal source memory and associative memory; and 2) for older adults, the self-reference effect may be unrelated to executive function, but individuals with low memory function may benefit more from self-reference.

Methods

Participants

Forty older adults from the community and forty undergraduates recruited from the University of Arizona participated in the study. None of them reported a history of neurological or psychiatric disorders, learning disability, or a major illness that may affect their cognitive function. All participants signed the written consent forms approved by the University of Arizona Institutional Review Board.

All participants completed the Shipley Vocabulary test (Shipley, 1986). Older adults also had received a battery of neuropsychological tests (within the past two years, with the average interval of 10 months) from which were generated two composite z-scores, one reflecting executive function associated with the frontal lobes (FL) and the other reflecting memory function associated with the medial temporal lobes (MTL) (Glisky & Kong, 2008).

The tests included in the FL battery were the FAS verbal fluency task (Spreen & Benton, 1977), Modified Wisconsin Card Sorting Test (Hart, Kwentus, Wade, & Taylor, 1988), Backward Digit Span and Mental Control (Wechsler, 1997), and Mental Arithmetic (Wechsler, 1981). The tests included in the MTL battery were Logical Memory I, Verbal Paired Associates I, Faces I (Wechsler, 1997), Visual Paired Associates II (Wechsler, 1987) and Long-delay Cued Recall from the California Verbal

Learning Test (Delis, Kramer, Kaplan, & Ober, 1987). Participant characteristics are shown in Table 1. Compared to young adults, older adults had higher vocabulary scores and years of education.

Table 1.

Demographics and mean standardized neuropsychological test scores for young and older adults (standard deviation).

	Young	Older
n	40	40
Age	19.23 (2.21)	77.03 (6.12)
Gender	24F, 16M	26F, 14M
Education	13.33 (1.14)	17.15 (2.47)
Shipley Vocabulary	29.50 (3.15)	36.35 (2.61)
FL score	N/A	.15 (.56)
MTL score	N/A	.28 (.57)

Stimuli

Stimuli were 128 object-location word pairs. The object words were selected from the MRC Psycholinguistic Database (Coltheart, 1981), and had high concreteness and imageability ratings (M=603 for concreteness and M= 590 for imageability, respectively). The location words were selected from the SUN database (Xiao, Hays, Ehinger, Oliva, & Torralba, 2010), stimuli used in Grilli and Glisky (2011), and names of locations found online. The object words and location words were paired randomly and were separated into 4 lists of 32 object-location pairs (e.g. ring-waterfall, drum-mansion, and rose-driveway), which were matched on concreteness and imageability according to the ratings of the object words. Lists were rotated across four encoding conditions. Each word list was further divided into two sub-lists which were used in the later source memory test and associative memory test, respectively. Importantly, the study materials were the same for both the source and associative memory tests.

Procedure

Participants received a short introduction and practiced the study and test phases before the formal experiment. The experiment consisted of two blocks, one in which encoding was in reference to the self, and the other in which encoding was in reference to either George Clooney or Oprah Winfrey, depending on which celebrity was more familiar to the participants. In each block, there was a study and a test phase. At study, there were two encoding tasks both of which we expected would produce deep encoding but would be discriminable: sentence-generation and imagination. In the sentence generation tasks, participants were instructed to generate a sentence aloud about themselves or George/Oprah and the object in the location presented. In the imagination tasks, they were asked to imagine themselves or George/Oprah interacting with the object in the location. The 64 study trials in each of the two blocks (self vs. other) were presented continuously in 8 mini-blocks, alternating between the two encoding conditions, with four blocks of sentence-generation tasks and four blocks of imagination tasks. For each trial, participants saw a person-object-location word triplet presented on the screen, with the person shown at the top of the object-location pair. Also, there was a reminder (e.g., imagination, sentence) shown above the triplet. Duration for each trial was 10s, and there was a beep at the end as a signal for the next trial. After each trial, there was an inter-trial interval of 300 milliseconds with blank screen.

At the end of each set of 64 study trials, participants counted backwards by 3s for 2 minutes and were then reminded of the instructions for the test phase. There were two tests with half of the trials from each mini-block tested in source memory and half tested in associative memory in different random orders. In the source memory test, participants saw a series of 32 studied object words on the screen, and they were asked to respond how they had studied those words earlier: “imagination”, “sentence-generation” or “don’t know”. The “don’t know” alternative was included to reduce the probability of guessing. In the associative memory test, the other 32 studied object words were presented and participants were instructed to recall the location words presented with the object words at study, or respond “don’t know” if they could not remember. All responses were recorded by the experimenter. The order of imagination vs. sentence generation tasks was alternated at encoding; orders of self-reference vs. other-reference blocks, and source memory test vs. associative test were counterbalanced across the participants.

Results

Results of the source memory and associative memory tests were analyzed separately since the levels of performance across tests were not directly comparable; although in both cases, the object served as a cue for recall, there were just two alternatives in the source memory task, but 32 alternatives in the associative memory task.

Source memory

Performance of both age groups on source memory is presented in Table 2. In the top half of the table are the proportion of correct responses, incorrect responses, and don't know responses as a function of age, self-reference, and encoding task. A 2 (Age: young, older) × 2 (Reference: self, other) × 2 (Task: imagination, sentence) mixed analysis of variance (ANOVA) of the don't know responses indicated that the response rates of "don't know" differed between age groups, $F(1,78) = 15.77$, $p < .001$, partial $\eta^2 = .17$, but not between Reference or Task (*Fs* < 1). Older people made more "don't know" responses ($M = .12$) than young people ($M = .04$). There were no significant interactions (*p*s > .29). Further analyses therefore excluded the "don't know" responses and recalculated the proportion of correct and incorrect sources based on the total number of source responses that were made (cf., Dulas & Duarte, 2014). These responses appear in the bottom half of the table.

Following prior studies (Duarte, Henson, & Graham, 2011; Dulas & Duarte, 2014), we estimated source accuracy with *Pr* (*p*(correct source) – *p*(incorrect source)), which represents the discriminability of the two sources, with the "don't know" responses excluded. A mixed 2 (Age: young, older) × 2 (Reference: self, other) × 2 (Task: imagination, sentence) ANOVA on source *Pr* was conducted, and there was a significant main effect of Age, $F(1,78) = 42.09$, $p < .001$, partial $\eta^2 = .35$. Older people ($M = .50$) performed more poorly on the source memory task than young ($M = .82$). Also the main effect of Reference was significant, $F(1,78) = 6.66$, $p = .012$, partial $\eta^2 = .08$; performance in the self-reference conditions ($M = .69$) was higher than performance in the other-reference conditions ($M = .63$). The main effect of Task was not significant (*p* > .207) and there were no significant interactions among any of the variables (*p*s > .174).

Table 2.

Performance on source memory (standard deviation).

	Young				Older			
	Self		Other		Self		Other	
	Imagination	Sentence	Imagination	Sentence	Imagination	Sentence	Imagination	Sentence
				Response proportions				
Correct Source	.88 (.11)	.90 (.11)	.84 (.14)	.88 (.10)	.66 (.24)	.69 (.17)	.64 (.28)	.66 (.17)
Incorrect Source	.07 (.08)	.08 (.10)	.11 (.11)	.09 (.10)	.22 (.18)	.19 (.15)	.24 (.22)	.21 (.12)
Don't Know Source	.05 (.09)	.03 (.06)	.05 (.08)	.03 (.04)	.12 (.17)	.11 (.14)	.12 (.15)	.13 (.15)
				Source Proportions				
p(correct source)	.93 (.08)	.92 (.10)	.88 (.11)	.90 (.10)	.74 (.21)	.78 (.16)	.71 (.27)	.76 (.14)
p(incorrect source)	.07 (.08)	.08 (.10)	.12 (.11)	.10 (.10)	.26 (.21)	.22 (.16)	.29 (.27)	.24 (.14)
*Pr*_source accuracy	.86 (.17)	.84 (.19)	.76 (.22)	.81 (.20)	.49 (.42)	.57 (.31)	.43 (.54)	.52 (.27)

These results suggest that self-reference relative to other-reference can enhance the source memory for internal sources (i.e., imagination and sentence generation), in both older and young adults. Although the self-reference effects were numerically higher in the imagination condition (M = .08) than in the sentence condition (M = .03), there were no overall task effects, nor did task interact with the self/other variable. We also calculated the values of Cohen's d for the self-reference effect for both groups. The effect size was medium in young adults (d = .550) and was small in older adults (d = .212), which may be related to the high variability in performance of older adults.

We then looked to see whether SRE in the older adults was related to the neuropsychological measures of memory (MTL) and executive functions (FL) (see Table 3). The SRE was computed as follows: self-reference *Pr* minus other-reference *Pr*, collapsed across imagination and sentence generation. Correlational analyses indicated that the SRE was correlated significantly with MTL scores (r = -.37, p = .018), but not with FL scores (r = .16, p = .34). Note that the former correlation is negative, indicating that the SRE was greater in people with poorer memory functioning. Further, source accuracy (*Pr*) was correlated with MTL scores in both self- and other-imagination conditions (r = .32, p = .043, r = .54, p < .001, respectively). Follow-up Steiger's z test indicated that the correlation between other-imagination and MTL scores was stronger than the correlation between self-imagination and MTL scores, Z = 2.16, p = .03. Overall performance in self- and other-sentence generation conditions was not related to MTL scores (r = .09, p = .58 for self-sentence generation; r = .17, p = .30 for other-sentence generation). Performance was not related to FL scores in any of the conditions (ps > .30).

Table 3.

Correlations between memory performance and neuropsychological functioning in older adults.

		Neuropsychological functioning	
		MTL score	FL score
Source memory			
SRE		$-.37^{*}$	.16
Self	Imagination	$.32^{*}$	.15
	Sentence	.09	.17
Other	Imagination	$.54^{**}$	.12
	Sentence	.17	-.07
Associative memory			
SRE	Imagination	-.01	.12
	Sentence	-.19	.04
Self	Imagination	$.47^{**}$	.01
	Sentence	$.54^{**}$	.15
Other	Imagination	$.48^{**}$	-.07
	Sentence	$.69^{**}$	.13

Note. * $p < .05$; ** $p < .01$.

Associative memory

Performance of both age groups on associative memory is presented in Table 4. A 2 (Age: young, older) × 2 (Reference: self, other) × 2 (Task: imagination, sentence) mixed ANOVA was conducted on the proportion of correct responses. There was a main effect of Age, $F(1,78) = 42.40$, $p < .001$, partial $\eta^2 = .35$. Older people ($M = .31$) performed more poorly on the associative memory task than young ($M = .58$). Also, the main effect of Reference was significant, $F(1,78) = 19.25$, $p < .001$, partial $\eta^2 = .20$, with performance in the self-referential conditions ($M = .48$) better than that in the other-referential conditions ($M = .41$). There was no main effect of Task, $F < 1$. However, the Reference × Task interaction was significant, $F(1,78) = 5.72$, $p = .019$, partial $\eta^2 = .07$. Further analyses showed that although the SRE was significant in both tasks, the size of the effect was greater in the imagination task ($M = .09$, $p < .001$) than in the sentence generation task ($M = .04$, $p = .042$). None of the interactions with age were significant (ps >.26). Further, the effect size of self-reference was close to medium in the two groups ($d = .525$ and $d = .487$ for young adults and older adults, respectively).

Table 4.

Proportion of correct responses in associative memory tasks (standard deviation).

	Young		Older	
	Self	Other	Self	Other
Imagination	.62 (.22)	.51 (.24)	.35 (.22)	.27 (.21)
Sentence	.60 (.20)	.57 (.20)	.34 (.23)	.30 (.23)

Because Task interacted with Reference, correlational analyses between SRE (self-referential performance – other referential performance) and neuropsychological measures were conducted separately for imagination and sentence generation conditions (see Table 3). In neither condition was the SRE significantly correlated with MTL scores (for imagination, $r = -.01$, $p = .93$; for sentence generation, $r = -.19$, $p = .24$). Similarly, neither task was correlated with FL scores ($r = .12$, $p = .45$; $r = .04$, $p = .83$ for imagination and sentence generation, respectively).

Further correlational analyses between overall memory performance in each task and neuropsychological measures indicate performance in all tasks was related to MTL scores (for self-imagination, $r = .47$, $p = .002$; for other-imagination, $r = .48$, $p = .002$; for self-sentence generation, $r = .54$, $p < .001$; for other-sentence generation, $r = .69$, $p < .001$). Follow-up Steiger's z tests indicated that the correlation between self-imagination and MTL was not significantly weaker than the correlation between other-imagination and MTL ($Z = -.12$, $p = .90$), nor was the correlation for the self-sentence generation significantly weaker than other-sentence generation ($Z = -1.61$, $p = .11$). Performance was not correlated with FL scores on any of the tasks (ps $> .34$).

Discussion

Several prior studies have indicated that relational memory, both source and associative, declines in normal cognitive aging, but relatively few studies have explored ways to reduce or compensate for that decline. In the present study we investigated the possible role of self-referential processing for enhancing relational memory in young and older adults. There were three main findings: 1) Both age groups benefitted from self-referential processing on internal source memory and associative memory, and although younger adults outperformed older adults, self-reference had benefits for both age groups; 2) For older adults, the advantage of self-reference over other reference (i.e., the SRE) was not limited by low MTL/H function or executive function, although memory performance on both tests was correlated with MTL/H function; and 3) The SRE was greater following imagination than sentence generation, although this effect was significant only in the associative memory test. These findings and their potential implications are discussed in greater detail below.

Self-reference effect (SRE) in relational memory

In regard to internal source memory in young and older adults, we found that compared to other-reference, self-reference enhanced the ability to discriminate between two internal sources—imagination and sentence generation— in both age groups. The SRE found in our current study is consistent with findings in prior studies in which participants showed higher source accuracy in self-referential conditions than in self-external conditions (e.g., Dulas et al., 2011; Hamami et al., 2011; Leshikar et al., 2015). In those prior studies, however, the self was always one of the sources. In our study, the source manipulation was nested within the self-other variable such that the required discrimination was between two internal sources, within both the self and other conditions. This allowed us to avoid the possible confounding of self-bias (a tendency to choose the "self" compared to other sources) (Leshikar et al., 2015). In contrast to our findings, however, Kalenzaga and colleagues (2015) did not observe a SRE on internal source memory in older adults. It is not clear what accounts for the different outcomes, given that there were many differences between the two studies. Materials, encoding tasks, and retrieval tasks were all more complex in the Kalenzaga and colleagues (2015) study. In particular, the encoding tasks for the self and non-self conditions were both very elaborate and shared many processes. This may have made the discrimination between sources particularly difficult for older adults.

On the associative memory test, we also found benefits in both young and older adults for self-reference. These results build on the prior study that demonstrated a positive SRE for face-impression associations (Cassidy & Gutchess, 2012). Moreover, our results go further and indicate that the effectiveness of self-reference is evident in situations where the mapping of elements within events is unique (i.e. one-to-one mapping) as well as where the mappings are overlapping (i.e. many-to-one mapping). Taken together, these results, along with those of prior studies, provide support for the notion that self-referential strategies can be flexibly applied to enhance relational memory among older adults, as evidenced by their effectiveness under distinct mnemonic demands (i.e., source versus associative) and materials (i.e., verbal and non-verbal).

Self-reference and neuropsychological functioning in older adults

Consistent with prior research on associative strategies, in the present study, the SRE was unrelated to FL scores, suggesting that self-related processes operate relatively independently of the processes supporting executive functions (Glisky et al., 2001). This is also in line with findings from some functional neuroimaging studies showing different neural correlates associated with self-referential processing (e.g., medial PFC) and executive functions (e.g., DLPFC) (Gutchess, Kensinger, & Schacter, 2007; Jurado & Rosselli, 2007). Interestingly, we did not find significant correlations between executive function and performance in any encoding conditions for either memory task. One possible reason for the null findings with respect to memory performance, is that the associative tasks given to the participants (i.e., imagination and sentence generation), constituted particularly effective encoding strategies, eliminating the need for people with low executive functioning to initiate strategies spontaneously (Glisky & Marquine, 2009).

We also found no positive relation between the SRE and MTL/H function in either memory test. In fact, on the source memory task, we found a negative correlation such that those with overall poorer memory function showed a larger SRE (see also Grilli & Glisky, 2010). This negative correlation was attributable to the fact that participants with better memory functioning performed at a higher level in the other-reference tasks, leaving less room for improvement from self-reference. They therefore showed smaller SREs than those with poorer memory function. A lack of positive correlation was previously observed by Marquine and Glisky (2009) in an item memory task, where it was found that the additional benefit of self-referential processing over and above semantic processing was unrelated to MTL/H function. On the other hand, we found that basic memory function was positively correlated with memory performance on both source and associative tests in all conditions except sentence generation in source memory. The involvement of MTL/H function in relational memory has been observed many times both in source memory tasks (Dulas & Duarte, 2011, 2014) and in studies of associative memory (e.g., Dennis et al., 2008; Tsukiura et al., 2011; for review, see Giovanello & Dew, 2015). Together these findings suggest that self-referential processing engages both basic memory functions mediated by MTL/H, and additional self-specific processes that may work with MTL/H to enhance memory.

Recently, the self has been referred to as the “integrative glue”, which helps to bind together different kinds of information and different processing stages (Sui & Humphreys, 2015, 2016). In a similar vein, functional neuroimaging studies have suggested that self-referential encoding in source memory is mediated by brain areas including medial PFC (Kalenzaga et al., 2015; Leshikar & Duarte, 2012, 2014), which may serve as a hub that integrates different kinds of information (Liu, Grady, & Moscovitch, 2016; Nieuwenhuis & Takashima, 2011). It is possible that the mPFC and/or other midline areas involved in self-referential processing (e.g., precuneus) work together with MTL/H to facilitate the binding processes involved in episodic memory (Diana, Yonelinas, & Ranganath, 2007; Mayes, Montaldi, & Migo, 2007), particularly in the context of self reference (Morel et al., 2014; Yamawaki et al., 2017). In the present study, it is possible that the engagement of these self-related brain regions may have reduced the demands of binding on MTL/H, such that performance of older adults was less dependent on basic memory functioning in the self-reference condition compared to the other-reference condition. A few functional neuroimaging studies shed further light on this point (Kalenzaga et al., 2015; Leshikar & Duarte, 2014). For example, Kalenzaga and colleagues (2015) found that although both mPFC and hippocampus were more activated in self-referential encoding, the activation of mPFC rather than hippocampus was related to later source accuracy. However, since brain activity was not measured in our study, further investigations with neuroimaging methods are needed to better understand the interaction between self-related regions and MTL/H.

Imagination versus sentence generation

It is noteworthy that in the associative memory task, we found a larger SRE following imagination than sentence generation. A benefit of self-imagination compared to other encoding tasks is consistent with the finding of Grilli and Glisky (2011), who observed a similar advantage for self-imagination on an associative memory test in brain-injured patients with memory impairments. In the present study, imagining a scene with three components (person, object, and location) may have created a unitized representation with all elements well-integrated. Further, when the self rather than another person is part of the memory, it may be better elaborated and have more emotional content. This could account for the SRE in the imagination conditions (Cabeza & Jacques, 2007; Grilli & Glisky, 2011). In the sentence generation task, however, participants may have formed adjacent links among person, object, and location in a more unidirectional way. Since participants generated the sentences aloud during study, we were able to observe that, in most of them, the word triplets followed the order of person-object-location. Thus, in the associative memory test, although an object may have served as a good cue for location, the link between the person and the location may be weaker. This phenomenon has been demonstrated by Horner and colleagues (Horner & Burgess, 2014), who showed that events encoded as an open chain of associations exhibited low multi-element dependency, compared to those encoded as a unitary image. Thus, retrieval of location following sentence generation would be less likely to activate the person thereby contributing to a reduced SRE. In the source memory test, however, where people were queried about internal processes, person information was also likely to be accessed, and so benefits of the self were observed following both encoding tasks.

We should also note that we did not observe a significant correlation between the memory composite score and performance on the source memory test in the sentence generation condition (although the correlation was seen on the associative test). We do not know exactly why MTL/H function was less relevant in this case. However, we speculate that people might have based source memory judgments following sentence generation on the absence of perceptual detail in the trace. In associative memory, however, where retrieval of a specific detail is required, MTL/H would be expected to be involved (Moscovitch, Cabeza, Winocur, & Nadel, 2016).

Implications

Although there is a large volume of research on relational memory and aging, the influence of self-reference on relational memory, especially internal source memory and associative memory, is relatively understudied. The present study demonstrates that self-reference can benefit both internal source memory and associative memory in young and older adults. One practical implication of our results is that self-reference may be a useful strategy to improve relational memory of older adults, especially individuals with low executive and/or memory functioning. As reviewed, executive functions and memory functioning have been assumed to play important roles in relational memory, and age-related changes in these functions may contribute to decreased memory performance in older adults. However, given the relatively independent relation between SRE and executive functions and the negative correlation between SRE and memory functioning, we consider that the strategy of self-reference might benefit the aging group as a whole and may be a viable way to improve relational memory in some individuals with low neuropsychological functioning.

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APPENDIX B: SUPPLEMENTAL MATERIALS FOR STUDY 2

Table S1. Performance for verbal and visual memory test (standard deviation).

	Young	Older
Verbal Memory Test		
trial 1	.27 (.16)	.30 (.14)
trial 2	.54 (.21)	.44 (.17)
trial 3	.71 (.24)	.58 (.20)
Visual Memory Test		
trial 1	.66 (.20)	.53 (.19)
trial 2	.71 (.15)	.65 (.14)
trial 3	.75 (.16)	.72 (.13)

A 2 (Age: young, older) x 2 (Test: verbal, visual) x 3 (Trial: 1st, 2nd, 3rd) mixed ANOVA was conducted on the memory performance. The main effects of Age, Test and Trial were significant [for Age, $F(1, 70) = 6.58$, $p = .012$, partial $\eta^2 = .09$; for Test, $F(1, 70) = 69.50$, $p < .001$, partial $\eta^2 = .50$; for Trial, , $F(2, 140) = 196.15$, $p < .001$, partial $\eta^2 = .74$]. Performance was better for young adults ($M = .61$) than for older adults ($M = .54$), and better for visual memory test ($M = .67$) than for verbal memory test ($M = .47$). Also, performance was higher for the 3rd trial ($M = .69$) than the 1st ($M = .44$, $p < .001$) and 2nd trial ($M = .59$, $p < .001$), and higher for the 2nd trial than the 1st trail, $p < .001$. There was a significant Test x Trial interaction $F(2, 140) = 35.30$, $p < .001$, partial $\eta^2 = .34$, as well as a three-way interaction of Age x Test x Trial, $F(2, 140) = 12.83$, $p < .001$, partial $\eta^2 = .16$. We thus conducted a 2 (Test: verbal, visual) x 3 (Trial: 1st, 2nd, 3rd) ANOVA in each group.

For young adults, both main effects of Test and Trial were significant [for Test, $F(1, 35) = 34.65$, $p < .001$, partial $\eta^2 = .50$; for Trial, $F(2, 70) = 102.63$, $p < .001$, partial $\eta^2 = .75$]. Performance was better for visual test ($M = .71$) than for verbal test ($M = .51$), and increased from the 1st trial to the 3rd trial (for the 1st trial, $M = .47$; for the 2nd trial, $M = .62$; for the 3rd trail, $M = .73$; for all the pairwise comparisons, *p*s < .001). The Test x Trial interaction was significant, $F(2, 70) = 38.09$, $p < .001$, partial $\eta^2 = .52$. For verbal memory test, the performance increased from the 1st trial to the 3rd trial, *p*s < .001. For visual memory test, the performance was higher for the 3rd trial than the 1st trail, $p = .021$, but there was no difference between the first two trials or the last two trials (*p*s > .400).

Similarly, for older adults, both main effects of Test and Trial were significant [for Test, $F(1, 35) = 34.86$, $p < .001$, partial $\eta^2 = .50$; for Trial, $F(2, 70) = 93.65$, $p < .001$, partial $\eta^2 = .73$]. Performance was better for visual test ($M = .64$) than for verbal test ($M = .44$), and increased from the 1st trial to the 3rd trial (for the 1st trial, $M = .42$; for the 2nd trial, $M = .55$; for the 3rd trail, $M = .65$; for all the pairwise comparisons, *p*s < .001). The Test x Trial interaction was significant, $F(2, 70) = 3.97$, $p = .023$, partial $\eta^2 = .10$. For verbal memory test, the performance increased from the 1st trial to the 3rd trial, *p*s < .001. For visual memory test, the performance for the 3rd trial was higher than the 1st trial, $p < .001$, and was marginally higher than the 2nd trial, $p = .058$, performance for the 2nd trial was higher than 1st trial, $p = .001$.

Table S2. Memory performance for pairwise associations (standard deviation).

Cue type		Retrieval type					
		Person		Object		Location	
		Young	Older	Young	Older	Young	Older
Self							
	Person	n/a		.86 (.12)	.63 (.20)	.83 (.15)	.63 (.18)
	Object	.81 (.16)	.62 (.18)	n/a		.91 (.11)	.74 (.16)
	Location	.83 (.14)	.59 (.20)	.91 (.12)	.68 (.18)	n/a	
Other							
	Person	n/a		.82 (.14)	.65 (.15)	.82 (.15)	.61 (.16)
	Object	.77 (.15)	.59 (.17)	n/a		.89 (.11)	.65 (.17)
	Location	.78 (.14)	.60 (.14)	.89 (.13)	.67 (.19)	n/a	
George							
	Person	n/a		.81 (.16)	.64 (.17)	.81 (.16)	.61 (.18)
	Object	.76 (.14)	.58 (.21)	n/a		.90 (.11)	.64 (.20)
	Location	.78 (.13)	.61 (.18)	.89 (.14)	.67 (.21)	n/a	
Oprah							
	Person	n/a		.84 (.14)	.65 (.17)	.82 (.17)	.61 (.17)
	Object	.78 (.17)	.60 (.16)	n/a		.88 (.12)	.65 (.18)
	Location	.78 (.19)	.59 (.17)	.88 (.14)	.68 (.20)	n/a	

Table S3. Memory performance on pairwise associations split by likelihood (standard deviation).

Cue type		Retrieval type					
		Person		Object		Location	
		Young	Older	Young	Older	Young	Older
High-L							
Self							
	Person	n/a		.89 (.13)	.67 (.25)	.85 (.14)	.62 (.22)
	Object	.86 (.14)	.73 (.22)	n/a		.94 (.09)	.78 (.18)
	Location	.86 (.14)	.62 (.25)	.92 (.12)	.76 (.22)	n/a	
Other							
	Person	n/a		.83 (.16)	.69 (.17)	.83 (.15)	.66 (.19)
	Object	.77 (.15)	.61 (.21)	n/a		.89 (.09)	.65 (.20)
	Location	.80 (.17)	.67 (.16)	.89 (.15)	.72 (.19)	n/a	
George							
	Person	n/a		.81 (.20)	.69 (.22)	.86 (.17)	.65 (.25)
	Object	.74 (.19)	.60 (.27)	n/a		.90 (.10)	.64 (.23)
	Location	.80 (.20)	.68 (.22)	.89 (.17)	.73 (.23)	n/a	
Oprah							
	Person	n/a		.85 (.16)	.69 (.19)	.81 (.18)	.67 (.20)
	Object	.81 (.17)	.63 (.20)	n/a		.88 (.13)	.66 (.25)
	Location	.80 (.20)	.66 (.17)	.89 (.18)	.72 (.21)	n/a	
Low-L							
Self							
	Person	n/a		.81 (.18)	.58 (.24)	.79 (.21)	.62 (.24)
	Object	.76 (.24)	.55 (.23)	n/a		.85 (.19)	.72 (.23)
	Location	.79 (.18)	.56 (.24)	.89 (.17)	.60 (.24)	n/a	
Other							
	Person	n/a		.81 (.17)	.61 (.18)	.80 (.18)	.58 (.17)
	Object	.76 (.17)	.56 (.20)	n/a		.88 (.15)	.63 (.19)
	Location	.76 (.17)	.54 (.16)	.86 (.15)	.63 (.22)	n/a	
George							
	Person	n/a		.79 (.20)	.60 (.19)	.79 (.20)	.59 (.18)
	Object	.78 (.15)	.55 (.24)	n/a		.89 (.16)	.60 (.25)
	Location	.77 (.19)	.54 (.20)	.86 (.18)	.61 (.28)	n/a	
Oprah							
	Person	n/a		.83 (.20)	.62 (.24)	.82 (.20)	.57 (.22)
	Object	.75 (.22)	.57 (.22)	n/a		.86 (.18)	.65 (.19)
	Location	.75 (.22)	.54 (.22)	.86 (.16)	.66 (.24)	n/a	

Memory for pairwise associations with the opposite testing directions

We conducted a 2 (Age: young, older) x 2 (Reference: self, other) x 6 (Task: person cuing object, person cuing location, object cuing person, object cuing location, location cuing person, location cuing object) ANOVA, and observed significant main effects of Age, Reference and Task [for Age, $F(1, 70) = 43.95$, $p <.001$, partial $\eta^2 = .39$; for Reference, $F(1, 70) = 9.48$, $p = .003$, partial $\eta^2 = .12$; and for Task, $F(5, 350) = 37.49$, $p < .001$, partial $\eta^2 = .35$]. There was also a marginally Reference x Task interaction, $F(5, 350) = 2.10$, $p = .066$, partial $\eta^2 = .03$ and a significant Age x Reference x Task interaction, $F(5, 350) = 2.99$, $p = .012$, partial $\eta^2 = .04$. We thus conducted a 2 (Reference) x 6 (Task) ANOVA in each group.

For young adults, we observed significant effects of Reference [$F(1, 35) = 12.64$, $p =.001$, partial $\eta^2 = .27$] and Task [$F(5, 175) = 27.19$, $p < .001$, partial $\eta^2 = .44$]. In the follow-up pairwise comparisons where we were focused on pairs with opposite directions, we did not observe difference between the opposite directions for the person-location or object-location pairs (*p*s > .914). For person-object pairs, performance for person cuing object was better than object cuing person ($p < .001$). However, the Reference x Task interaction was not significant, $F < 1$, suggesting similar patterns on testing directions between the self and other-reference conditions.

For older adults, there was a significant main effect of Task, $F(5, 175) = 13.79$, $p < .001$, partial $\eta^2 = .28$, as well as a significant Reference x Task interaction, $F(5, 175) = 3.53$, $p = .005$, partial $\eta^2 = .09$. Further analyses suggested that for the self-reference condition, tasks with the opposite directions did not differ, *p*s > .144. For the other-reference condition, performance for person cuing object was higher than object cuing person, $p = .002$. No significant difference was observed for the other two pairs, $ps > .601$. Two direct comparisons suggested that neither the performance for person cueing object or object cueing person differed between the self and other-reference condition [for person cueing object, $t(35) = -.93$, $p = .361$, $d = .16$; for object cuing person, $t(35) = 1.68$, $p = .103$, $d = .28$].

Because the self-reference effect is the focus of our study, we chose to combine tasks with the opposite directions and present the results in the main text, since the findings about direction were consistent across the reference conditions in young adults, and were consistent with the null finding of self-reference effect in older adults reported in the main text.

Memory for pairwise associations split by likelihood

We conducted a Reference (2: self, other) x Likelihood (2: high-L, low-L) x Pair (3: person-object, person-location, object-location) ANOVA for each age group.

For young adults, there was a main effect of Reference, $F(1, 35) = 7.57$, $p = .009$, partial $\eta^2 = .18$, and a main effect of Likelihood, $F(1, 35) = 12.89$, $p = .001$, partial $\eta^2 = .27$, as well as a main effect of Pair, $F(2, 70) = 33.08$, $p < .001$, partial $\eta^2 = .49$. Performance was better for the self-referenced pairs ($M = .85$) than other-referenced pairs ($M = .82$), better for high-L pairs ($M = .86$) than low-L pairs ($M = .81$), and better for object-location pairs ($M = .89$) than person-object pairs ($M = .81$, $p < .001$) and person-location pairs ($M = 81$, $p < .001$), which did not differ with each other ($p = 1.000$). There was also a Reference x Likelihood interaction, $F(1, 35) = 7.77$, $p = .009$, partial $\eta^2 = .18$. Further analyses suggested that the performance in the self-reference condition was better than other-reference condition for the high-L events ($M_{\text{diff}} = .050$, $p < .001$) but not for the low-L events ($M_{\text{diff}} = .003$, $p = .853$).

For older adults, the main effect of Likelihood was significant, $F(1, 35) = 35.30$, $p < .001$, partial $\eta^2 = .50$, so was the main effect of Pair, $F(2, 70) = 17.99$, $p < .001$, partial $\eta^2 = .34$. There was a trend for Reference x Pair interaction, $F(2, 70) = 3.13$, $p = .050$, partial $\eta^2 = .08$, as well as a Reference x Likelihood x Pair interaction, $F(2, 70) = 6.35$, $p = .003$, partial $\eta^2 = .15$. For high-L events, there was a significant main effect of Pair, $F(2, 70) = 12.02$, p < .001, partial $\eta^2 = .26$, and Reference x Pair interaction, $F(2, 70) = 6.19$, $p = .003$, partial $\eta^2 = .15$. Accuracy for the self-referenced events was higher than other-referenced events for the object-location pair ($M_{\text{diff}} = .084$, $p = .007$), somewhat higher for person-object pair (M_{diff} = .049, p = .071) but not for person-location pair (M_{diff} = .044, p = .213). For low-L events, there was a significant main effect of Pair, $F(2, 70)$ = 8.19, p = .001, partial η^2 = .19. Performance was better for object-location pairs (M = .64) than person-object pairs (M = .58, p = .008) and person-location pairs (M = .57, p = .004), which did not differ with each other (p = 1.000). The main effect of Reference or Reference x Pair interaction was not significant, ps > .182.

Memory coherence with the consideration of likelihood

We conducted an Age (2: young, older) x Reference (2: self, other) x Likelihood (2: high-L, low-L) x Measure (2: data, independent model) ANOVA on dependency. The main effect of Measure was significant, $F(1, 70) = 65.14$, $p < .001$, partial $\eta^2 = .48$, indicating overall *D* ($M = .70$) was higher than *Di* ($M = .68$). Besides, there was a main effect of Age, $F(1, 70) = 39.37$, $p < .001$, partial $\eta^2 = .36$, a main effect of Reference, $F(1, 70) = 7.24$, $p = .009$, partial $\eta^2 = .09$, and a main effect of Likelihood, $F(1, 70) = 27.24$, $p < .001$, partial $\eta^2 = .28$. None of the interactions with Measure was significant, *p*s > .391, except an Age x Measure marginal interaction, $F(1, 70) = 3.55$, $p = .064$, partial $\eta^2 = .05$. Further analyses suggested that the although *D* was higher than *Di* for both young ($M_{diff} = .019$, $p < .001$) and older adults ($M_{diff} = .031$, $p < .001$), the difference (*D* - *Di*) tended to be larger for older adults than young adults, $t(70) = 1.89$, $p = .064$.

Controlling for the overall *Di* (collapsed across high-L and low-L, and across self-reference and other-reference), we compared the difference score of dependency (*D* - *Di*) between young and older adults. Based on the median splitting, *Di* for high-performing older adult ($M = .66$) was similar to *Di* for low-performing young adults ($M = .66$), $t(34) = .07$, $p = .942$, $d = .02$. Dependency difference in these two groups did not differ (for young adults, $M = .03$; for older adults, $M = .03$), $t(34) = .18$, $p = .856$, $d = .06$.