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Investigating age-related changes in adults' cue-integration: An eye-tracking study

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Abstract

The present study investigated age-related changes in the ability to engage cue integration capacities to understand a speaker's referential intention. Forty young adults (*M*age = 22.18 years, *SD* = 1.39) and 40 older adults (*M*age = 67.70 years, *SD* = 4.86) were tested on a cue-integration task with eye-tracking, where they integrated multiple cues to identify a target object across two conditions. In the three-cue condition, they were presented with contextual, semantic and gaze cues, while the two-cue condition consisted of only the contextual and semantic cues. Behavioral results showed that overall, older adults were less accurate in selecting the target object than young adults in our task. Furthermore, eye-tracking results indicated that older adults were less likely to distinguish between the target and non-target objects than young adults. Our results suggest an age-related decline in the ability to integrate multiple cues when inferring referential intention. These findings provide evidence for communicative challenges in late adulthood.

Keywords: aging; communicative cues; cue integration; eye-tracking

Introduction

Humans rely on others to learn about the world. This process of learning involves a dynamic exchange of information through communication. To communicate effectively, one needs to infer a speaker's intentions by processing and integrating multiple sources of information in communicative contexts (Bohn et al., 2022; Epley et al., 2004). These include linguistic cues such as the semantics of a word or an utterance, nonlinguistic cues such as eye gaze, as well as contextual cues that pertain to the speaker's situation or perspective (e.g., Keysar et al., 2000; Nappa & Arnold, 2014). Previous studies suggest an age-related decline in older adults' social cognitive skills, such as gaze-processing and theory-of-mind (Grainger et al., 2022; Paal & Bereczkei, 2007). However, little is known about how the *inference* of communicative cues may be affected in normal aging. The present research investigates the age-related changes in young and older adults' cue-integration ability when they reason about a speaker's referential intent.

Aging seems to have a specific effect on some but not all kinds of communicative cue processing. On the one hand, behavioral and neuroscience evidence suggests that healthy aging is associated with deficits in interpretation of nonlinguistic cues and mental states (e.g., Fernandes et al., 2021; Grainger et al., 2017; Moran, 2013; Yow et al., 2019). For example, compared to younger adults, older adults (aged 60 and above) exhibited poorer performance in social cue decoding (Phillips et al., 2011; Moran et al., 2012), facial emotion recognition (Ruffman et al., 2008; Grainger et al., 2017), perspective taking (de Lillo & Ferguson, in press; Martin et al., 2019), and belief reasoning (Bradford et al., 2020; Henry et al., 2013). On the other hand, older adults' ability to infer linguistic cues in communication is relatively preserved, partly due to their intact or improved semantic systems (Alwin & McCammon 2001; Park et al., 2002; Verhaeghen 2003). These findings together suggest that older adults may face some difficulties in processing communicative cues, particularly the nonlinguistic aspects.

However, little prior work has examined older adults' ability to integrate the different communicative cues in social communication. As communication often happens in complex social settings and language can be ambiguous, listeners must reconstruct speakers' intended meanings by integrating co-occurring cues in context. For instance, one may misunderstand an utterance's intended meaning if he or she simply interprets the content of what is said while ignoring the interlocutor's facial expression, tone of voice, or communicative context (Paulmann & Pell, 2011). Hence, this cue integration process is key to understanding communicative intentions, especially when multiple cues are present and incongruent (e.g., Bohn et al., 2022; Yow & Markman, 2011). Several studies have examined this process in children and young adults by using a cue integration task, where participants need to integrate multiple cues (i.e., contextual, semantic, and gaze cues) to learn the meaning of novel words (see more details below). For example, Nurmsoo and Bloom (2008) found a developmental change in children's cue integration ability, where 4-year-olds, but not younger, were able to make inferences about the speaker's referential intent. There is also evidence suggesting how sociolinguistic factors (e.g., bilingualism) may shape this ability in children and young adults (Lee et al., 2021; Yow & Markman, 2015). Yet, the question remains about how aging affects older adults' ability to integrate multiple cues to communicative intent.

In this study, we sought to investigate how and whether the ability to integrate communicative cues to understand a speaker's referential intention changes with age in older

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adulthood. To address these aims, we replicated an eye-tracked version of the cue integration task (see Lee et al., 2021) with community dwelling older adults (aged 60-77) and their young counterparts (aged 20-25).

In the cue integration task, two novel unnamed objects were placed in a box such that the speaker could see only one of them while the participant could see both. The speaker looked at the object she could see and said either "There's the [novel word]!" or "Where's the [novel word]?" Participants were then asked to identify the speaker's referent object. In doing so, participants would need to integrate the context of the speaker's visual perspective (whether the speaker could see or could not see the object), semantics of the speaker's utterance (there vs. where), and gaze information (which object the speaker looked at when the name of the novel object was uttered), that is, *three* communicative cues. Specifically, the participants were expected to map the novel word to the mutually visible object in *there* trials, where semantic cues and gaze cues were congruent. In contrast, *where* trials required a more nuanced interpretation of the speaker's eye gaze as a cue to referential intent, and participants were expected to map the novel word to the hidden object from the speaker's perspective (i.e., the speaker could not see the object that he/she was looking for), despite the conflicting gaze cues. Considering previous research suggesting some deficits in processing communicative cues with aging, we hypothesized that older adults would be less accurate than young adults in using the multiple cues to identify the referent object in our task.

Lee et al. (2021) introduced a second condition that has a lesser demand on cue-integration where participants only received contextual and semantic cues, but not the gaze cue (i.e., *two* cues). Their study revealed a differential effect in young adults' cue-integration only in the three-cue condition (w*here* trials), but not in the two-cue condition. It is possible that integrating the contextual and semantic cues with the conflicting gaze cue (three cue "where" trials) is more challenging because it requires participants to accurately interpret the referential intent of the speaker's eye gaze (he/she looked at one object but asked for the other object he/she could not see). Past research has shown that older adults face difficulties understanding others' perspective that is different from their own (e.g., Back & Apperly, 2010; Bradford et al., 2015). Eye-tracking research also suggests that older adults are more likely to be distracted by a non-target object which interferes with their fixation on the target object (Bradford et al., 2022). Therefore, we included the two-cue condition in the current study to examine how the older adults would perform when there was a lower cue-integration demand.

In addition to recording participants' behavioral responses, we also recorded participants' gaze movements while they completed the task. By analyzing fixations to the referent object during the task, we aimed to track in real-time the way young and older adults process and integrate information to understand a speaker's perspective (Epley et al., 2004; Huettig et al., 2011). To our best knowledge, there has been no research comparing young and older adults' cue integration process using eye-tracking. We expect a lower proportion of gaze fixations to the referent object in older adults than young adults in the cue task if there were age-related declines in the process of cue integration. Together with behavioral performance, eye-tracking data provides a deeper insight into older adults' decisional processes, such as their information processing and focus of attention in a given task (Ekstein, et al., 2017).

Methods

Participants

The final sample included 40 young adults (M_{age} = 22.18 years, *SD* = 1.39; 21 females) and 40 older adults (M_{age} = 67.70 years, *SD* = 4.86; 20 females). Participants were recruited through online posters and word-of-mouth. All participants were residents in Singapore and ethnic Chinese, and all reported speaking English and Mandarin, except one speaking only Cantonese and Mandarin. All participants were cognitively healthy and reported no history of any neurological or psychiatric disorders. Older adults were also screened for cognitive impairment using Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) that was validated for use in Singapore (Dong et al., 2010; Ng, et al., 2015). We followed Ng et al.'s (2015) recommended cutoff score of 23 (out of 30) for our community-based sample, with those scoring 22 and below suspected of mild cognitive impairment. Older adults' MoCA score ranged from 24 to 30 (*M* = 28.14, *SD* = 1.37). Four additional older adults were excluded from the final sample as two of them scored below the MoCA cut-off, while another two of them did not complete the cue task. Most older adults completed pre-university education (*n* = 15) or secondary school education (*n* = 12), while others completed an undergraduate or postgraduate degree (*n* = 11), and a few completed primary school education (*n* = 2). Most young adults were undergraduate students who have completed pre-university education (*n* = 35) and some completed an undergraduate or postgraduate degree (*n* = 5). On average, the two groups were comparable in terms of the highest level of education achieved, *W* = 923.5, *p* = .17.

This study was approved by the University's Institutional Review Board. The data reported in this paper was part of a larger social cognition project (preregistered at https://tinyurl.com/studypreregistration). Participants were reimbursed with vouchers worth SGD30 for their participation. The study was conducted in participants' preferred language; English for all young and majority of older participants, except five older participants who completed the study in Mandarin.

Design and Materials

The task used to assess cue-integration was adapted from Nurmsoo and Bloom (2008) and Lee et al. (2021). Video clips of a speaker (female and Asian) and a puppet elephant playing a "hide-and-find" game were pre-recorded and edited as stimuli. Stimuli were presented on a 24-inch monitor (1920 x 1080) from a computer using Tobii Pro Lab software.

Materials included an opaque cardboard box (32 cm x 22 cm), two familiar objects (a pen and a toy flower), and 16 novel objects (uncommon objects or parts of a bigger object). The box had two open compartments, each with a cut-out window. A movable screen covered one of the windows (see Figure 1). In the videos, the box was placed on a table, facing participants such that they could see through both windows. The speaker was seated behind the table/box so that she could only see through the uncovered window. In each video, a pair of novel objects were used with a novel label. There were in total eight pairs of novel objects and eight novel labels (*spoodle*, *nurmy*, *flurggle*, *gorpy*, *modi*, *blicket*, *coodle*, and *toma*, as per Lee et al., 2021). Four pairs of objects and labels were used for four trials in the three-cue condition (see below), and the other four pairs were used for four trials in the two-cue condition. Pairs of objects were fixed across participants, but placement of objects in each compartment was counterbalanced across trials. The Mandarin version of the task used the same design and objects, except that a set of eight two-syllable pseudowords in Mandarin were created and used. Note that the English and Mandarin versions of the test questions were different in word order: "*There/Where is the* [novel word]" were equivalent to "[novel word]*在(is)这里(here)/哪里(where)*". On average, the duration of the English test questions was about 1180ms, and it was 1130ms for the Mandarin test questions.

Procedure

The procedure was similar to Lee et al.'s (2021) study except that participants responded by pointing to the object presented on the monitor instead of key presses using a keyboard. Participants' eye movements were recorded using a Tobii Pro Spectrum eye-tracker with a sampling rate of 300 Hz. Participants sat about 60-65 cm away from the screen and viewed the video stimuli in 720p (1280 x 720 pixels) presented on the screen. The eye-tracker was calibrated for each participant using a five-point calibration.

The task began with the speaker in the video introducing the box to participants. This familiarization procedure was to ensure that participants understood the properties of the box and the speaker's perspective of the box. Two familiar objects were placed into the box, one in each compartment. Participants were asked to identify the object the speaker could and could not see. Next, during the experimental phase, they were tested on their multiple cue-integration abilities in the three-cue and two-cue conditions. Each condition consisted of two *there* trials and two *where* trials (i.e., four trials per condition). Half of the participants completed the three-cue condition first, followed by the two-cue condition, and vice versa. Within each condition, the order of each trial was also counterbalanced across participants.

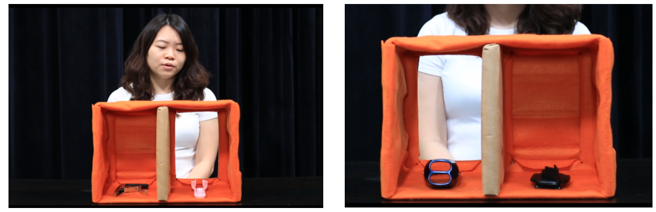

Figure 1: Screenshot of the key frame in (a) three-cue condition and (b) two-cue condition. In each trial, the speaker looked at the mutually visible object, and said either, "There's the [novel word]!" (i.e., *there* trial) or "Where's the [novel word]?" (i.e., *where* trial).

In each trial of the experimental phase, two novel objects were presented to participants by the speaker, who said, "Look at these two objects. Aren't they interesting?" Next, while the speaker turned around with her back facing the box, the assistant (i.e., puppet elephant) placed the two novel objects in the box, one in each compartment. The speaker then turned around to face the box and, without prior knowledge of which compartment the target object was placed in, asked the *test question* – a "there" or a "where" question. On *there* trials, the speaker referred to the object of mutual focus by saying, "There is the [novel word]! There it is." On *where* trials, the speaker asked, "Where is the [novel word]? Where is it?" On both types of trials, the speaker then directed attention to the participant and asked, "Can I have the [novel word]?" or "请给我[novel word]" in Mandarin. Participants were instructed to respond by pointing to the screen. No feedback was given.

The procedure for three-cue and two-cue conditions was identical except that the speaker's gaze cue was omitted while she was asking the test question in the two-cue condition (see examples in Figure 1). In the three-cue condition, after the speaker turned back around, facing the box, the video showed her facing down and looking at the object that she could see (i.e., mutually visible object). The speaker kept fixated at the object until she finished the test question. Whereas in the two-cue condition, the scene was zoomed in so that the speaker's face was not shown while she asked the test question. In both three-cue and two-cue conditions, the correct referent object (i.e., target object) was the mutually visible object for *there* trials and the hidden object from the speaker's view for *where* trials.

Data Analysis

Based on previous work by Lee et al. (2021), we derived two measures of cue integration performance: (1) the number of responses that participants pointed to the correct referent object, and (2) the proportion of looking time directed to the correct referent object during the Response Window (see below). Trials with no pointing were considered incorrect responses. All participants pointed to either one of the two objects in all eight trials during the experimental phase except four participants who failed to point in one of the eight test trials (they reported "don't know"). However, excluding these four trials did not change the results. Statistical analyses were conducted in R version 3.5.2 using RStudio.

Eye-tracking data were pre-processed and analyzed using *eyetrackingR* package (Dink & Ferguson, 2015). Area of Interests (AOIs) were drawn for the two novel objects (both two-cue and three-cue conditions) and the speaker's face (only three-cue conditions). Individual test trials with more than 50% track-loss (i.e., no eye gaze was detected) were excluded from further analyses (about 9.1% of all trials). The critical window of analysis was the two-second interval following the onset of the novel label when the speaker asked for the target object ("Can I have the xxx" or "请给我 xxx"). Because we were interested in whether participants looked at the target object more than the non-target in response to the speaker's request, the average proportional looking time toward the target object during the *Response Window* was calculated with respect to the total amount of time spent looking at both objects (excluding face AOI).[1] To explore how participants' attention was distributed in processing multiple cues when the speaker asked the test question ("There/Where is the xxx" or "xxx 在这里/哪里"), we also analyzed eye-tracking data during the two-second interval that started from the onset of the disambiguation word (i.e., *there/where*, or *这里/哪里*) and until the onset of the next sentence (i.e., *Test Question Window*). Out of the 80 participants, eight were excluded from the eye-tracking data analyses because they did not accumulate enough looking time toward the two objects in more than half of the test trials (6 older adults) or no eye-tracking was employed due to technical problems (1 young adult and 1 older adult). Hence, the final sample for the eye-tracking analysis consisted of 39 young adults and 33 older adults.

Results

Behavioral Performance

To test the hypothesis on age differences in participants' behavioral performance in cue integration, a 2 (age group: young vs. older) x 2 (question: there vs. where) x 2 (cue: three-cue vs. two-cue) ANOVA was conducted on the number of correct response (max = 2) in choosing the target object. Group means for each question and cue type are presented in Figure 2.

Results revealed a significant main effect of age group, $F(1, 78) = 25.12$, $p < .001$, partial $\eta^2 = 0.11$. The other main effects of question and cue, and all the two- and three-way interactions were not significant, Fs < 3.10, ps $> .082$. Hence, across the different trials and conditions, young adults were more accurate than older adults in choosing the target object in the cue integration task. These results were robust when controlling for education level and when excluding the five participants who completed the study in Mandarin.

One-sample t-tests showed that both groups of participants performed significantly above chance level (= 1) across trials and conditions, all ps $< .004$ (see Figure 2). Despite evidence of declined task performance with age, older participants in our study were still able to engage in cue integration and map the novel word to the target object the speaker referred to.

Response Window Eye-Tracking Results

A similar 2 x 2 x 2 ANOVA was conducted on the proportion looking to the target object with respect to the total looking time toward both objects during the Response Window, which measures how participants directed their attention to the target object in response to the speaker's request for the referent object (see Figure 3).

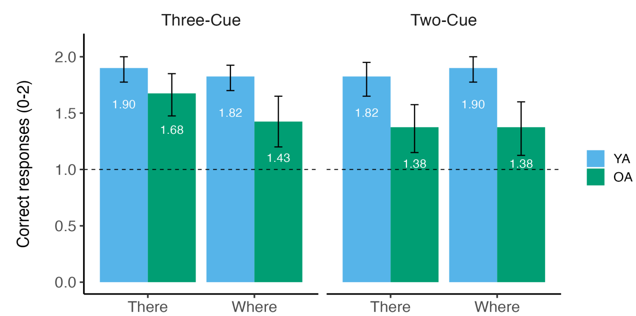

Figure 2: Number of correct responses pointing to the target object by experimental condition and age group. YA = young adult, OA = older adult. Error bars represent 95% confidence intervals. All means were above chance level (chance = 1).

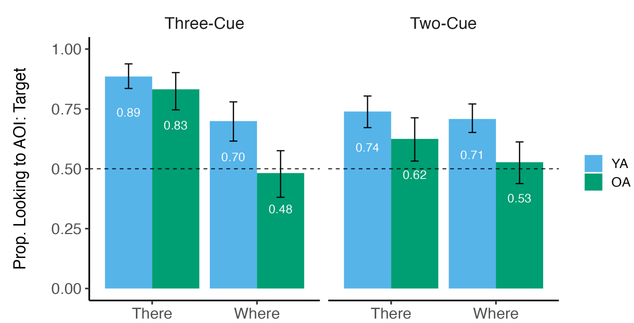

Figure 3: Proportion looking toward target during the response window by experimental condition and age group. YA = young adult, OA = older adult. Error bars represent 95% confidence intervals. All means were above chance (0.5) except older adults' performance in the *where* trials in both three-cue and two-cue conditions.

[1] Excluding face AOI makes the measures in three-cue and two-cue conditions comparable, and including face AOI did not change the age differences reported in the response window results.

There were significant main effects of age group, $F(1, 59) = 14.93$, $p < .001$, partial $\eta^2 = 0.08$, question, $F(1, 59) = 29.61$, $p < .001$, partial $\eta^2 = 0.11$, and cue, $F(1, 59) = 10.84$, $p = .002$, partial $\eta^2 = 0.04$. Overall, participants' proportion of looking time (to target) was higher in the young group, on the *there* trials, and in the three-cue condition than otherwise. We also found a significant interaction between question and cue, $F(1, 59) = 12.48$, $p < .001$, partial $\eta^2 = 0.04$; post-hoc analyses showed significant differences between *there* and *where* trials in three-cue condition ($p < .001$)—higher proportional looking to target in *there* than *where*—but not in two-cue condition ($p = .14$). No interactions of age group were significant, Fs < 3.23, $ps > .08$. Controlling for education and excluding participants who completed the Mandarin version of the task did not change the findings. Overall, these results suggest that young adults spent more time looking at the target object versus the non-target than the older adults during the two-second interval that immediately followed the speaker's request for the referent object.

Follow-up comparisons to chance confirmed that young adults were above chance level in their proportion of looks to the target object on both there and where trials, and in both three-cue and two-cue conditions, all $ps < .001$. In contrast, older adults were above chance only on *there* trials, in both three-cue and two-cue condition, $ps < .012$, while they looked at the target object only at chance-level on *where* trials in both conditions, $ps > .55$ (see Figure 3). Note that these results deviate from the behavioral results, where even the older adults demonstrated successful multiple-cue integration in their explicit selection of the target object across different trials and conditions. Here, the older adults failed to identify the target object in terms of their implicit looking on *where* trials above chance level. Interestingly, the eye-tracking results could reflect hesitation or uncertainty in the older adults' decision-making process, even though they made the right behavioral response at the end of the task.

Test Question Window Looking Patterns

To explore participants' looking patterns during the test question window, proportion of looking time toward each AOI was calculated for each 100ms time bin during the two-second period and plotted against time. As illustrated in Figure 4, the time course plots demonstrated the dynamic changes of looking during the task: while participants (both young and older) clearly looked more toward the target object than the non-target on *there* trials, their attention was relatively distributed across the two objects on *where* trials. Note that in the three-cue condition, participants spent a great amount of time looking at the face AOI; hence, proportional looking to the target AOI was calculated with respect to the total looking time across three AOIs (i.e., target, non-target, and face) for the three-cue condition. This was different than the two-cue condition, where only the target and non-target AOIs were included in the analysis. As such, we ran two ANOVAs examining the effects of age group and question on proportion looking directed to target during the test window, for the three-cue and two-cue condition separately.

ANOVA results revealed no significant effect of age group for both three-cue condition, $F(1, 68) = 0.15$, $p = .70$, and two-cue condition, $F(1, 68) = 5.78$, $p = .08$; young and

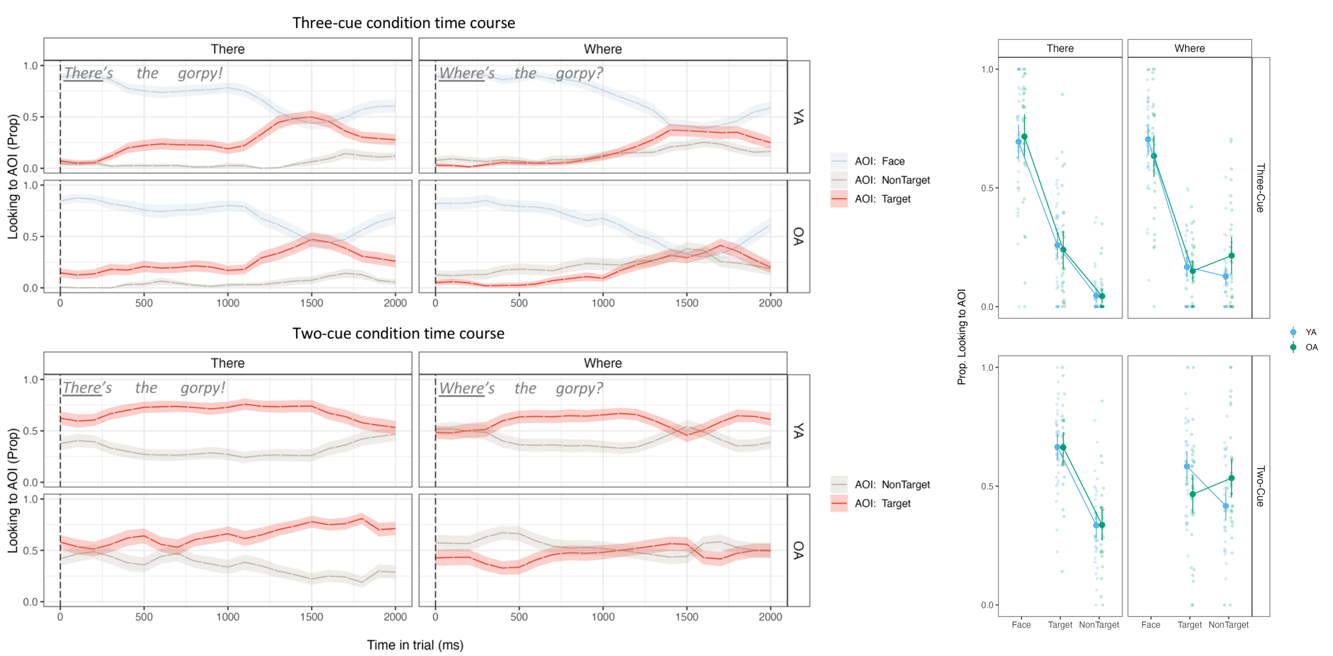

Figure 4: Test window eye-tracking results. Left: Time course of proportionate looking toward the respective area of interest (AOI) over the window of analysis (shaded regions indicate standard error). Right: Mean proportion looking time to different AOIs by condition and age group (error bars indicate 95% confidence intervals, and jitter points represent individual data).

older adults spent similar time looking at the target object across trials and conditions (Figure 4). For both conditions, there were significant effects of question, Fs > 14.11, ps < .002, and no significant interaction between age group and question, Fs < 3.05, ps > .25. Overall, participants looked at the target more on *there* trials than *where* trials. Thus, unlike the results in behavioral performance and response window looking behavior, young and older adults similarly spent time looking at the target object during the test window as the speaker asked the test question ("There/Where is xxx").

Discussion

The present study examined age effects on the ability to integrate multiple communicative cues to understand a speaker's referential intentions. Using the cue integration task with eye-tracking, we investigated the performance of young and older adults in processing contextual, semantic, and gaze cues to understand a speaker's referential intent. Overall, both behavioral and eye-tracking results suggest that young adults were more accurate than older adults in identifying the intended referent object in our task.

Our behavioral results suggest that older adults might face more difficulty integrating multiple cues to understand speakers' communicative intent than young adults. In line with previous work that examined the developmental trajectory of cue-integration abilities in older adults (Yow et al., 2019), our study showed that overall, older adults were less accurate than young adults in the current cue-integration task that required an integration of three or two cues (contextual, semantic, either plus gaze or no gaze) to identify the speaker's referent object. One may argue that older adults' performance in our task may simply reflect their deficits in inhibitory control (Alain & Woods, 1999). While the inhibitory control deficits hypothesis might explain the performance differences between young and older participants in the three-cue condition, where they would need to inhibit the prepotent response to follow the eye gaze (especially in the *where* trials). However, the age differences also emerged in the two-cue condition where the eye gaze cue was omitted, hence prepotent response inhibition was not required. A more plausible explanation of the current results is that aging may be associated with impairments in the process of reasoning another individual's communicative intent especially when multiple cues are present. This is congruent with several previous studies that reported deficits in perspective-taking in communication in older adults (Bradford et al., 2022; Slessor et al., 2016).

Our eye-tracking results provide additional insights into young and older adults' decision-making process in completing the cue-integration task. Overall, consistent with the behavioral results, we found that young adults spent more time looking at the target object versus the non-target than the older adults during the two-second response window following the speaker's request for the referent object. Interestingly, unlike their young counterparts who readily distinguished between the target and non-target during this time (i.e., spent more time looking at the target, significantly above chance), older adults did not do so, in particular, in the *where* trials across the conditions. Given their above-chance performance as revealed by the behavioral responses, it is possible that the older adults might still be reasoning about the speaker's intended meaning during this timeframe and have yet to decide which object is likely the target referent. Furthermore, the forced-choice nature of the behavioral test could influence the behavioral performance in older adults, especially if they required more time to respond accurately. These findings highlight a trajectory change in integrating cues to understand speakers' communicative intent that has not yet been well understood.

Surprisingly, the eye-tracking results in the test question window revealed no significant age group differences in participants' looking patterns during this window. Despite the unexpected result, we argue that it revealed how older and young adults process multiple cues while inferring a speaker's referential intent. Simply put, the eye-tracking results in the test question window indicated that both older and young adults weighed the target and non-target object comparably during their processing of cues in the communicative context. Overall, our results suggest similar attentional mechanisms in cue processing across adulthood but age-related changes in the coordination of multiple communicative cues to understand referential intentions.

This raises the question of what underlies the age differences found in our cue-integration task. Based on past research on age-related cognitive decline, it is possible that older adults' inferential and cue-integration abilities are limited by their social cognitive abilities such as theory of mind or general cognitive abilities such as working memory (e.g., Bopp & Verhaeghen, 2005; Crawford, et al., 2017; Henry et al., 2013). This could explain why older adults may face more difficulties coordinating multiple cues of others' mental states than young adults. On the other hand, older adults may take more time to process multiple cues. If so, their performance in the present study could have reflected low efficiency instead of impaired cue-integration abilities. Future studies could focus on exploring possible social cognitive mechanisms underlying these age-related differences in cue-integration ability. For example, future work could utilize pupillometry to investigate if older adults experience a higher mental workload than their young counterparts in cue-integration tasks or give the older adults more time to process and respond.

In conclusion, the present study provided behavioral and eye-tracking evidence for age differences between young and older adults in the ability to integrate multiple communicative cues to infer a speaker's referential intent. Our study shows the effects of aging on the inference of communicative cues in older adults. The findings contribute to the current understanding of the age-related changes of social-cognitive processes in healthy aging.

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