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Visual context benefits spoken sentence comprehension across the lifespan

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ABSTRACT

Evidence for age-related declines in syntactic comprehension is mixed, often modulated by concomitant cognitive changes. Further, while older (vs. younger) adults may make greater use of semantic information for sentence comprehension, it is unclear whether this extends to visual information. We investigated whether visual-scene depictions benefit sentence comprehension in adults with varying cognitive-ability levels. 153 participants (18–70 years) listened to German relative clauses with canonical/noncanonical structure ("This is the man who follows the woman"/"…whom the woman follows") presented in isolation or alongside visual-scene depictions, and answered agent-identification questions. Visual-scene depictions facilitated comprehension, especially when individuals with lower cognitive-ability levels encountered noncanonical structures. Individual differences in cognitive ability tended to modulate age-related changes in comprehension of utterances presented in isolation. These findings indicate beneficial effects of visual information for thematic-role comprehension – especially when task demands are high – and that cognitive-ability levels may modulate age-related changes in comprehension.

Introduction

Every day, we are surrounded by visual stimuli alongside linguistically encoded information in spoken or written form. Most, if not all, linguistic processes are situated in an environment with a visual component: whether engaged in a conversation in a crowded café, watching a video with voice-over, or reading a newspaper on the subway – these are all prime examples of highly cross-modal experiences wherein information is concurrently encoded both visually and linguistically.

Research on language processing across the lifespan has sought to identify which aspects of language may change during aging, and whether these changes manifest as improvements or declines (Nyberg et al., 2012; Reifegerste et al., 2022; Rey-Mermet & Gade, 2018; Sánchez-Izquierdo & Fernández-Ballesteros, 2021). Moreover, the developmental trajectories of cognitive skills underlying specific linguistic processes may indeed mediate age-related changes in language processing.

Generally, lexical-retrieval difficulties are considered a hallmark of aging (see, e.g., Connor et al., 2004; Verhaegen & Poncelet, 2013), while the evidence for declines in other language domains, such as syntax, is more mixed (Campbell et al., 2016; Hardy et al., 2020; Poulisse et al., 2019). Furthermore, it appears that when non-syntactic cues (e.g., plausibility) support the linguistically encoded interpretation of a sentence, comprehension performance in older and younger adults is comparable (Amichetti et al., 2016; Caplan & Waters, 2005; Campbell et al., 2016), suggesting that access to information from non-syntactic sources may remain relatively stable throughout the lifespan. One proposed explanation for this stability involves an age-related shift in the information sources (or "heuristics") that older adults rely on during sentence comprehension (Beese et al., 2019; Stine-Morrow & Radvansky, 2017; van Boxtel & Lawyer, 2021). However, there is little research examining whether such a 'syntactic-to-semantic-processing strategy shift' (Beese, et al., 2019) extends to the use of visual information.

In the remainder of the Introduction, we describe theoretical accounts of the interaction of utterance and scene during visually situated comprehension. We then briefly review research on the processing heuristics used during sentence comprehension across the adult lifespan and on the role of perceptual and visual information in older adults' sentence comprehension, before turning to the present study.

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Models of visually situated sentence comprehension

Research on ‘situated’ language processing has considered language as naturally immersed in a visual environment (Knoeferle, 2019). The Constituent Comparison Model (CCM; Carpenter & Just, 1975) and the “CACTRAS” model (Clark & Chase, 1972; Trabasso et al., 1971) are early models of visuo-linguistic integration proposed to account for response-time patterns of sentence-picture verification (Clark & Chase, 1972; Wannemacher, 1974). In this paradigm, participants respond to questions such as *Is this sentence true for this picture?* Typically, congruent (i.e., *yes*) trials are responded to faster than incongruent trials. To explain this finding, these early models proposed that both sentences and depictions are represented as propositional constituents. During sentence-picture verification, visual and linguistic constituents are verified against each other (cf. the notion of spatial structure in Jackendoff, 2002); the detection of incongruence between the two components triggers the re-initiation of the verification process, resulting in longer response times for incongruent trials (Carpenter & Just, 1975).

The advent of on-line methodologies enabled researchers to investigate the time course of the integration of visual and linguistic information during language processing (Spivey & Huette, 2016). The study of attention allocation, for example using the visual-world eye-tracking paradigm, has informed our understanding of the timing of linguistic processing. This method assumes that linguistic processing immediately directs the language user’s attention to visually available entities (Cooper, 1974). In turn, visual information has been shown to exhibit a pervasive influence on sentence processing, for example, for the resolution of referential (Sedivy et al., 1999; Spivey et al., 2002; Tanenhaus et al., 1995) and thematic-role ambiguities (Knoeferle et al., 2005; Knoeferle & Crocker, 2006). For instance, the difficulty associated with the processing of temporarily ambiguous instructions (e.g., *Put the apple on the towel in the box*) was shown to be influenced by the visual display – for example, whether one or two apples were presented visually (Tanenhaus et al., 1995). Importantly, and of relevance for the present paper, visual information has also been shown to interact with morphological-case processing for (predictive) thematic-role assignment (e.g., Kamide et al., 2003; Knoeferle et al., 2005; Knoeferle & Crocker, 2005, 2006). For instance, Knoeferle et al. (2005) monitored eye movements to visual scenes while participants listened to German Subject-Verb-Object/Object-Verb-Subject sentences, which are initially locally ambiguous regarding their thematic-role assignment (e.g., *Die Prinzessin malt gleich den Fechter*, "The princess.NOM/ACC will soon paint the.ACC fencer", i.e., "The princess will soon paint the fencer"). Crucially, the princess was depicted either as painting a character and as being washed by another character. Participants used visual cues (the princess as agent of the painting action) to infer the upcoming referent (the fencer) at the verb, that is, before encountering the disambiguating case marker on the second NP’s determiner.

The Coordinated Interplay Account (CIA; Knoeferle and Crocker, 2006) offers a theoretical framework accounting for the mutual influence of visual and linguistic information during utterance comprehension. This model outlines a cyclic mechanism: Initially, as utterances are understood, the currently preferred interpretation of the sentence guides visual attention to the relevant entities in the environment. Then, utterance interpretation and visual entities are verified against each other, potentially leading to revisions of the interpretation based on the visual input. This interpretation is then used to form further expectations about upcoming items. Throughout this cycle, currently relevant information (e.g., prior context and visual entities) is stored in working memory (WM) and updated as the speech progresses and/or the display changes.

While most prior work has focused on the time course of visuo-linguistic integration, its consequences for thematic-role comprehension have been investigated to a considerably lesser extent (Knoeferle et al., 2014; but see Kreysa et al., 2018; Zona & Felser, 2023). In addition, whereas the interaction between language and visual cues during early developmental stages has received extensive attention (Borovsky et al., 2012; Eiteljoerge et al., 2019; Tomasello et al., 2007; Wellsby & Pexman, 2014), few studies have examined visually situated language in aging (see Münster & Knoeferle, 2017).

Heuristics for sentence comprehension in healthy aging

Findings regarding the effects of aging on syntactic comprehension are somewhat mixed. While some studies have reported age-related performance declines in sentence comprehension (e.g., Christianson et al., 2006; Poulisse et al., 2019), these may be confined to conditions of increased task demands (Beese et al., 2019; Reifegerste & Felser, 2017) or to participants with lower WM capacity (Peelle et al., 2010; Stine-Morrow et al., 2000; Reifegerste et al., 2017). Instead, some studies have found no age-related changes in syntactic processing, such as in younger and older individuals’ ability to revise interpretations based on agreement cues (Samu et al., 2017), or their propensity to develop syntactically and semantically coherent sentential representations (Davis et al., 2014; Tyler et al., 2010).

For instance, Alatorre-Cruz et al. (2018) tested 30 younger and 30 older adults (mean ages = 25.7 and 66.1 years, respectively) with a grammaticality-judgement task targeting adjective-noun gender agreement in Spanish, manipulating the length of the crucial adjective-noun dependency to examine the role of WM load. Older participants performed more slowly than younger participants, but both groups showed comparable accuracy rates, regardless of dependency length. In another study, Reifegerste et al. (2017, Exp. 2) asked 32 younger and 32 older adults (mean ages = 24.4 and 66.8, respectively) to perform grammaticality judgments on written sentences containing agreement errors (e.g., **The letter to the friends were sent today*). Older participants were less accurate than younger adults at noticing these agreement errors and showed disproportionate reading slow-downs at the critical word containing the error; importantly, both of these effects were driven by older participants’ WM capacity, with the effects being greatest for older individuals with lower WM and comparable performance between younger adults and older adults with higher WM. Lastly, Fernandes et al. (2024) administered a spoken word-monitoring task in which 40 younger and 40 older adults (mean ages = 23.1 and 69.6 years, respectively) listened to sentences and word strings that provided either high constraint (based on both semantics and syntax; *I flipped the pancake with the spatula*), low constraint (based only on syntax; *I tried to quickly find the spatula*), or no constraint (words in pseudorandom order; **Tried I find to quickly the spatula*) for the word-monitoring task. The authors reported no age differences in the benefits conferred via syntactic (vs. no) constraints, indicating that both younger and older adults exploited syntactic cues to predict the category of the upcoming word. Importantly, older participants tended to outperform the younger group in the high-constraint condition, that is, when additional semantic cues were available. This latter tendency suggests that the use of semantic information during sentence processing is preserved in older adults, in line with studies reporting lifespan changes in comprehenders’ reliance on cues from different sources for text and sentence comprehension (Kemtes & Kemper, 1997; Stine-Morrow et al., 1996).

Indeed, evidence suggests that older adults may rely on non-syntactic cues during comprehension more than younger adults (e.g., Amichetti et al., 2016, Exp. 1; Ayasse et al., 2021; Beese et al., 2019; Christianson et al., 2006; Poulisse et al., 2019; Rangel Ferrari et al., 2019; Yoon et al., 2015). For example, Beese et al. (2019; Exp. 2) compared younger and older adults’ propensity to utilize morphosyntactic and semantic constraints during sentence comprehension. Participants were presented with written sentences or word lists, both of which consisted of either existing words or a mix of words and pseudowords, and then answered questions probing serial order position of the words in the sentence/word list they had just read (e.g., *Did the word* X *come before the word* Y*?*). While older adults showed overall lower accuracy than younger adults for words presented in sentences, no age differences in performance emerged for word lists. Importantly, younger and older adults did not differ in the extent to which meaningful words (vs. non-words) facilitated task performance, indicating that the ability to use semantic cues for the task was preserved in older adults. Lopukhina et al. (2022) found that older adults relied on semantic plausibility to a greater extent than did younger adults and adolescents during sentence reading, while both older and younger adults relied on syntactic attachment preferences to a similar extent.

These findings suggest that the ability to make use of semantic information is at least preserved with increasing age, and it may become more central to sentence comprehension, perhaps particularly so in the face of age-related declines in cognitive capacity. Thus, older adults may achieve sentence comprehension by relying increasingly on semantic relations between different sentence elements (Taler et al., 2009), plausibility (Amichetti et al., 2016), and other aspects of crystallized knowledge (e.g., 'verbal intelligence'; Campbell et al., 2016).

As for the neurocognitive mechanisms underlying such a hypothesized shift in heuristic strategies for comprehension, one influential proposal posits that older adults have reduced suppression of irrelevant information due to age-related declines in the connectivity of the frontoparietal control network (Spreng et al., 2010; Campbell et al. 2012). Such network supports enhancement of brain activity associated with task-relevant information and the suppression of activity associated with task-irrelevant information (Gazzaley et al., 2005). Older adults have been found to exhibit preserved enhancement of brain activity associated with processing task-relevant information, while suppression of activity related to task-irrelevant information was reduced in older adults, and especially those exhibiting disproportional WM deficits (Gazzaley, Cooney, Rissman & D'Esposito, 2005). During syntactic parsing, this may cause age-related difficulties in controlling interference from semantics- and inference-based interpretations that are stored in WM but have been disconfirmed by morphosyntactic markers. For example, when a noncanonical syntactic structure disconfirms the expectation for a canonical structure, older adults may have greater difficulties inhibiting the previously preferred canonical interpretation than younger adults. This line of research has also highlighted how enhanced susceptibility to distracting information need not be a disadvantage, but it can also manifest as a benefit depending on the situation (Healey et al., 2008). Indeed, semantic and word-order information is often not irrelevant and relying on it can aid successful comprehension by contributing to "filling the gaps", especially in situations that are taxing for WM and interference control (IC). As suggested by Stine-Morrow (2007), age-related shifts in heuristic strategies underlying comprehension may be finely tuned to achieve comprehension in the face of age-related cognitive declines in WM and IC abilities.

For example, studies have shown greater advantages from a matching (vs. mismatching) visual depiction latencies of lexical processing in older (vs. younger) adults (Dijkstra et al., 2004; Madden and Dijkstra, 2010), suggesting that the interference from task-irrelevant perceptual features may increase with increasing age, and that this may be helpful for task performance (see also Radvansky et al., 2001). Other evidence, however, has suggested that visuo-linguistic integration may represent a burden on older adults' cognitive resources. Stine et al. (1990) compared free recall of spoken excerpts from television news broadcasts presented to 12 younger and 12 older adults (mean ages 18 and 68, respectively) either in isolation, alongside the corresponding video component, or alongside a written transcript of the excerpt. Of relevance here, younger participants' recall was aided when the spoken information was augmented by video or transcript, indicating that visual information facilitated younger adults' recall of spoken language. In contrast, older adults did not benefit from either the video or the written transcript. Interestingly, comprehension differences between the age groups in the audio-only condition disappeared once participants' WM capacity was considered. This latter result suggests that changes in cognitive abilities – rather than aging *per se* – play a crucial role in the comprehension of spoken sentences presented in isolation.

To summarize, evidence on the integration of visual and linguistic cues for comprehension across the adult lifespan is scarce; moreover, this work has thus far focused on lexical processing, and we are not aware of any research that has examined the role of visual information for syntactic comprehension in aging. Additionally, previous studies have typically operationalized age as a categorical variable, contrasting (often relatively small) groups of younger/older adults. The present study seeks to address these gaps by investigating changes in syntactic comprehension, as well as in the use of visual-scene information, in a continuous-age sample ($n = 153$, age range = 18–70 years).

The present study

We investigated whether visual information benefits spoken sentence comprehension, and whether the size of such a benefit changes across the lifespan and/or as a function of varying levels of cognitive ability. We employed a 2 × 2 design with Sentence Structure (2 levels: subject-object, object-subject) and Visual Scene (2 levels: baseline, visual scene) as within-participant factors. Participants listened to 24 spoken sentences presented either in isolation (baseline) or alongside a photo of two characters acting out the action described by the sentence (visual scene) and were asked to respond to comprehension questions targeting agent identification.

Subject-object (SO) and object-subject (OS) structures were subject- and object-extracted relative clauses (e.g., SO: *Das ist der Koch, der die Braut verfolgt* "This is the cook who follows the bride"; OS: *Das ist der Koch, den die Braut verfolgt* "This is the cook whom the bride follows") used to model conditions of increased task demands, based on extensive evidence indicating greater processing difficulty for and less accurate comprehension of noncanonical OS (vs. canonical SO) relative-clause structures (including in German; Adelt et al., 2017; Mecklinger et al., 1995; Schriefers et al., 1995; Vos et al., 2001), and particularly so at older ages (e.g., Kemper & Liu, 2007; Obler et al., 1991; Stine-Morrow et al., 2000; Tun et al., 2009; Wingfield et al., 2003). We thus hypothesized that OS (vs. SO) clause structures would be associated with poorer comprehension performance (main effect of Sentence Structure), and perhaps particularly so at older ages (Sentence Structure × Age interaction).

The interplay of WM and Interference Control (IC) has been argued to contribute to an individual's ability to maintain task-related goals (Duell et al., 2018; Egner & Hirsch, 2005; Long & Prat, 2002; Miller & Cohen, 2001; Weldon et al., 2013), including specifically for the comprehension of object-extracted relative clauses in older adults (e.g., Goral et al., 2011; Gordon et al., 2002; King & Just, 1991). This is because comprehenders of German assume that the first-mentioned referent in an utterance will take on the agent (rather than the patient) role of an upcoming action (e.g., Schriefers et al., 1995). Encountering a relative pronoun in the accusative (*den* "whom," vs. nominative, *der* "who") form, as is the case in object-extracted relative clauses, disconfirms this expectation and requires participants to revise their preferred interpretation based on the case information. Such disconfirmation engenders more interference as compared to subject-extracted clauses, in which the previously held interpretation is endorsed by the case information and no revision takes place. The ability to control interference from competing representations is then relevant for determining the amount and accuracy of the information that will be stored in WM. In turn, individual WM capacity will determine how well such interference-control mechanisms need to operate to support the comprehension of more complex syntax. To quantify these abilities in our sample, we computed a composite score of cognitive ability for each participant by averaging across their z-transformed WM scores and IC scores, providing an individual proxy of cognitive-ability levels. This approach also allowed us to keep as few collinear predictors as possible in our statistical models. Greater cognitive abilities are expected to be associated with better comprehension performance across the lifespan (main effect of Cognitive Score). Moreover, if our sentence-structure manipulation increases cognitive task demands, we might expect individuals at the lower end of the cognitive-ability range to be more greatly affected by this manipulation than those at the higher end (Sentence Structure × Cognitive Score interaction).

If increasing age yields declines in sentence comprehension, we should observe a main effect of Age yielding poorer performance across the cognitive-ability range, and potentially an interaction between Sentence Structure and Age, indicating that the detrimental effects of increasing age on comprehension performance might be more prominent in response to noncanonical OS structures. Further, if such age-related declines are modulated by changes in cognitive abilities throughout the lifespan, age effects on comprehension might emerge only in individuals with relatively lower cognitive abilities (Age × Cognitive Score interaction). This further prediction is in line with previous evidence for age-related declines in situations of increased demands and/or lower abilities to overcome such demands (e.g., Reifegerste et al., 2017).

Turning to the visual scenes, we hypothesized that supporting visual information might yield overall improvements in sentence comprehension (a main effect of Visual Scene), in line with predictions from the CIA and with previous studies that reported a benefit of matching visual information for lexical processing in both younger and older adults (Dijkstra et al., 2004; Madden & Dijkstra, 2010). Further, the benefits of visual information may become more evident for the comprehension of OS (vs. SO) structures (Sentence Structure × Visual Scene interaction), given the relatively greater syntactic complexity of the former versus the latter. For example, Knoeferle and Kreysa (2012) used visual-world eye-tracking to investigate how comprehenders use deictic visual information (e.g., a speaker's gaze directed towards the depiction of an upcoming sentence referent) to predict this referent. The authors found that visual cues enabled participants to accurately predict the upcoming referent in response to both SO and OS clause structures; while a baseline condition without deictic information yielded SO-OS differences in fixation latencies, this effect was neutralized in the presence of deictic cues.

Turning to the interactive effects of age, based on prior studies that reported evidence for a heuristic shift in older adults' sentence comprehension (from reliance on syntax to inference- and context-based reasoning), we explored whether this general pattern extends to age-related increases in reliance on visual-scene information. Thus, we hypothesized that the facilitatory role of visual information may become more pronounced with increasing age (Visual Scene × Age interaction).

Lastly, we also investigated the role of varying cognitive-ability levels in determining potential heuristic shifts, examining the hypothesis that visual-scene information might support comprehension performance particularly (or possibly exclusively) in situations of increased cognitive demands – that is, in response to noncanonical OS (vs. canonical SO) structures (Sentence Structure × Visual Scene interaction), and/or in individuals with lower (vs. higher) cognitive abilities (Visual Scene × Cognitive Score interaction).

Methods

Participants

Participants were recruited through multiple channels, including the online participant recruitment platform of the University of Potsdam, web-based ads across Germany, and by directly contacting participants from previous experiments. All participants provided informed consent to participate in the study and received 10€/h or university credit as compensation.

The final dataset included 153 participants, 99 women and 54 men, ranging between 18 and 70 years of age. All participants were native speakers of German and had not learned another language before the age of 5. Participants had received formal education in German for an average of 16 years (SD: 3, range: 7–25) and reported no perceptual, cognitive, or language-related impairments, and normal or corrected-to-normal vision (including intact colour vision). A computer-based adaptation of the German version of the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005; German version: Thomann et al., 2018) was administered to limit the inclusion of participants with signs of age-related neurological impairment. No participants were excluded as a result of this screening, as all participants scored at least 26 out of 30 points. MoCA scores were not considered in further analyses. Additional participant information is reported in Table 1, and the sample's distribution over the age range is illustrated in Fig. 1.

Materials

The linguistic stimuli comprised spoken sentences recorded by a female native speaker of German. The target sentences consisted of copular sentences with a defining relative clause (see Table 2). The main clause introduced a human male referent, followed by a relative clause introducing a human female referent and a transitive verb. All referents (both in the main clause and the relative clause) were common nouns denoting professions (e.g., *der Koch* "the cook") or ranks of nobility (e.g., *die Prinzessin* "the princess") that have gender-specific terms in German (e.g., *der Koch* vs. *die Köchin* "the cook"$_{\text{Masc}}$ vs. "the cook"$_{\text{Fem}}$), or otherwise stereotypically gendered terms (e.g., *die Braut* "the bride"), and had masculine and feminine gender, respectively. To manipulate syntactic structure, half of the relative pronouns were in nominative case (*der* "who"$_{\text{Masc}}$) and half in accusative case (*den* "whom"$_{\text{Masc}}$), thereby forming subject-object-verb (SO) and object-subject-verb (OS) relative clauses, respectively. Only masculine nouns were included as pronoun antecedents because masculine singular pronouns always allow for unambiguous thematic role assignment in German, while feminine and neuter relative pronouns as well as plurals can render sentences ambiguous due to case syncretism.

Each presentation list consisted of eight practice items, 24 target items, and 60 fillers ($n = 92$). An additional 56 items that were part of another project were intermixed with the other items; these are not discussed here. Thus, 148 items were presented in total. To deter participants from relying only on the visual scenes and responding without parsing the sentence, half of the visual scenes of filler trials depicted the sentence incorrectly. Sentence-picture incongruence in these items was realized in terms of the depicted action ($n = 8$), action direction ($n = 12$), or number/location mismatches ($n = 8$). All visual scenes depicted only the referents mentioned in the sentence. Item order within each list was fully randomized for each participant.

Half of the spoken sentences were presented in isolation, and half alongside visual-scene depictions (see Table 2, "Visual Scene"). Depictions consisted of photos of Playmobil© figurines performing actions, against a white background. The photos were taken in a well-lit room with a Canon EOS 40D digital camera and subsequently edited using the open-source software GIMP (GNU Image Manipulation Program) software (version 2.10.20; The GIMP Development Team, 2019). All pictures were cropped to a 1:1 width-to-height ratio, and their visual features were kept as similar as possible across the different conditions (e.g., characters' size and location on the screen, their respective position, brightness, saturation of colour features, etc). Following each sentence presentation, participants saw a written probe question (in the passive voice) targeting agent identification (see Table 2, "Probe"). Half of the questions referred to the male and half to the female character. Half of the questions required a *yes* and half a *no* response.

Procedure

Testing was conducted fully remotely due to the Covid-19 pandemic. The experiment was programmed in E-Prime 3.0 (Psychology Software Tools Inc., 2016) and conducted remotely through E-Prime Go 1.0 (Psychology Software Tools Inc., 2020). Prior to the experiment, all participants completed a demographic questionnaire, providing information on their gender, date of birth, education (in years), native

Table 1
Participant information by decade (means and SDs). WM and Stroop scores z-transformed and centred around their means. 'Cognitive Score' was computed by averaging across z-transformed WM and Stroop scores (and thus also represents a z-transformed score).

Age Decade	*n*	Gender	Age in years (SD)	Education in years (SD)	Cognitive Score (SD)	Z-transformed WM score (SD)	Z-transformed Interference control score (SD)
18–29	42	33F, 9 M	22 (3.16)	14 (3.10)	0.39 (0.50)	0.38 (0.48)	0.39 (0.83)
30–39	21	16F, 5 M	34 (2.94)	18 (2.60)	0.17 (0.74)	0.26 (0.82)	0.08 (1.00)
40–49	32	21F, 11 M	43 (2.97)	17 (3.26)	−0.18 (0.96)	−0.11 (1.18)	−0.25 (1.13)
50–59	26	14F, 12 M	55 (3.43)	16 (2.78)	−0.19 (0.76)	−0.20 (1.12)	−0.18 (0.76)
60–70	32	15F, 17 M	64 (2.86)	15 (3.03)	−0.13 (0.75)	−0.19 (1.03)	−0.06 (1.05)
Total	153	99F, 54 M	44 (16.05)	16 (3.35)	0 (0.78)	0 (0.98)	0 (0.99)

Note. Gender: F = female, M = male.

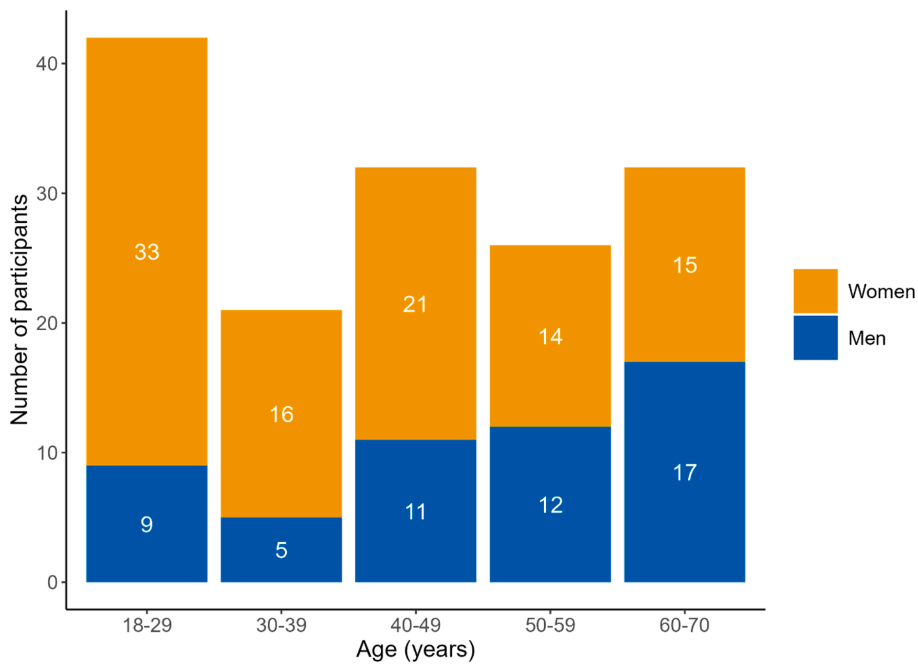

Fig. 1. Number of participants by age and by gender.

language, other languages spoken (specifying age-of-acquisition and acquisition context), handedness, vision/hearing deficits, and (past or current) language-related/cognitive/neurological impairments.

Task administration was arranged in two parts. The first part included the MoCA, a Stroop task (measuring IC), and a 1-back task (measuring WM span), presented to each participant in random order. The tasks were presented in black text against a white background in Consolas font size 18. The second part comprised the sentence-comprehension task. Participants were allowed to take a break between cognitive-task and sentence-comprehension parts. The duration of the experiment was approximately 25 min.

Cognitive tasks

Victoria Stroop test

In this version of the Stroop test, participants saw words that appeared in isolation in the center of the screen and were asked to indicate (by keystroke) the ink color of each word. Items belonged to one of three conditions: a) "x" condition (*xxxx*); b) "word" condition (e.g., *vorn* "in front"); c) "color" condition (e.g., *gelb* "yellow"). Key-color mappings were shown on-screen throughout the task. The task was untimed, and its total duration was about five minutes. Efficiency scores for "word"- and "color"-conditions were computed by dividing each participant's mean response time to correctly answered trials by the proportion of accurately answered trials. Then, IC scores were obtained by subtracting score in the "word" condition from the score in the "color"-condition. Lastly, scores were reversed for clarity, such that higher scores correspond to better IC ability.

N-back task

The *n*-back task was presented in three conditions in ascending order: 0-back, 1-back, 2-back. In this task, participants saw a series of letters and indicated whether each character was identical to a) a pre-defined character (e.g., *z*; 0-back), b) the character presented in the previous trial (1-back), or c) the character presented two trials earlier (2-back). Participants had 500 ms to respond to each character, after which a fixation cross appeared on the screen for 500 ms. The total duration of this task was about seven minutes. WM scores were computed by dividing mean latency by mean accuracy as described above. Scores were then reversed for clarity, such that higher scores represent better WM capacities. Due to ceiling and floor effects in the 0-back and 2-back conditions, respectively, only trials from the 1-back tasks were used to compute WM scores (see Pelegrina et al., 2015).

Sentence-comprehension task

Each trial in the sentence-comprehension tasks consisted of two steps (see Table 2): during the first slide, participants heard a spoken sentence; the second slide presented a written binary forced-choice probe question that participants were asked to answer through keypress on the

Table 2
Experimental design and example stimuli.

Condition	First slide Sentence	Visual Scene	Second slide Probe
SO, baseline	*Das ist der Koch, der die Braut verfolgt* "This is the cook who follows the bride"		*Wird die Braut verfolgt? / Wird der Koch verfolgt?* "Is the bride being followed?" / "Is the cook being followed?"
SO, scene			
OS, baseline	*Das ist der Koch, den die Braut verfolgt* "This is the cook whom the bride follows"		
OS, scene			

keyboard within 4000 ms (left-hand side: "Yes"; right-hand side: "No"; reminders of which key corresponds to which response remained on-screen throughout the task).

Data analysis

We computed Inverse Efficiency Scores (IES, Townsend & Ashby, 1978; 1983) by dividing each participant's response time for each correctly answered trial by their mean accuracy in that trial's condition. IES were computed for each trial separately (rather than by condition), thus keeping the data in non-aggregated form to avoid loss in statistical power (Barr, 2008; Schad et al., 2022). IES account for both latency and accuracy of responses within the same performance index (Bruyer & Brysbaert, 2011; Vandierendonck, 2018) and are an effective measure of overall task efficiency to quantify age-related changes in visuo-motor and language tasks (e.g., Reifegerste, 2024; Reifegerste et al., 2020; Statsenko et al., 2020). IES were reversed for clarity, such that higher scores correspond to better performance ("efficiency scores" henceforth).

All analyses were performed in R 2021.09.0 (RStudio Team, 2021). Efficiency scores were analyzed with linear mixed-effects regression models. All continuous predictors were centered around their mean. *P*-values were obtained from *t*-tests (degrees of freedom = difference between the number of observations and the number of fixed effects estimates in the model; Baayen et al., 2008). Following previous research (e.g., Connor et al., 2004; Reifegerste et al., 2021; Veríssimo et al., 2022), we also tested for non-linear effects of Age. Since no significant quadratic or cubic effects of Age emerged, higher-order polynomials were not tested for inclusion.

All regression analyses were carried out with the *lme4* R package (Bates et al., 2015), and figures based on model estimates were plotted using the *ggplot2* (Wickham, 2016) and *sjPlot* packages (Lüdecke, 2018). Where relevant, *p* values were adjusted with the Tukey method for a family of several estimates.

The linear mixed-effects regression model included Age, Sentence Structure, Visual Scene, Cognitive Score, and their interactions as fixed factors. Using a composite score for cognitive ability enabled us to decrease the number of collinear predictors as compared to the model including both WM and IC scores alongside age (see, e.g., Yoo et al., 2014).

In the initial model, the Sentence-Structure factor was sum-coded (SO: −0.5, OS: 0.5) and the Visual-Scene factor was treatment-coded (Baseline: 0, Visual Scene: 1). Thus, the intercept represents the average efficiency scores in response to Baseline conditions across clause types. The random-effects structure included by-item intercepts, by-item slopes for the effect of Cognitive Score, by-participant intercepts and slope adjustments for Sentence Structure, Visual Scene, Sentence Structure by Visual Scene, and Correct Response (i.e., whether the comprehension question required a *Yes* or *No* response).

Results

Descriptive results

Fig. 2 displays by-participant response times, accuracy, and efficiency scores by condition for each age decade. Pearson's product-moment correlation tests revealed that age and IC correlated negatively, as did age and WM capacity (see Table 3 and Fig. 3a-c). WM and IC correlated positively, in line with prior work (e.g., Morey et al., 2012). The composite cognitive-ability scores (i.e., the average of the z-transformed n-back and Stroop scores) showed strong positive correlations with IC and WM, and a negative correlation with age (Table 3, Fig. 3d-f).

Inferential statistics

Table 4 reports the number of correctly and incorrectly answered trials by Sentence Structure in each decade. Table 5 reports the results from the linear mixed-effects regression model fit to the data.

We detected significant effects of all fixed factors except for Age. The

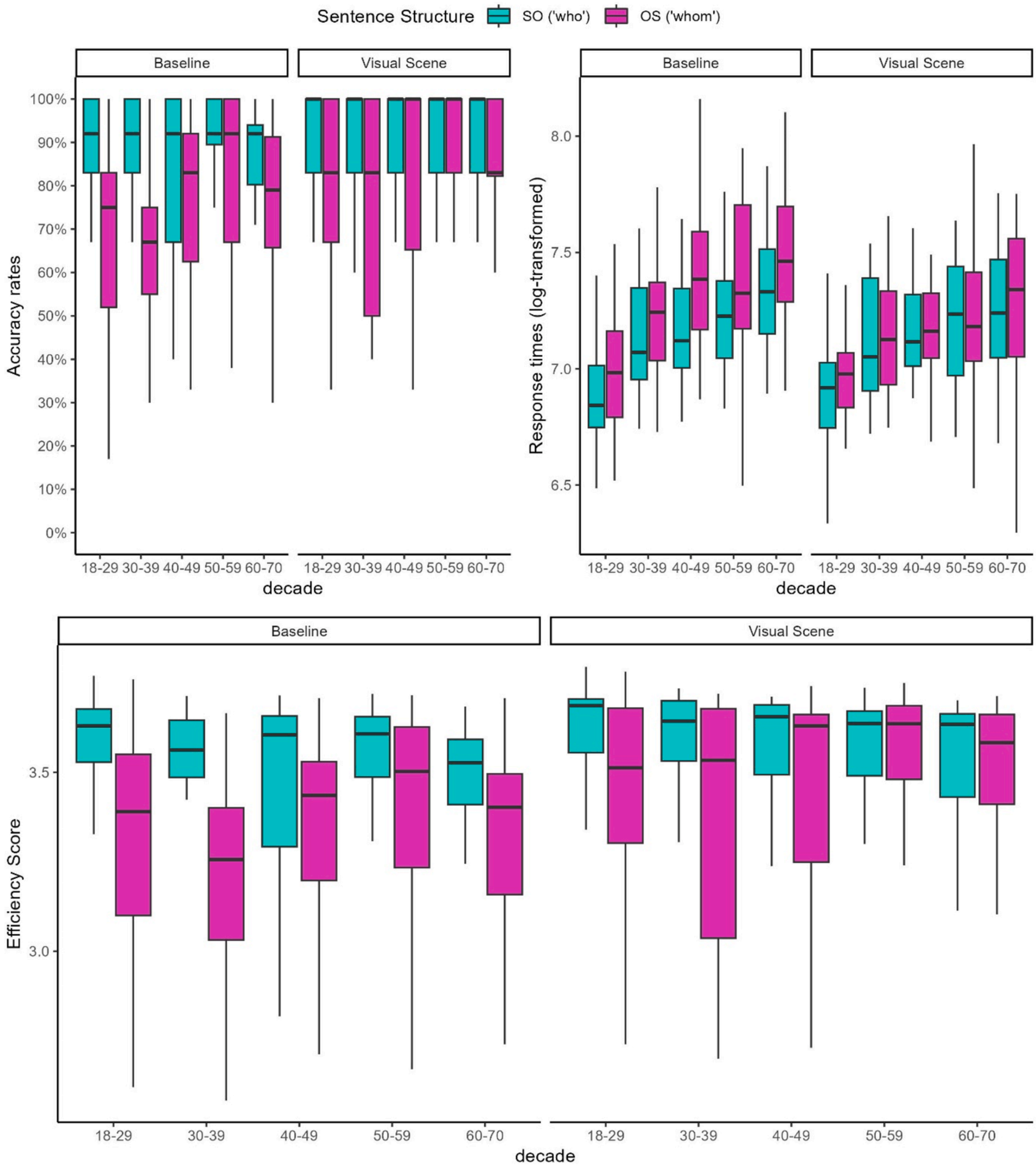

Fig. 2. Descriptive plots: Mean agent-identification Accuracy rates (top left), Response Times (top right) and Efficiency Scores (bottom) by condition by age. The boxes correspond to first and third quantiles of the distribution. Whiskers represent the location of the largest and lowest observed values (within 1.5 times the interquantile range)

Table 3
Correlations of age, WM score, Stroop score, and cognitive score.

Variables	Correlation Coefficient	P Value	T Value
Age ~ WM	−.222	.006	−2.81
Age ~ Interference Control	−.201	.012	−2.53
WM ~ Interference Control	.258	.001	3.30
Cognitive score ~ WM	.793	<.001	16.10
Cognitive score ~ Interference Control	.793	<.001	16.10
Cognitive score ~ Age	−.266	.001	−3.42

effect of Sentence Structure indicated that OS clauses were associated with worse performance than the average of both clause types in Baseline trials. An effect of Visual Scene revealed that performance was higher in response to sentences presented with visual scenes versus in isolation. In addition, the effect of Cognitive Score indicated that higher cognitive abilities were associated with better comprehension performance in Baseline trials. These main effects were qualified by several interactions.

First, a significant interaction of Sentence Structure × Visual Scene indicated that the difficulty associated with the comprehension of noncanonical OS clauses (i.e., the main effect of Sentence Structure in Baseline trials) was significantly smaller when a visual scene was

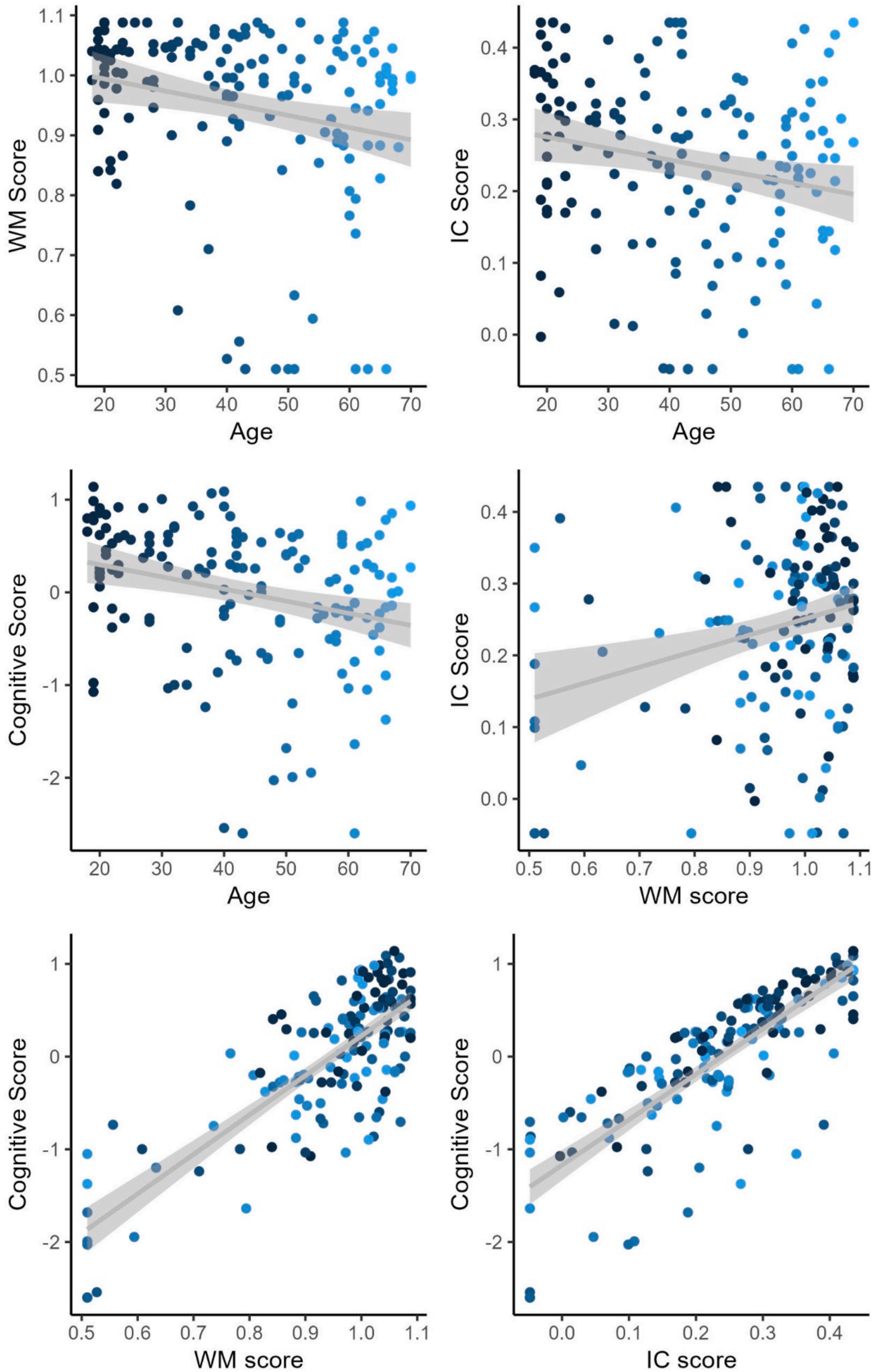

Fig. 3. Correlations of individual-level variables. All correlations were significant (ps ≤ .013). Each dot represents one participant. Dots are colored by age, with darker dots corresponding to younger age.

presented alongside the utterance. Second, greater Cognitive Scores were associated with particularly better performance in response to noncanonical OS clauses (vs. the average of both clause structures) (Sentence Structure × Cognitive Score interaction), and even more so when compared to OS utterances presented in isolation (Sentence Structure × Visual Scene × Cognitive Score interaction). Together, these patterns suggest that visual scenes were particularly helpful for comprehension in situations of greater task demands, such as when encountering noncanonical (vs. canonical) structures and/or for individuals with lower cognitive abilities.

Lastly, we found a nearly significant three-way interaction between Sentence Structure, Cognitive Score, and Age; this marginal effect

Table 4
Number of correctly answered trials by Sentence Structure in each decade.

Accuracy	Sentence Structure	18–29	30–39	40–49	50–59	60–70
Inaccurate	**SO**	72	38	77	42	75
Accurate	**SO**	645	323	487	416	486
Inaccurate	**OS**	194	113	136	67	127
Accurate	**OS**	522	238	427	391	429

indicated that increasing age was associated with smaller SO-OS differences (i.e., smaller effects of Sentence Structure) in individuals with higher cognitive-ability levels – but only when utterances were presented in isolation.

To follow up on both three-way interactions, Sentence Structure was re-coded with treatment contrasts (i.e., SO structures were coded as 0 and OS structures as 1) and the model was re-fitted to provide slope estimates for each level of Sentence Structure separately. The effect of Cognitive Score was assessed by changing treatment-coding weights for the Visual Scene factor (Tables S1 and S2 in Supplementary Materials).

Table 5
Coefficients of fixed and random effects of the linear regression fitted to efficiency scores. Sentence Structure was sum-coded with 0.5 weights (SO: −0.5, OS: 0.5) to index the effect of an OS structure compared to the mean of both SO and OS structures. Visual Scene was treatment-coded to compare the presence of a Scene (coded as 1) to the Baseline (coded as 0). Thus, the intercept represents the mean efficiency score in Baseline conditions across both Sentence-Structure levels and at the mean values of Age and Cognitive Score.

Predictor		**Estimate**		**Std. Error**	**t value**	**p value**	
(Intercept)		3.40		0.02	150.15	<.001	
Sentence Structure		**−0.21**		**0.03**	**−6.29**	**<.001**	
Visual Scene		**0.11**		**0.02**	**6.01**	**<.001**	
Age		<0.01		<0.01	0.03	.978	
Cognitive Score		**0.07**		**0.02**	**2.96**	**.004**	
Sentence Structure × Visual Scene		**0.09**		**0.04**	**2.29**	**.023**	
Sentence Structure × Age		<0.01		<0.01	1.67	.096	
Visual Scene × Age		<0.01		<0.01	0.87	.386	
Sentence Structure × Cognitive Score		**0.13**		**0.04**	**3.24**	**.001**	
Visual Scene × Cognitive Score		−0.03		0.02	−1.22	.225	
Cognitive Score × Age		<0.01		<0.01	0.04	.971	
Sentence Structure × Visual Scene × Age		<0.01		<0.01	−0.29	.775	
Sentence Structure × Visual Scene × Cognitive Score		**−0.15**		**0.05**	**−3.02**	**.003**	
Sentence Structure × Cognitive Score × Age		**0.01**		**<0.01**	**1.95**	**.053**	
Visual Scene × Cognitive Score × Age		<0.01		<0.01	0.08	.936	
Sentence Structure × Visual Scene × Cognitive Score × Age		<0.01		<0.01	−1.06	.290	
Random effects	**Name**	**Variance**	**SD**	**Correlation**			
Subject	(Intercept)	0.05	0.22				
	Sentence Structure	0.14	0.38	.51			
	Visual Scene	0.03	0.18	−.63	−.40		
	Correct Response	<0.01	0.01	.02	.08	−.18	
	Sentence Structure × Visual Scene	0.20	0.45	−.36	−.69	.58	.03
Item	(Intercept)	<0.01	0.01				
	Cognitive Score	<0.01	<0.01	−.65			
Residual		<0.01	0.11				

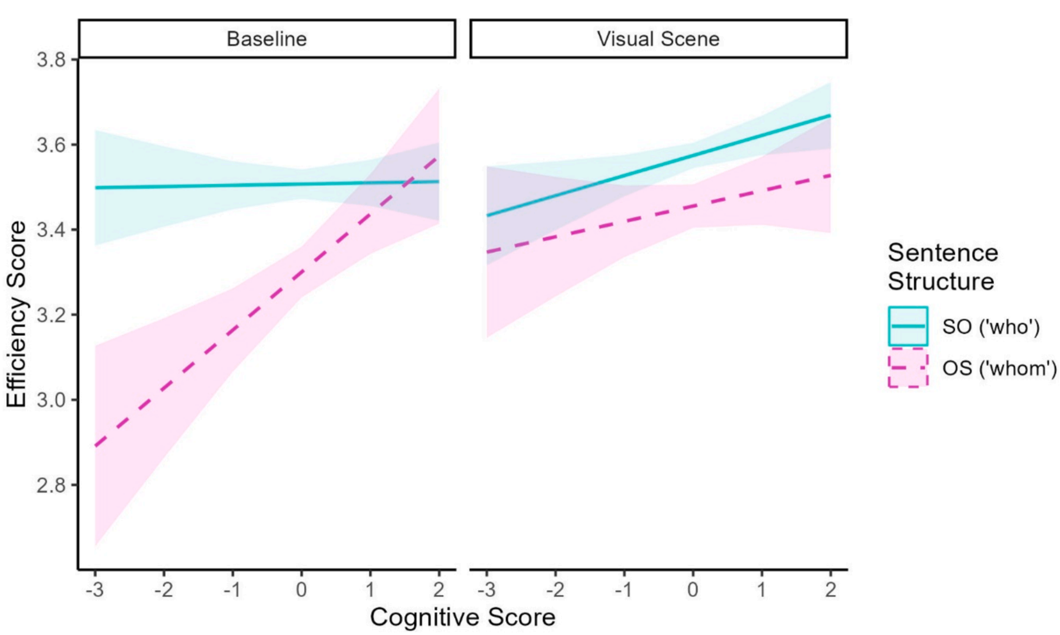

Fig. 4. Linear regression predicted values for Sentence Structure × Visual Scene × Cognitive Score on efficiency. Dashed and solid lines represent mean efficiency (solid: canonical SO sentences, dashed: noncanonical OS sentences) and the shaded bands represent 95 % confidence intervals.

In Baseline conditions, we did not find an effect of Cognitive Score on comprehension of SO structures ($t = 0.13$, $p = .898$), while increasing Cognitive Scores were associated with significantly better comprehension of OS structures ($t = 3.25$, $p = .001$). In Visual-Scene conditions, increasing Cognitive Scores were associated with smaller but significant performance increases ($t = 2.39$, $p = .018$) regardless of Sentence Structure (Fig. 4).

Turning to the Sentence Structure × Cognitive Score × Age interaction (Fig. 5), increasing age showed a marginal tendency to be associated with poorer performance in individuals with higher cognitive scores in Baseline SO conditions ($t = -1.78$, $p = .077$). Instead, increasing age tended to improve performance in individuals with higher cognitive scores responding to Baseline OS trials ($t = 1.95$, $p = .095$). In younger participants (e.g., the lower quartile of the age range, Fig. 5, left), increasing cognitive-ability levels led to similar performance increases in response to canonical and noncanonical sentences. In the median quartile (Fig. 5, center), increasing cognitive-ability levels led to performance increases only in response to noncanonical sentences. In the upper quartile (Fig. 5, right), increasing cognitive-ability levels led to performance increases in response to noncanonical sentences and decreases in response to canonical sentences. We discuss these patterns below. The Age × Cognitive Score interaction was non-significant in either Visual Scene condition, suggesting that the visual cues rendered cognitive-ability levels less central to successful performance.

Finally, we investigated whether the effects of WM and IC on performance were dissociable from one another. A model was fitted including the interactions of 1) Sentence Structure, Visual Scene, and WM score, 2) Sentence Structure, Visual Scene, and IC score, 3) Sentence Structure, Age, and WM score, and 4) Sentence Structure, Age and IC score; see Table S3 in Supplementary Materials. This latter model exhibited numerically worse AIC and BIC compared to the model including composite Cognitive Scores.

Discussion

The current study investigated whether visual information benefits syntactic comprehension across the adult lifespan and at varying levels of cognitive abilities. Participants listened to canonical subject-object (SO) and noncanonical object-subject (OS) clauses (e.g., *Das ist der Koch, der die Braut verfolgt* "This is the cook who follows the bride" vs. *Das ist der Koch, den die Braut verfolgt* "This is the cook whom the bride follows") presented either in isolation or alongside an image depicting the scene, and answered binary questions targeting agent identification (e.g., *Wird die Braut verfolgt?* "Is the bride being followed?"). Our results showed that:

- Visual-scene information benefited comprehension performance, especially in response to noncanonical structures. This interaction was modulated by cognitive-ability levels, rather than by age.
- Age-related changes in comprehension performance tended to be modulated by individual levels of cognitive ability: increasing age was associated with marginally greater benefits from increasing cognitive-ability levels in response to noncanonical (but not canonical) sentences.

Our results indicated that spoken comprehension performance was affected by the structural complexity of the relative clause (effects of Sentence Structure), by whether it was accompanied by a visual scene (effects of Visual Scene), and by participants' performance in our cognitive tasks tapping WM and IC (effects of Cognitive Score), both additively and interactively. We discuss these effects in turn.

The results as to the effect of Sentence Structure closely align with the assumption that noncanonical (vs. canonical) clause structures increase sentence comprehension demands in German (Adelt et al., 2017; Vos et al., 2001), which confirms the suitability of our sentence materials to manipulate syntactic complexity. In noncanonical clauses, a superficial, frequency-based heuristic strategy – assigning the subject role to the first-mentioned referent – supports an interpretation that is at odds with an interpretation conveyed by the morphosyntactic markers, which instead signal that the first-mentioned referent is in fact the object of the relative clause (Ferreira et al., 2009, Karimi & Ferreira, 2016). In contrast, canonical clauses do not entail competing representations from word-order and morphosyntactic information, and the interpretation can be derived with minimal cognitive conflict.

The findings as to the effect of Visual Scene support our hypothesis that the availability of visual information benefits utterance comprehension compared to utterances presented in isolation. This result is in line with current models of visuo-linguistic integration positing that the contents of the visual display contribute to sentence interpretation (Knoeferle & Crocker, 2006). Extending prior work on the time course of

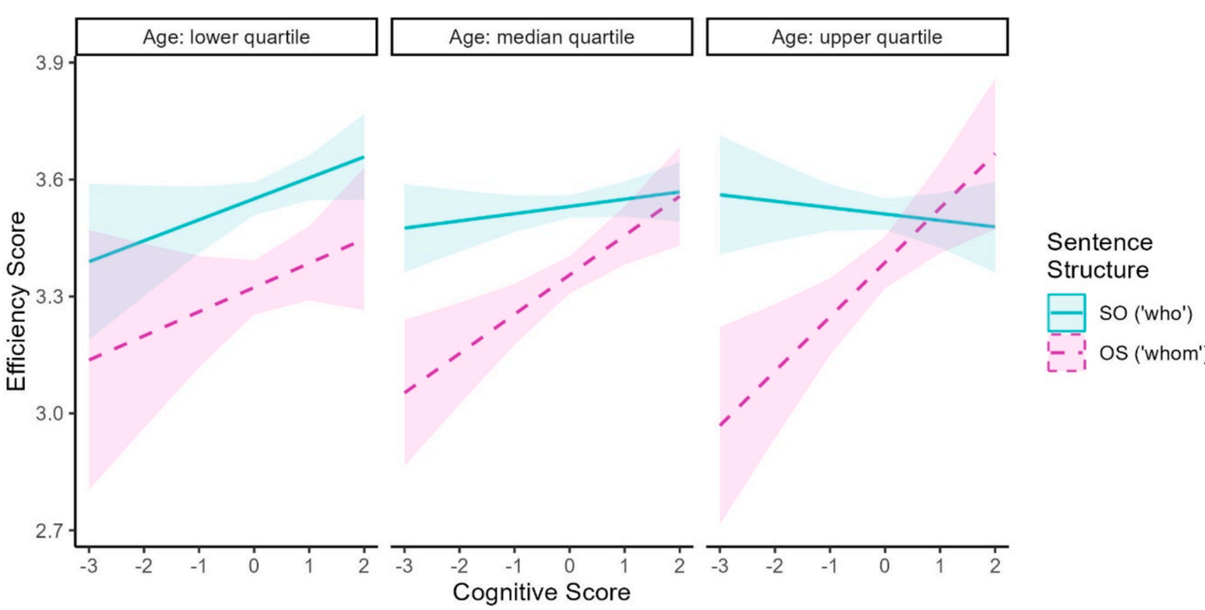

Fig. 5. Linear regression predicted values for Sentence Structure × Age × Cognitive Score on efficiency. Solid and dashed lines represent mean efficiency (solid: canonical SO sentences,dashed: noncanonical OS sentences) and the shaded bands represent 95 % confidence intervals.

visuo-linguistic integration, the current results provide novel insights as to its consequences, by showing beneficial effects of visual information on the recall of thematic-role representations post-sentence. Additionally, the interaction between Sentence Structure and Visual Scene indicated that visual-scene information was particularly beneficial for the comprehension of utterances containing noncanonical (vs. canonical) clauses. Such effect of visual cues can be explained in terms of the visually conveyed thematic roles (contributing to) determining which thematic-role configuration (i.e., action direction) is perceived as the most likely to be expressed by the sentence. While the first-mentioned referent is overwhelmingly assumed to take on the agent (vs. patient) role of the action when utterances are presented in isolation, inspecting a visual depiction in which the first-mentioned referent is taking on the patient role increases the likelihood of the patient-first interpretation, and may thus facilitate comprehension by rendering generally dispreferred configurations easier to predict, comprehend, and recall.

In their eye-tracking study, Knoeferle and Kreysa (2012) found that a speaker's gaze towards an upcoming sentence referent neutralized SO-OS differences in fixation latencies; in contrast, in the current study the presence of visual information yielded attenuated but still significant SO-OS differences. This apparent discrepancy might be attributed to differences in the tasks and visual stimuli used in the two studies. First, the probe questions administered in the current study presented an additional level of complexity as compared to oculomotor behavior captured by eye-tracking. Indeed, the use of agent-identification questions has been criticized, as inaccurate responses may be caused not only by erroneous representations formed during sentence processing, but also by failures in the retrieval of accurate representations from memory (Bader & Meng, 2023; Meng & Bader, 2021). Our results may thus indicate that visual information supported the formation of more accurate thematic-role representations, the retrieval of such representations, or both.

Second, unlike a speaker's gaze, the visual information presented in the present study was not deictic in nature, but rather conveyed meaning semantically. Decoding semantic (vs. deictic) meaning is likely to be less automatic, as it does not physically point to its referred meaning, which might cause our visual scenes to be more effortful and less immediate to integrate with representations conveyed by the utterance. For example, Kamide et al. (2003, Exp. 2) tracked participants' eye movements towards non-deictic depictions of sentence referents while listening to German SO/OS sentences (e.g., *The hare will soon eat the cabbage*). Anticipatory fixations were detected only in response to SO structures. This suggests that syntactic prediction preferences may be influenced by semantic and deictic visual information to different degrees (see also Kreysa et al., 2018). Against this background, the current study provides evidence for a durable effect of the interaction of syntactic interpretation preferences and (semantic) visual cues on thematic-role comprehension.

Importantly, both effects discussed so far (main effect of Sentence Structure and Sentence Structure × Visual Scene interaction) were further modulated by varying levels of cognitive abilities. A Sentence Structure × Cognitive Score interaction revealed that greater cognitive ability was particularly beneficial for performance with noncanonical OS structures, compatible with the idea that canonical sentences entailed little to no cognitive conflict, thus rendering individual cognitive-ability levels less critical for successful comprehension. Furthermore, the Sentence Structure × Cognitive Score interaction was only detected when utterances were presented in isolation (Sentence Structure × Visual Scene × Cognitive Score).

This pattern broadly supports previous work highlighting the role of measures such as WM and IC for sentence comprehension, particularly in the face of increased task demands (for a review, see Lau & Tanaka, 2021). It moreover underscores that the sentence-structure manipulation effectively increased cognitive task demands, and that our composite measure of cognitive ability was able to predict individual differences in performance selectively in the more challenging condition.

In response to noncanonical OS sentences, participants at the higher end of the cognitive-score scale successfully made use of the morphosyntactic markers to achieve comprehension regardless of the visual scene. In contrast, participants at the lower end of the cognitive-score scale relied more prominently on the visual scenes to achieve comprehension of these more challenging syntactic constructions (Fig. 4).

Our findings indicate that cognitive skills such as WM and IC can exert positive effects on sentence comprehension. These effects were particularly pronounced in situations of greater task demand – such as when the sentence is relatively more complex or when no other information sources are available to guide sentence interpretation. Further, the presence of visual information may alter comprehenders' preference for a thematic-role configuration over another – namely biasing comprehension towards the visually conveyed interpretation of the utterance. As a consequence, the conflict engendered by the personal pronoun in accusative (*den* "whom," vs. nominative, *der* "who") is significantly diminished, and thus participants do not need high levels of cognitive abilities to resolve such conflict successfully.

We did not find conclusive effects of Age on comprehension, with marginal decreases and increases for SO and OS sentences, respectively. This is consistent with previous work showing only relatively small age-related changes in syntactic comprehension, and with the results from Stine et al. (1990), as changes in cognitive abilities, but not age, played a central role in the comprehension of utterances in isolation. Given our relatively young sample, which spanned until only 70 years of age, it is also possible that declines in sentence comprehension may occur only at later stages, as has been found for other aspects of language (e.g., vocabulary size; Salthouse, 2010). Based on the proposal for a shift from algorithmically to semantically derived representations with increasing age, we had hypothesized that increasing age may be associated with greater benefits from the presence of visual cues supporting comprehension. This hypothesis was not supported: We found that the presence of visual cues benefited performance across the lifespan to a similar extent. On the one hand, this evidence extends the applicability of the CIA by demonstrating the validity of its claims in participants from across the adult lifespan. On the other hand, we did find effects of increasing age that were selective to Baseline trials and modulated by varying cognitive-ability levels (Fig. 5): greater cognitive abilities were more beneficial for the comprehension of noncanonical sentences in older than in younger participants. In contrast, the pattern for canonical sentences was somewhat puzzling, as the beneficial effects of increasing Cognitive Scores on comprehension were limited to younger participants (i.e., lower age quartile) and reversed for older participants (upper age quartile). One tentative explanation might be that older participants with low cognitive-ability levels overwhelmingly responded to utterances in isolation based on word order (rather than morphosyntactic case markers), leading to the largest observed SO-OS differences. In contrast, higher cognitive-ability levels might have allowed older participants to refrain from using heuristic strategies that work well in naturalistic settings (e.g., based on word order) – for example, because they might have noticed that the frequency with which noncanonical sentences appeared in our stimulus set (50%) was far higher compared to their probability in spoken German (Zubin, 1979). If so, high-ability older participants might have been able to adjust their own interpretation preferences (or expectations, or "priors") towards a noncanonical patient-first interpretation, leading to the observed increases in performance when responding to noncanonical sentences and decreases when responding to canonical sentences. Some support for these speculations comes from Stine-Morrow (2007), who argued that older adults may exploit their explicit knowledge strategically to support comprehension in the face of specific age-related declines (e.g., the large SO/OS differences which were particularly evident in older versus younger individuals with lower cognitive-ability levels), thus suggesting that age-related shifts in heuristic strategies for comprehension might be self-regulated and based on considerations of effort and attention allocation. However, more research is needed to pinpoint the source of this unexpected pattern.

Limitations and future directions

This study presents a few limitations. For one, collecting data remotely is likely to have triggered a sampling bias, as the older participants who signed up for and were able to complete a web-based study were likely quite familiar with computer technology. Perhaps because of this, our sample was relatively young, limiting the generalizability of our conclusions. In addition, the technological equipment of our participants may have varied systematically as a function of age, as older participants are likely to possess older and less powerful hardware than younger university students.

Furthermore, the use of efficiency scores for our analysis limits our investigations to imbalances in the number of trials available for the analysis, which exhibited systematic variability as a function of condition and age.

Moreover, as with most studies on cognitive aging, our cross-sectional sample may be subject to cohort effects and similar between-subject differences that were not assessed and thus not controlled for. Future work should address this shortcoming – for example by combining cross-sectional and longitudinal sampling – to advance our understanding of how individual levels of cognitive abilities modulate lifespan changes in comprehension and recall.

Lastly, while the present study pointed to important roles for cognitive abilities in the use of visual information during sentence comprehension, future studies might complement the behavioral approaches used here with brain-imaging techniques (e.g., (f)MRI). As laid out in the Introduction, it has been suggested that (age-related) shifts in heuristic-strategy use might be tied to declines in the connectivity of the frontoparietal control network (Spreng et al., 2010; Campbell et al. 2012). If this is the case, we might, for example, expect similar correlations between the amount of benefit conferred by visual information and measures of neural connectivity (e.g., fractional anisotropy, mean diffusivity) as we found for measures of cognitive capacity (i.e., cognitive scores) in the present study, further elucidating the (neuro-)cognitive mechanisms involved in sentence comprehension.

CRediT authorship contribution statement

Carlotta Isabella Zona: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jana Reifegerste:** Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Experimental materials, collected data, and analysis scripts are available on OSF (https://osf.io/z9ach/).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jml.2024.104576.

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