# No evidence for strategic nature of age-related slowing in sentence processing

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**Abstract**

Older adults demonstrate a slower speed of linguistic processing, including sentence processing. In non-linguistic cognitive domains such as memory, research suggests that age-related slowing of processing speed may be a strategy adopted in order to avoid potential error and/or to spare “cognitive resources". So far, very few studies have tested whether older adults’ slower processing speed in the linguistic domain has a strategic nature as well. To fill this gap, we tested whether older adults can maintain language processing accuracy when a faster processing speed is enforced externally. Specifically, we compared sentence comprehension accuracy in younger and older adults when sentences were presented at the participant’s median self-paced reading speed versus twice as fast. We hypothesized that an external speed increase will cause a smaller accuracy decline in older than younger adults because older adults tend to adopt self-paced processing speeds “further away” from their performance limits. The hypothesis was not confirmed: the decline in accuracy due to faster presentation did not differ by age group. Thus, we found no evidence for strategic nature of age-related slowing of sentence processing. Based on our experimental design, we suggest that the age-related slowing of sentence processing is caused not only by motor slowdown, but also by a slowdown in cognitive processing.

*Keywords:* aging; processing speed; sentence comprehension; language and aging; processing strategies

**Introduction**

Aging is known to affect various levels of language processing: phonological perception (Pichora-Fuller, 2003; Strouse, Ashmead, Ohde, & Grantham, 1998; Ward, Shen, Souza, & Grieco-Calub, 2017), word finding (Gordon & Kindred, 2011; Schmitter-Edgecombe, Vesneski. & Jones, 2000), comprehension of complex syntactic structures (Obler, Fein, Nicholas, & Albert, 1991; Stine-Morrow, Ryan, & Leonard, 2000), discourse production (Juncos-Rabadán, Pereiro, & Rodríguez, 2005), and other language domains (for reviews, see Burke & Shafto, 2008; Clark-Cotton, Goral, Williams, & Obler, 2007; Thornton & Light, 2006). Across domains, an age-related decline has primarily been demonstrated in language processing speed, both in language production and in behavioral response to language comprehension, whereas evidence for declines in language processing accuracy is somewhat more mixed. For example, in sentence comprehension, a large body of research has shown a general age-related slowing of sentence processing, whereas comprehension accuracy declines only for most difficult sentence types (Caplan, DeDe, Waters, Michaud, & Tripodis, 2011; Caplan & Waters, 2005; Stine-Morrow et al., 2000). A general decrease in processing speed is undoubtedly the core manifestation of age-related changes in cognition, and some also consider it to be the underlying cause of changes in other performance measures (Earles & Kersten, 1998; Salthouse, 1996, Salthouse & Ferrer-Caja, 2003; Takeuchi et al., 2011; although see Finkel, Reynolds, McArdle, & Pedersen, 2007, and Deary, Johnson, & Starr, 2010, for more complex relations between speed of processing and other cognitive measures).

Previous research has shown that older adults are not only slower in their own linguistic behavior (language production and behavioral response to language comprehension), which could be explained by purely motor slowdown, but also more vulnerable to faster presentation rate of linguistic input. As demonstrated in both classic and recent works in the auditory modality (Gordon-Salant & Fitzgibbons, 1997; Janse, 2009; Wingfield, McCoy, Peelle, Tun, & Cox, 2006; Wingfield, Peelle, & Grossman, 2003; Wingfield, Poon, Lombardi, & Lowe, 1985), older adults have steeper rates of comprehension decline when speech presentation rate is increased. In other words, their disadvantage in comprehension accuracy compared to younger adults is amplified by or emerges at faster speech presentation rates. Janse (2009) extended this finding to the visual modality, showing that the negative effect of faster presentation rate in auditory sentence comprehension in older adults was correlated to its negative effect in visual sentence presentation. The findings for the visual modality are inconsistent though (Humes, Burk, Coughlin, Busey, & Strauser, 2007; Spehar, Tye-Murray, & Sommers, 2004), so further research is needed to establish whether older adults are affected by faster presentation rate in the visual modality more than younger adults.

However, as also pointed out by Janse (2009), an equally relevant question is what rate of linguistic input older adults adopt if given control over it: namely, whether they always choose slower rates than younger adults, and when they do, why. In the visual modality, this question is particularly relevant to real-world language processing because we are typically free to choose our own speed while reading. But even regardless of ecological validity, investigation of preferred reading speed can provide an insight into the nature of apparent behavioral slowing of older adults in language processing in general. Specifically, it is of interest whether older adults’ slowing in preferred reading speed is necessary to ensure maximum comprehension accuracy or reflects ‘underperformance’ adopted for other, ‘strategic’, reasons.

One possible reason why older adults could choose slower language processing rates strategically is caution. Caution as a reason for strategical slowing in older adults has already been implicated in non-linguistic cognitive domains. For example, older adults show relatively greater relative post-error slowing than younger adults (Band & Kok, 2000, mental rotation task; Dutilh, Forstmann, Vandekerckhove, & Wagenmakers, 2013, visual random dot motion task and also a linguistic lexical decision task; Smith & Brewer, 1995, visual discrimination task). This slowing is likely a strategy adopted to avoid future errors. Beyond post-error slowing data, further evidence for older adults' more cautious response strategies comes from computational approaches such as diffusion modeling. Diffusion models are usually fitted to data from two-choice decision tasks and allow to model speed-accuracy tradeoffs – in particular, in terms of a model parameter called "boundary separation". This parameter reflects response conservativeness: that is, how much evidence is needed before the individual is ready to produce a response. Based on diffusion modeling of speed-accuracy data, many studies have concluded that older adults show wider "boundary separation" than younger adults and need more evidence, accumulated over time, to produce a response (Ratcliff, Thapar, Gomez, & McKoon, 2004, lexical decision task; Starns & Ratcliff, 2010, letter discrimination, brightness discrimination, memory recognition tasks; see also Reike & Schwarz, 2018, number comparison, using random-walk models). This implies that their slower responses are driven by more conservative response strategies, possibly due to caution, rather than by a general cognitive slowdown. These "conservative" / cautious processing strategies are not necessarily adopted consciously. For example, post-error slowing can occur even when an individual is not consciously aware of the error (Hester, Foxe, Molholm, Shpaner, & Garavan, 2005). So here, by using the term 'strategy', we mean any adaptation of behavior to processing circumstances, without implying any purposefulness or awareness. Similarly to motor adaptation strategies, whereby new movement patterns are adopted by the motor system in response to joint fatigue or pain (Cowley, Dingwell, & Gates, 2014; Lund, Donga, Widmer, & Stohler, 1991), unconscious strategies can also emerge in the aging cognitive system in order to adapt to its limited resources.

Possible reasons for more cautious strategies, which could underlie the age-related slowing in language tasks as well, are negative expectations (Löckenhoff, 2009) and self-perceptions (Levy, 2003) of the impact of aging on cognition. Negative self-expectations as the reason driving more cautious processing strategies have not been investigated in the linguistic domain, to the best of our knowledge, but have been widely discussed in memory research. Older adults often perceive changes in their cognitive functioning as more severe than they actually are. For example, Rahhal, Hasher & Colcombe (2001) conducted a memory test on newly learned trivia and showed that older adults performed worse than younger adults only when test instructions emphasized the memory component of the task, thus evoking negative self-expectations (see also Chasteen, Pichora-Fuller, Dupuis, Smith, & Singh, 2015; Hess, Auman, Colcombe, & Rahhal, 2003; also in the memory domain). In the same vein, Lachman & Andreoletti (2006) showed that older adults who perceived less control over own cognitive functioning were less likely to apply effective strategies in a word list recall task, likely due to low expectations for their own performance.

But more cautious strategies are not the only reason to hypothesize that the age-related slowdown of language processing speed can be strategic, rather than strictly necessary to ensure high performance. Another strategic reason why older adults may prefer slower language processing speed is to spare cognitive resources. Older adults commonly experience not only general and/or physical fatigue (Avlund, Rantanen, & Schroll, 2007; Vestergaard et al., 2009), but also mental / cognitive / “brain” fatigue (Holtzer, Shuman, Mahoney, Lipton,

& Verghese, 2011). This is likely due to age-related physiological changes negatively affecting the functioning of the brain, such as grey-matter loss, myelin sheath deterioration, possible subclinical ischaemia and microvascular changes (Eckert, 2011; Eckert, Keren, Roberts, Calhoun, & Harris, 2010; Lu et al., 2011; Peters, 2006), and to compensatory recruitment of more extensive neural substrate than in younger adults (Wingfield & Grossman, 2006). To avoid excessive cognitive fatigue caused by exhausting the resources of the aging brain, older adults may avoid conditions presenting a high cognitive load. For example, Hess and colleagues (Hess, 2014; Hess, Smith, & Sharifian, 2016) argue that older adults show less engagement into cognitively demanding activities that are perceived as more effortful and are associated with greater fatigue and cognitive depletion than in younger adults. Similarly, in the language domain, older adults may attempt to minimize cognitive fatigue by using slower and thus less challenging language processing speeds than necessary to ensure comprehension accuracy (Brébion, 2003).

Lastly, one more reason to hypothesize that older adults' slower language processing speed is an optional strategy, rather than an absolute necessity for maintaining high accuracy, comes from studies showing that non-motor reactions to linguistic stimuli are not always slowed in older adults. Although numerous electrophysiological studies show delayed N400 or P600 components in older adults (Gunter et al., 1992; Kutas & Iragui, 1998; Zhu, Hou, & Yang, 2018), there are exceptions. For example, Kemmer, Coulson, De Ochoa & Kutas (2004) showed that P600 in response to syntactic violations did not have an increased latency in older compared to younger adults. Interestingly, older adults were still slower in the grammaticality judgment task following each sentence. This dissociation between electrophysiological and behavioral effects suggests that the slowing occurs in memory or motor processing (Kemmer et al., 2004) or in syntactic processing subsequent to P600.

Another example is the absence of age-related shifts in N400 latency in response to auditory words in connected speech (Federmeier et al., 2003), even though earlier sensory components were delayed in older adults. In Faustmann, Murdoch, Finnigan, & Copland (2007), N400 in response to semantic anomalies in auditory sentences was decreased in amplitude but not delayed in latency in elderly compared to middle-aged adults. Along the same lines as these electrophysiological studies, some eye-tracking research shows that eye movements in response to linguistic stimuli are not necessarily slowed in older adults even if subsequent behavioral response is (Ayasse, Lash, & Wingfield, 2016, in a population with mild hearing impairment). Taken together, these findings suggest that age-related slowing does not uniformly occur over the entire course of any type of language processing. Perhaps, the delays do not occur “across the board” and instead emerge in particular components of language processing, possibly for strategic reasons outlined above, such as cautious response criteria or sparing of cognitive resources. Alternatively, a motor slowing can largely account for the age-related slowdown in behavioral measures of language processing that require an overt or motor response. If any of this is true, it is imaginable that the age-related slowdown in language processing can be eliminated under certain processing conditions.

To summarize, we have presented evidence of older adults’ more cautious strategies in non-linguistic tasks (implicated by greater post-error slowing and by diffusion modelling), possibly driven by negative self-expectations, of their general tendency to spare cognitive resources, and of sporadic lack of age-related slowdown in language processing measures that do not require an overt/motor response. Based on this evidence, one can hypothesize that older adults may ‘underperform’ in their choice of language processing speed and adopt a slower speed than necessary for successful comprehension, due to caution and/or economy of cognitive resources. So far, this hypothesis has been tested only in few experiments using speed-accuracy tradeoff paradigms. In the study by Brébion (2001), older and younger adults judged semantic plausibility of sentences; instructions emphasized either speed or accuracy. Even when the instructions emphasized speed, older adults were not able to reach the processing speed of younger adults. Thus, the author concluded that the older adults' slower processing speed was an inevitable consequence of aging rather than an 'optional' strategy. In the same vein, Stine-Morrow, Shake, Miles and Noh (2006) used a speed-accuracy tradeoff paradigm in a sentence learning task and also found that older adults were less flexible in adapting their speed depending on task instructions. In other words, older adults showed less differentiation between the conditions emphasizing accuracy versus speed: in the condition emphasizing accuracy, they were similar in time allocation to younger adults; but in the condition emphasizing speed, they showed longer reading times than young adults.

However, speed-accuracy tradeoff paradigms used by Brébion (2001) and Stine-Morrow et al. (2006) focused on testing whether older adults' slower linguistic processing speed (specifically, sentence reading speed) is consciously adopted and easily self-controlled. It still appears possible that, although not consciously / purposefully, older adults may be underperforming with regard to language processing speed, using a slower speed than the fastest one allowing them to maintain high comprehension accuracy. In our study, we hypothesize that they do and thus will be able to still maintain high accuracy when task conditions force them to use a higher processing speed. Specifically, we test sentence comprehension accuracy under several presentation conditions: when sentence presentation is self-paced and when it is externally paced at two different speed levels. We expect that the self-paced reading speed adopted by older adults will be slower than the externally-set speed at which they would still maintain the same level of accuracy, whereas younger adults will tend to use self-paced speeds that are closer to their performance limits.

The novelty compared to work by Brébion (2001) and Stine-Morrow and colleagues (2006) is that our method eliminates confounding by conscious control and is not limited to testing whether older adults can consciously increase their processing speed relative to baseline. Somewhat similar designs have also been used by Hartley, Stojack, Mushaney, Annon, & Lee (1994), also in the visual modality, and Peelle & Wingfield (2005), in the auditory modality. Both of them also investigated the effects of changing the presentation rate in older versus younger adults relative to individually-determined values. However, the crucial difference is that their individually-determined values were rates at which a participant demonstrated a certain accuracy level. In our case, we manipulate the presentation rate relative to preferred (self-paced) reading speed, regardless of respective accuracy. So, even though our design seems to resemble that of Hartley et al. (1994) and Peelle & Wingfield (2005), it addresses a different question: namely, preferences in reading speed in older versus younger adults, rather than patterns of performance decline when presentation rate is changed relative to the one ensuring a certain level of performance in an individual.

## Method

### Participants

Twenty-four younger people (14 females; age: M = 19.8 years, SD = 1.9, range = 18-24; years of formal education: M = 13.0, SD = 1.7, range = 11-17) and twenty-four older people (16 females; age: M = 67.2 years, SD = 6.3, range = 59-81; years of formal education: M = 15.5, SD = 2.7, range = 10-21) took part in the experiment. Participants in the younger group were all recruited by word of mouth and were primarily (but not exclusively) undergraduate university students. Participants in the older group were recruited either by word of mouth or via advertising at a local senior center; all of them were communitydwelling. Although older participants had more years of education, $t(46) = 3.86$, $p < .001$, younger adults were on track to achieving the same level of education. Both groups included mixed occupations and did not include linguists or psychologists except for three Psychology students in the younger group.

All participants were native speakers of Russian and did not report any speech, language or reading disorders, or any psychiatric, neurological, or vascular disorders, with an exception of self-reported hypertension (seven in the older group and three in the younger group). All participants had normal or corrected to normal vision; no participants reported any diagnosed hearing impairment. The study was carried out in accordance with the ethical standards of the American Psychological Association (1992) and was approved by the local Institutional Review Board. All participants signed an informed consent form in accordance with the Declaration of Helsinki.

**Stimuli**

The experiment used three stimuli sets, counterbalanced between the experimental sessions. Each set included 100 sentences: 74 grammatically complex sentences and 26 grammatically simpler sentences. Grammatically complex sentences belonged to grammatical types previously shown to cause difficulties even for individuals without any language deficits: sentences with a non-finite (participial) clause attached to one of the two nouns in the genitive noun phrase (Chernova & Slioussar, 2014, 2016); with semantically reversible subject and object (with non-canonical object-verb-subject and canonical subject-verb-object word order; Sekerina, 2003, Slobin, 1966); with subject- and object-relative clauses (Wanner & Maratsos, 1978; Traxler, Morris, & Seely, 2002); and with object relative clauses and reflexive pronouns (Laurinavichyute, Jäger, Akinina, Roß, & Dragoy, 2017). Both grammatically complex and simple sentences were included in order to avoid floor or ceiling effects and to ensure sufficient diversity of stimuli and thus to minimize within-experimental heuristics for processing repeating syntactic structures. No sentences contained any local or global syntactic ambiguities, there always was only one correct parsing of the sentence structure. Examples of each sentence type, along with comprehension questions, are presented in Table 1.

*Table 1.* Experimental stimuli.

| Sentence type | Example, with glosses and translations | N |
|---|---|---|
| 1. Grammatically complex sentences<br><br>1.1. With participle clause attached to one of the nouns in the genitive noun phrase | | |
| High attachment | *Мы совсем не знали компаньонк-у вдов-ы, переexa-вш-ую сюда недавно.*<br>companion-ACC widow-GEN move-PP-ACC<br>We did not know the widow's companion who moved here recently.<br><br>*Кто переехал сюда недавно?*<br>Who moved here recently?<br><br>*Компаньонка / Вдова*<br>Companion / Widow | 15 |
| Low attachment | *Распоряжение было отдано начальник-ом менеджер-а, выплати-вш-его премии.*<br>boss-INSTR manager-GEN pay-PP-GEN<br>The order was given by the boss of the manager who paid the bonuses.<br><br>*Кто выплатил премии?*<br>Who paid the bonuses?<br><br>*Менеджер / Начальник*<br>Manager / Boss | 15 |
| 1.2. With reversible subject and object | | |
| Non-canonical word order (object-verb-subject) | *Логопед-а на прошлой неделе попроси-л о помощи психолог.*<br>speech.therapist-GEN ask-PAST.3SG.M psychologist.NOM<br>The speech therapist was asked for help by the psychologist last week.<br><br>*Кто обратился за помощью?*<br>Who asked for help?<br><br>*Психолог / Логопед*<br>Psychologist / Speech therapist | 10 |
| Canonical word order (subject-verb-object) | *Пианистк-а во время перерыва рисова-л-а в блокноте скрипачк-у.*<br>Pianist.F-NOM draw-PAST-3SG.F violinist.F-ACC<br>The pianist was drawing the violinist in a sketchbook during the break.<br><br>*Кто рисовал?* | |

| | | |
|---|---|---|
| | Who was drawing?<br><br>*Пианистка / Скрипачка*<br>Pianist / Violinist | |
| 1.3. With dependent relative clause | | |
| Object-relative | *Географ, которого мудро наставлял историк, всегда уходи-л с работы поздно.*<br>Geographer.NOM historian.NOM leave-PAST.3SG.M<br>The geographer, who was wisely supervised by the historian, always left the office late.<br><br>*Кто был наставником?*<br>Who was supervising?<br><br>*Историк / Географ*<br>Historian / Geographer | 9 |
| Subject-relative | Режиссёр, которого представи-л начальству практикант, заикался от робости.<br>Film.director.NOM introduce-PAST.3SG.M intern.NOM<br><br>The film director, who was introduced to the authorities by the intern, was stuttering because of shyness.<br><br>*Кого представили начальству?*<br>Who was introduced to the authorities?<br><br>*Режиссёра / Практиканта*<br>Film director / Intern | 9 |
| 1.4. With reflexive pronouns | | |
| | *Танцовщица, которую актриса уговарива-ет выступать совместно,*<br>dancer.F.NOM actress.NOM persuade-PRES.3SG<br><br>*постоянно ограничива-ет себя в еде.*<br>limit-PRES.3SG REFL<br><br>The dancer, who the actress persuades to perform together, is always limiting her (*own*) food intake.<br><br>*Кто мало ест?*<br>Who limits her food intake?<br><br>*Танцовщица / Актриса*<br>Dancer / Actress | 10 |
| 2. Grammatically simple sentences<br>Besides the types below, fillers also included items with questions to inanimate objects, causal adjuncts, locative adjuncts, etc. | | |
| Question to numeral | *Изобретатель упорно работал над этим прибором в течение восьм-и лет.*<br>eight-GEN<br>The inventor has worked hard on this device for eight years.<br><br>*Сколько лет изобретатель работал над прибором?*<br>How many years has the inventor worked on the device?<br><br>*Восемь / Девять*<br>Eight / Nine | 5 |
| Question to adjective | *Малыш спрятал своего любимого плюшевого мишку в средн-ий ящик комода.*<br>middle-ACC<br>The kid hid his favorite teddy bear in the middle drawer.<br><br>*В какой ящик малыш спрятал мишку?* | 5 |

| | | |
|---|---|---|
| | In what drawer did the kid hide the teddy bear?<br><br>*В средний/В нижний*<br>Middle / Lower | |
| Question to time adjunct | *В пятниц-у домработница обычно мыла полы во всей квартире.*<br>Friday-ACC<br>On Fridays, the housekeeper usually washed the floors in the entire apartment.<br><br>*Когда домработница мыла полы?*<br>When did the housekeeper wash the floors?<br><br>В пятницу / В субботу<br>On Friday / On Saturday | 2 |

*Note.* Please note that, unlike their English translations, no Russian stimuli contained any local or global syntactic ambiguities; there was always only one correct response to the question. Glosses: NOM – nominative case, GEN – genitive case, ACC – accusative case, INSTR – instrumental case; M – male gender, F – female gender; SG – singular; PAST – past tense, PRES – present tense; REFL – reflexive pronoun; PP – participle.

Every sentence was followed by a comprehension question with two response options. In questions to grammatically complex sentences, the incorrect response was a noun that was mentioned in the sentence. Thus, the question assessed whether the participant correctly analyzed the grammatical structure of the sentence. To answer correctly, it was insufficient to rely on remembering individual lexical items from the sentences. In contrast, in questions to grammatically simple sentences, the incorrect response option was not mentioned in the sentence. Thus, these comprehension questions only probed lexico-semantic representations of sentences and did not assess the accuracy of the grammatical analysis. Questions to grammatically simple sentences probed not only nouns, but also adjectives, numerals, adverbs, and prepositional phrases, to ensure that participants paid attention to all of sentence content rather than only nouns.

The three stimuli sets used in the three experimental sessions were balanced on the following psycholinguistic variables, overall and within sentence types: lengths of sentences and comprehension questions (in words and syllables), average lemma frequency in sentences (Lyashevskaya & Sharov, 2012), lemma frequency of correct and incorrect question responses (Lyashevskaya & Sharov, 2012), length of correct and incorrect question responses (in syllables), number of grammatical genders in question responses, distance in words between subject and object (only for sentences with reversible subject and object), and number of verb tenses (past / present). Each stimuli set was pseudo-randomized in five different orders that were counterbalanced across participants. Pseudo-randomizations ensured that no two sentences of the same type appeared a row, except for grammatically simple sentences.

**Experimental design**

Prior to data collection, the experiment was pre-registered at the Open Science Framework (OSF) website[1]. The goal of the experiment was to test whether older adults, unlike younger adults, normally use reading speeds below their performance limits and thus would be able to maintain their comprehension level when forced to use a relatively faster reading speed (twice as fast as their self-paced speed). The experiment was conducted in two non-consecutive days (the mean interval between them did not significantly differ between participant groups: M = 4.6, SD = 2.9, range = 1-14 in the younger group; M = 4.9, SD = 4.1, range = 1-10 in the older group; $t(46) = 0.29$, $p = .78$). On both days, participants read sentences and answered a comprehension question after each sentence. On day 1, reading was self-paced (hereafter, self-paced session). Data from day 1 were used to calculate the median reading speed for each participant. On day 2, word presentation was paced externally. Day 2 included two conditions: in one condition, the presentation rate was set at the participant's median reading speed (hereafter, 'normal' session); in the other condition, the presentation rate was twice as fast (hereafter, 'fast' session). This experimental design has not been used before, so the choice of the speed increase factor had to be arbitrary. On the one hand, we aimed for a considerable speed increase, to make the experimental manipulation strong enough. On the other hand, based on piloting data, we chose a factor that would keep the presentation rate in the 'fast' session of high-performing young individuals slower than extreme values of below 100 ms/word. The speed increase by the factor of two was selected as the middle ground between these considerations. The order of 'normal' and 'fast' session on day 2 was counterbalanced across participants. The self-paced, 'fast' and 'normal' sessions used non-repeating stimuli.

Within our hypothesis of strategic slowing, we expected that the decrease of comprehension accuracy in the 'fast' compared to 'normal' session will be smaller in older adults: in other words, the same relative speed increase compared to the self-paced reading speed would provide a weaker manipulation for older than younger adults. The reasoning is that, hypothetically, older adults initially adopt an overcautious self-paced reading speed in order to avoid error and/or to spare cognitive resources. This speed is further away from their performance limits, so they should be less affected when the presentation rate is externally accelerated relative to their self-paced speed, compared to younger adults who are presumably more likely to adopt a self-paced speed closer to the limits of their capacity. Even though numerous previous studies have demonstrated that older adults are more negatively affected by faster presentation rates, at least in the auditory modality (Gordon-Salant & Fitzgibbons, 1997; Janse, 2009; Wingfield et al., 1985, 2003, 2006), our design addresses a different research question. Namely, our design is concerned with effects of relative change of presentation rate compared to self-paced reading speed, rather than with effects of *absolute* presentation rate values, and is aimed at providing an insight about the choices of self-paced reading speed in older versus younger adults.

We compared two externally-paced sessions, rather than simply comparing self-paced session to the ‘fast’ externally-paced session, for several reasons. First, this eliminated confounding by motor responses required in the self-paced session. The commonly observed age-related slowdown in behavioral measures can be due to slower motor responses in older adults, whereas ‘covert’ measures such as electrophysiological response or eye movements sometimes remain unaffected by age (Kemmer et al., 2004; Ayasse et al., 2016). Our design allowed to eliminate confounding by motor processing. Secondly, conscious control over presentation rate may also be a confound. Older adults appear to particularly benefit from self-paced presentation: for example, Piquado et al. (2012) showed that self-paced listening, compared to continuous presentation, compensated for negative effects of age-related hearing loss on discourse memory. In the visual modality as well, older adults have greater variability of self-paced reading times than younger adults (Payne & Stine-Morrow, 2014), which may also have a compensatory nature. Thus, our critical comparison was between the accuracy in two externally-paced sessions, eliminating confounding by motor response and control over presentation speed.

**Procedure**

All experimental paradigms were programmed in the DMDX software (Forster & Forster, 2003). Stimuli were presented on the laptop screen, in black font against a light gray background. On both days, sentences were presented word-by-word (see Figure 1). Words appeared in the center of the screen one at a time; the only exception was that monosyllabic and non-syllabic prepositions were appended to the corresponding nouns.


*Figure 1.* Word by word sentence representation, followed by a comprehension question. (Stimulus translation: ‘*The tutor truly respected the student for his rare qualities*’, with object-verb-subject word order; question: ‘*Who was respected for his rare qualities?*’, in active voice; response options: ‘*Student*’ / ‘*Tutor*’).

On day 1, presentation was self-paced: participants had to press the spacebar to move to the next word. On day 2, presentation was externally-paced: in the ‘normal’ session, words replaced each other at the median speed with which the participant pressed the spacebar on day 1; in the ‘fast’ session, words replaced each other twice as fast. All words were presented for the same time regardless of their length or other linguistic characteristics (for a similar approach, see e.g. Mitchell, 1979, or Hagoort & Brown, 2000). One second after the presentation of the final word was over, a comprehension question was presented in the center of the screen, with two possible answers - in the lower left and right corners of the screen. The position of the correct response was counterbalanced across questions. Participants had to press the left or right arrow on the keyboard to answer the question. Their response, or lack of response for 10 seconds, was followed with a fixation cross (‘+’) displayed for one second in the center of the screen, and then the start of the next sentence.

Before each experimental session, participants received instructions and completed a short training session. Each experimental session included two self-timed breaks, which were actually skipped by most participants, and lasted in the range of approximately 10-25 minutes overall, depending on session type and the participant's individual speed and length of breaks. If desired, they could also take a break (up to 20 minutes) between the two sessions on day 2. After each experimental session, participants were asked to rate task difficulty and their fatigue caused by the task on a scale from 1 (minimum fatigue / difficulty) to 10. The ratings turned out to be an insensitive measure, so their pre-registered analysis is only presented in Online Supplement 1.

**Data analysis**

Statistical analysis and data visualization were performed using R (R Core Team, 2017) and ggplot2 package version 2.2.1 (Wickham, 2009). As a prerequisite for all further analysis, data from the self-paced reading session were analyzed with a one-tailed independent-samples t-tests on median reaction times of younger vs. older participants. This served as a basic quality check to confirm that the processing speed was expectedly slower in older than younger adults.

The main pre-registered data analysis was conducted using generalized linear mixed models (GLMMs). GLMMs were estimated with lme4 package, version 1.1-13 (Bates, Maechler, Bolker, & Walker, 2015). The predictor variables were age (younger vs. older) and sentence presentation rate ('normal' vs. 'fast' session' in the main analysis; self-paced session added in a supplementary exploratory analysis). The model included by-participant and by-item random intercepts, as well as by-participant random slopes for presentation rate (but not for age, since age is a between-participant factor) and by-item random slopes for the main effects of age and presentation rate as well as their interaction. Correlations between random parameters were excluded from the model. The main tested hypothesis was that there would be an interaction between age and sentence presentation rate, namely a smaller decrease in accuracy with an increase in presentation rate in older adults than younger adults. In addition to this pre-registered analysis, we ran an additional model which included data from the self-paced session. The added benefit of this model, compared to the one including only data from the two externally-paced sessions, was two-fold. First, it allowed to test the general effect of reading with self-paced versus externally-paced speed in younger and older adults. Also, this model better estimated by-participant and by-item variance, since more data points from each participant and each item became available.

Since the expected interaction between age and sentence presentation rate was non-significant in the above frequentist analysis, we further explored this null result in a Bayesian analysis, which could provide insights on whether the interaction was non-significant due to lack of power or due to a true null effect (Nicenboim & Vasishth, 2016). We fit a Bayesian generalized linear mixed model using the brms package in R (Bürkner, 2017) in order to compute the Bayes factor for the interaction. The Bayesian model was equivalent to the frequentist model described above, except for random slopes: we had to eliminate them and leave only random intercepts in the model, otherwise the Bayes factor estimation failed. In our case, the absence of the random slope for the interaction should not be crucial, since it has been shown to lead to overestimation but, critically, not to the underestimation of the interaction term itself (Barr et al., 2013; Barr, 2013). So, if anything, such model is more likely to detect a spurious interaction effect than to miss an existing effect, which is suitable for our goal of checking whether the null result of the frequentist model is a false negative. We set weakly informative priors on the predictors (Table 2).

*Table 2.* Priors for predictors in the Bayesian model.

| Coefficient | Prior (in the log-odds space) | Motivation |
|---|---|---|
| Intercept | Normal(1.5, 0.7) | We expect the mean accuracy to be in the range between 50% and 95%. |
| Age | Normal(-0.2, 0.5) | We expect older adults to have lower accuracy. |
| 'Fast' speed (compared to 'Normal' speed) | Normal(-0.2, 1) | We expect the fast presentation rate to cause a decrease in accuracy. |
| Self-paced speed (compared to 'Normal' speed) | Normal(0.2, 1) | We expect self-paced presentation to have the highest accuracy. |
| 'Fast' speed x Age | Normal(0, 0.5) | The priors for the interaction were centered at 0 since the effect has not yet been demonstrated. |
| Self-paced speed x Age | Normal(0, 0.5) | |

## Results

### Descriptive statistics

Descriptive statistics of the younger and older participants' performance in the three experimental sessions, as well as the comparison of the 'fast' and 'normal' externally-paced session, are presented in Table 3 and Figure 2 (individual data are presented in Online Supplement 2).

*Table 3*. Descriptive statistics of younger versus older participants' performance in the three experimental sessions.

| Experimental session | Measure | Younger group | Older group |
|---|---|---|---|
| Self-paced session | Reading speed: median; mean (SD), ms/word | 423<br>530 (118) | 746<br>871 (250) |
| | Question response accuracy, mean (SD), % | 84 (8) | 79 (6) |
| 'Normal' externally-paced session | Question response accuracy, mean (SD), % | 81 (10) | 76 (9) |

| | | | |
|---|---|---|---|
| ‘Fast’ externally-paced session | Question response accuracy, mean (SD), % | 79 (10) | 74 (10) |
| ‘Normal’ vs ‘fast’ externally-paced session | Decrease in question response accuracy, mean (SD), % | 1 (6) | 2 (6) |
| | Percent decrease in question response accuracy (see Note below), mean (SD), % | 1 (7) | 2 (8) |

*Note*. Decrease in question response accuracy as a percentage is calculated as the difference between the accuracy in the ‘normal’ externally-paced session versus in the ‘fast’ externally-paced session, divided by the accuracy in the ‘normal’ externally-paced session.

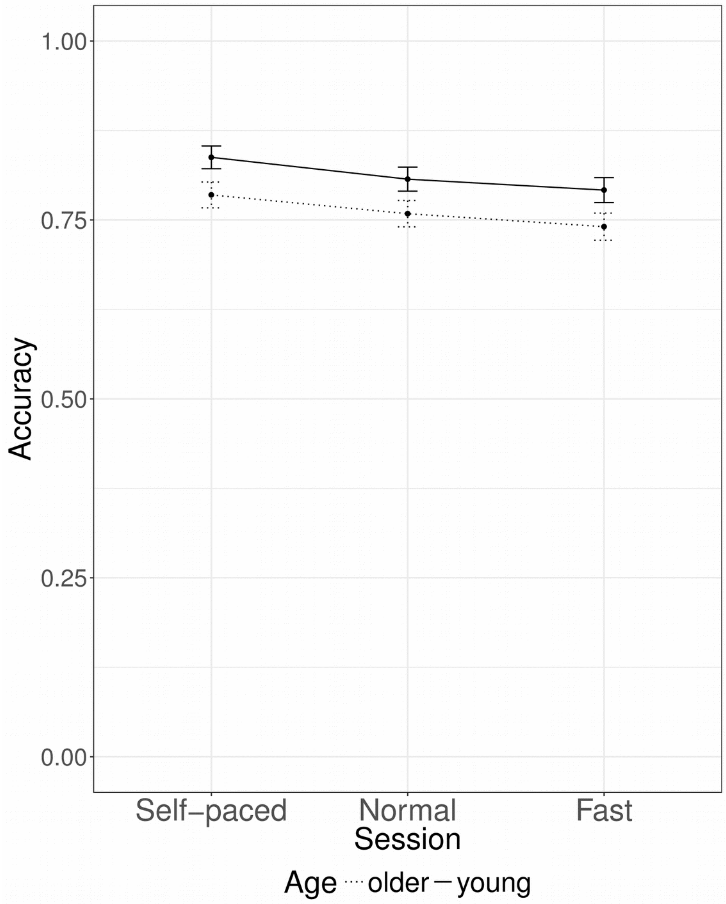


*Figure 2.* Mean sentence comprehension accuracies by experimental condition. Error bars indicate standard deviations.

A two-tailed unequal-variances (Welch) independent-samples t-test on median reaction times confirmed that older adults had a slower reading speed than younger adults, $t(32.84) = 5.73$, $p < .001$, which was an expected and necessary pre-requisite for the experimental design[2].

**Main analysis**

In the generalized linear mixed-effects model (see Table 4), we observed a main effect of age (older adults made more errors on comprehension questions) and a main effect of presentation rate (more errors were made in the ‘fast’ than ‘normal’ session). No interaction between age and presentation rate was found. That is, we found no evidence that older adults were less (or more) affected by a presentation rate increase than younger adults.

In the additional exploratory analysis with the self-paced session data added to the model. We found that accuracy decreased significantly in the ‘normal’ compared to self-paced session, and decreased again in the ‘fast’ compared to ‘normal’ session. There was a main effect of age: older adults made more errors. Again, there was no significant interaction between presentation rate and age.

*Table 4.* Model summaries for the main analysis and the additional analysis with added SPR session.

| | Main analysis | | | Additional analysis | | |
|---|---|---|---|---|---|---|
| | *Log-Odds* | *Std. Error* | *p* | *Log-Odds* | *Std. Error* | *p* |
| **Fixed Effects** | | | | | | |
| (Intercept) | 1.661 | 0.123 | <.001 | 1.749 | 0.137 | <.001 |
| Speed: Self-paced vs. ‘Normal’ | | n/a | | 0.277 | 0.102 | **.007** |
| Speed: ‘Fast’ vs. ‘Normal’ | -0.073 | 0.029 | **.012** | -0.161 | 0.072 | **.025** |
| Age: Older vs. Younger | -0.206 | 0.100 | **.039** | -0.214 | 0.116 | .065 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Age x Speed (Self-paced vs. 'Normal') | | n/a | | -0.064 | 0.094 | .500 |
| Age x Speed ('Fast' vs. 'Normal') | -0.005 | 0.030 | .872 | 0.000 | 0.064 | .995 |
| **Random Effects** | | | | | | |
| τ00, sentence | | 0.036 | | | 0.048 | |
| τ00, participant | | 0.010 | | | 1.443 | |
| $N_{sentence}$ | | 300 | | | 300 | |
| $N_{participant}$ | | 48 | | | 48 | |
| Observations | | 9593 | | | 14399 | |
| Deviance | | 7602.782 | | | 10967.078 | |

*Note.* Significant effects are in bold.

**Bayesian analysis**

The estimates of the Bayesian model are consistent with the estimates of the generalized linear mixed-effects model reported above. Accuracy is significantly affected by both age and presentation rate, but not by their interaction (Table 5). The resulting Bayes factor is 0.0198, which constitutes «very strong» evidence in favor of the model without the interaction - that is, for the absence of interaction.

*Table 5.* Model summary for the Bayesian analysis.

| | *Log-Odds* | *Std. Error* | *Lower limit of the 95% credible interval* | *Upper limit of the 95% credible interval* |
|---|---|---|---|---|
| **Fixed Effects** | | | | |
| (Intercept) | 1.71 | 0.13 | 1.47 | 1.96 |
| Speed:  Self-paced vs. 'Normal' | 0.24 | 0.06 | 0.12 | 0.35 |
| Speed: 'Fast' vs. 'Normal' | -0.14 | 0.06 | -0.25 | -0.02 |
| Age: Older vs. Younger | -0.21 | 0.10 | -0.41 | -0.01 |

| | | | | |
|---|---|---|---|---|
| Age x Speed (Self-paced vs. ‘Normal’) | -0.06 | 0.06 | -0.17 | 0.06 |
| Age x Speed (‘Fast’ vs. ‘Normal’ ) | -0.01 | 0.06 | -0.12 | 0.10 |
| **Random Effects** | | | | |
| τ00, sentence | | 1.25 (0.06) | | |
| τ00, participant | | 0.65 (0.08) | | |
| Nsentence | | 300 | | |
| Nparticipant | | 48 | | |
| Observations | | 14399 | | |

## Discussion

In many non-linguistic cognitive domains such as memory, previous research suggests that older adults perform below their capabilities. They do so as a caution to avoid potential errors (Dutilh et al., 2013; Ratcliff et al., 2004; Smith & Brewer, 1995; Starns & Ratcliff, 2010), especially due to negative self-expectations (Chasteen et al., 2015; Rahhal et al., 2001), or to spare increasingly limited cognitive resources (Brébion, 2003). To date, very few studies have investigated whether older adults also ‘underperform’ in the linguistic domain and specifically whether the slower language processing speed observed in this population across language tasks (in language production, behavioral response to language comprehension, and optimal linguistic input rate) also has a ‘strategic’ nature. In other words, the question is whether older adults’ slower language processing is necessary to ensure optimal processing accuracy or is a strategy serving a different goal, such as to spare cognitive resources, even though not necessarily consciously. The few studies that have tackled this question used speed-accuracy trade-off paradigms and thus were focused on testing whether older adults were able to increase their language processing speed consciously (Brébion, 2001; Stine-Morrow et al., 2006). The present study expanded the scope of previous research and tested whether older adults can maintain high language processing accuracy when reading speed is externally accelerated relative to their self-paced speed. Specifically, we compared sentence comprehension accuracy in younger and older adults when sentences were presented at the participant's median self-paced reading speed versus twice as fast. Although extensive evidence shows that older adults are more negatively affected by faster absolute presentation rates, particularly in the auditory modality (Gordon-Salant & Fitzgibbons, 1997; Janse, 2009; Wingfield et al., 1985, 2003, 2006), our design addressed a different research question. It tested the effects of *relative* changes in presentation rate as a function of individual self-paced speed, rather than any effects of identical absolute presentation rate increase across individuals. In our case, manipulation of presentation rate aimed to provide an insight about the nature of *self-paced* reading speed adopted by older versus younger adults: namely, how far it is from the individual's performance limits.

Originally, we hypothesized that an external speed increase will cause a smaller accuracy decline in older than younger adults because the former tend to adopt self-paced processing speeds "further away" from their performance limits. The average self-paced reading speed was indeed much slower in older than younger adults, in line with numerous previous studies showing age-related slowing of linguistic (Caplan et al., 2011; Caplan & Waters, 2005; Feyereisen, Demaeght, & Samson, 1998; Rodríguez-Aranda & Jakobsen, 2011; Stine-Morrow et al., 2000) and cognitive (Baudouin, Vanneste, & Isingrini, 2004; Birren & Fisher, 1992; Godefroy, Roussel, Despretz, Quaglino, & Boucart, 2010) performance. We also found lower sentence comprehension accuracy in older than younger adults across all three sentence presentation conditions. This is consistent with extensive previous literature showing an age-related decrease in sentence comprehension accuracy, either for the most complex sentence types and the most challenging processing conditions (Caplan et al., 2011; Caplan & Waters, 2005; Stine-Morrow et al., 2000; Wingfield et al., 2003) or “across the board” (Goral et al., 2011; Kemmer et al., 2004; Maguinness et al., 2011; Malyutina & Den Ouden, 2015).

However, the hypothesis was not confirmed. We did not find a significant difference in how much younger versus older adults’ sentence comprehension accuracy declined with an external increase in sentence presentation rate – and thus, no evidence that younger versus older adults adopt self-paced reading speeds at a different “distance” from their performance limits. Since it is impossible to argue for the null hypothesis based on an insignificant result in a frequentist statistical model, we performed additional Bayesian analysis. It provided evidence for the null hypothesis, that is, for the true absence of an interaction between age and presentation rate. Thus, we found no evidence that the age-related slowing of language processing is an “optional” strategy, consciously or non-consciously adopted in order to avoid errors or to spare limited cognitive resources and avoid excessive mental fatigue. Rather, it appears inherent to language processing in aging. This is consistent with the findings by Brébion (2001) and Stine-Morrow et al. (2006), where older adults were not able to consciously accelerate sentence processing beyond their usual speed. Unlike in these previous studies, our experimental design did not require participants to consciously manipulate their processing speed, but the conclusions remained the same.

Interestingly, both age groups performed significantly better in the self-paced session compared to the ‘normal’ externally-paced session with the same median reading speed (in line with, for example, Piquado et al., 2012, in the auditory modality). The benefit of self-paced presentation is likely due to being able not only to control the overall presentation rate, but also to adjust the presentation time of each word according to linguistic demands imposed by its lexical characteristics and its position in the sentence and text structure (Stine, 1990; Stine-Morrow, Gagne, Miller, & Hertzog, 2008). But this positive effect did not interact with age group, again demonstrating no evidence of qualitatively different choices in self-paced reading speed in younger versus older adults (cf. self-regulated language processing model, Stine-Morrow & Miller, 2009).

The exact mechanisms of age-related slowing in language processing are yet to be determined. On the one hand, the slowing may have a compensatory nature, allowing older adults to maintain language processing accuracy at the highest possible level. For example, it may provide the time to make the necessary semantic and grammatical computations, which may be slowed like any other “mental mechanics” (Stine-Morrow et al., 2008) as a natural consequence of age-related neurophysiological changes (Eckert, 2011; Eckert et al., 2010; Lu et al., 2011; etc.). In terms of self-regulated language processing model (Stine-Morrow & Miller, 2009), older adults may allocate longer processing times to their “region of proximal learning”: that is, to items of intermediate difficulty that they can process successfully if they use additional time to compensate for any processing inefficiency. As an alternative positive role, the slowing of language processing can be a productive means to counter distraction, which has a greater negative effect on older than younger adults (Lustig, Hasher, & Tonev, 2006), and to direct attention to task-relevant stimuli. On the other hand, the slowing may result from a maladaptive language processing pattern: for example, it may paradoxically emerge from more irregular / “risky” reading strategies. The evidence for older adults’ “risky” processing strategies with high reliance on prediction comes from self-paced reading (DeDe, 2014) and eye-tracking, where they tend to skip more words (Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; although see Choi et al., 2017) and produce more irregular scanpaths in reading (von der Malsburg, Kliegl, & Vasishth, 2014; although also see evidence against greater use or negative effect of prediction in older adults: Wlotko, Federmeier, & Kutas, 2012; Payne & Federmeier, 2017, Choi et al., 2017). According to Rayner et al. (2006), older adults' "risky" processing strategies may emerge to compensate for slowed lexical processing but then paradoxically contribute to slower overall processing times, because additional time is needed to compensate for incorrect predictions. In our experimental design, sentences were presented word by word, so technically word skipping and regressions were not possible. Yet, it is possible that older individuals still showed more risky / irregular reading patterns and 'skipped' some words by not concentrating on them and relying on prediction, thus showing inefficient allocation of resources (Stine-Morrow & Miller, 2009). If so, they possibly needed additional time later in order to recall the 'skipped' words and restore a complete sentence representation.

Although our findings do not disentangle between compensatory versus maladaptive role of slowdown in language processing, they still make an important contribution to broader understanding of its nature. Namely, we demonstrate that the slowdown is at least partly caused by cognitive reasons rather than has a purely motor nature. By now, this idea has prompted surprisingly little experimental investigation. The logic of our contribution is as follows. Our estimation of self-paced reading speed included motor activity (time required to press the button to move to the next word in a sentence). If older adults were slower for motor reasons alone, the calculated self-paced reading speed would provide an even greater underestimation of their fastest possible reading speed. Accordingly, when sentence presentation rate is increased externally (not requiring a button press), we would expect an even smaller accuracy decrease in older than younger adults, since they are now exempt from motor demands that were slowing them down. In other words, the motor nature of the slowdown would increase the hypothesized effect – but in reality, the data did not show the hypothesized effect at all. Furthermore, both younger and older adults' accuracy significantly decreased in the 'normal' externally-paced session compared to the self-paced reading session (with no interactions with age), likely because the 'normal' session did not allow flexible allocation of attention depending on the words' lexical and syntactic characteristics. This again demonstrates that older adults do not process language faster when motor demands are eliminated. This finding contributes to the surprisingly sparse literature showing an also cognitive rather than purely motor nature of age-related slowdown of language processing. An example of a previous study with the same conclusion is by Rodríguez-Aranda and Jakobsen (2011). They showed that variance in word naming speed in older individuals was best predicted by vocabulary scores (18% variance explained), whereas psychomotor measures added only 8%, and executive functioning and working memory predictors were not significant, suggesting partly cognitive (in their case, specifically linguistic) reasons for slowdown of language production. The relative role of cognitive versus sensorimotor factors in age-related slowdown of language processing deserves further attention.

Our conclusions are inevitably limited by the experimental design. Here, the double increase of the presentation rate in the 'fast' compared to 'normal' externally-paced session yielded only a minor decrease in comprehension accuracy. Possibly, a speed increase by a greater factor would cause different effects in younger versus older individuals. Moreover, perhaps comprehension is not linearly related to presentation rate, which further complicates the choice of the speed increase factor. Another limitation of our design is that it used the same external presentation rate for all words, regardless of their linguistic characteristics. Perhaps, more flexible presentation adjusted for psycholinguistic variables, simulating the natural accommodation of word presentation times in self-paced reading, would yield different results. It is also possible that the "underperformance" hypothesis is relevant to aspects of language processing that were not addressed in this study. For example, “underperformance” may arise in processing specific linguistic structures, whereas our design analyzed pooled data from diverse sentence structures of varying complexity. Then, we only investigated written sentence comprehension, so we cannot rule out that the hypothesis is relevant to language production, such as sentence construction or ecologically valid discourse production tasks. For example, strategic reasons could contribute to the use of simpler syntactic structures by older adults (Kemper, Herman, & Liu, 2004; Kynette & Kemper, 1986; Rabaglia & Salthouse, 2011; Sung, 2015; although see Nippold, Cramond, & Hayward-Mayhew, 2014; Hardy, Messenger, & Maylor, 2017). Finally, strategic “underperformance” could be contingent upon individual self-expectations and views on own linguistic abilities, as suggested in memory research (Chasteen et al., 2015; Hess et al., 2003).

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Footnotes

[1]The project pre-registration is available at https://osf.io/zn3gx. Additional materials are available from the project main page at the OSF website (https://osf.io/x28dq): full participant information, including occupations / majors; full stimuli; raw data; the R code used for linear-mixed effect models and for the Bayesian analysis.

[2]An exploratory analysis of the speed-accuracy relation did not reveal any meaningful correlations between speed and accuracy either in the younger or the older group, failing to replicate the findings by Brébion (2003). More details are presented in Online Supplement 3.

**Online supplement 1.**

**Fatigue and difficulty ratings**

**Procedure**

After each experimental session, participants were asked to rate task difficulty and their fatigue caused by the task on a scale from 1 (minimum fatigue / difficulty) to 10.

**Statistical analysis**

The pre-registered analysis of task difficulty and fatigue ratings was meant to test the strategic nature of slower reading speed in the self-paced session. We used Pearson's correlation to correlate the speed-related accuracy decrease (difference in scores between 'fast' and 'normal' session) with task difficulty and fatigue ratings after the self-paced session, in younger and older adults. We assumed that task difficulty and fatigue ratings will be higher in older than younger adults.

We expected to find a negative correlation between task difficulty ratings in the self-paced session and the speed-related accuracy decrease in older adults, since perceiving the task as difficult would make them adopt more 'cautious' processing speeds, in order to avoid potential error and/or to spare cognitive resources. This would be consistent with previous literature showing that older adults show less engagement into tasks that they perceive as cognitively demanding (Hess, 2014; Hess et al., 2016) – in our case, lack of engagement would manifest as using a 'cautious', rather than 'maximum-performance', reading speed. On the other hand, we hypothesized that higher ratings of fatigue in the self-paced session would correspond to a greater speed-related accuracy decrease, since greater fatigue reflects an 'objective', as opposed to perceived, cognitive load. Finally, we hypothesized that a speed increase would lead to a greater increase in fatigue ratings in older than younger adults, because even if they can maintain sentence comprehension accuracy at an externally-enforced fast presentation rate, this comes at a cost of greater effort. To account for cross-individual variation in using the rating scale, we standardized the ratings within participants prior to analyses. This was done by subtracting the participant's mean fatigue / difficulty rating from each of his/her ratings.

**Results and Discussion**

Descriptive statistics for younger and older participants' ratings of fatigue and task difficulty in the three experimental sessions are presented in Table 1.

*Table 1.* Fatigue and task difficulty ratings

| Experimental session | Rating, mean (SD) | Raw | | Standardized within individual | |
|---|---|---|---|---|---|
| | | Younger | Older | Younger | Older |
| Self-paced session | Fatigue | 5.0 (2.4) | 3.7 (2.4) | -0.9 (2.1) | -0.6 (1.8) |
| | Difficulty | 5.0 (2.2) | 4.0 (2.2) | -0.6 (1.3) | -0.4 (1.2) |
| 'Normal' externally-paced session | Fatigue | 6.1 (2.2) | 4.6 (2.2) | 0.2 (1.4) | 0.3 (1.1) |
| | Difficulty | 5.5 (1.9) | 4.8 (1.6) | -0.1 (-0.3) | -0.3 (1.1) |
| 'Fast' externally-paced session | Fatigue | 6.6 (2.3) | 4.5 (2.4) | 0.7 (1.3) | 0.2 (1.2) |
| | Difficulty | 6.3 (1.9) | 5.7 (2.1) | 0.7 (1.1) | 0.7 (1.0) |

*Note*. Raw fatigue ratings are on a scale from 0 (no fatigue) to 10 (extremely strong fatigue). Raw task difficulty ratings are on a scale from 1 (extremely easy) to 10 (extremely difficult). Standardized ratings were obtained by centering the individual's ratings around his/her mean fatigue / difficulty rating.

Unexpectedly, younger adults had higher fatigue and difficulty ratings than older adults, inconsistent with previous research (Hess, 2014; Hess et al., 2016). We can speculate that this surprising pattern emerged because participants were not able to distinguish between their task-related versus general fatigue and, similarly, between task-specific difficulty versus general amount of effort they need to make to perform any task. Our older sample largely consisted of retired individuals, whereas the younger group primarily included full-time university students. This population experiences multiple academic, financial and lifestyle challenges, which can cause increased fatigue (Lee et al., 2007; Varni & Limbers, 2008). Speculatively, we suppose that general fatigue could have confounded the task-related fatigue and task difficulty ratings in the younger group. Alternatively, the age groups could differ in their use of the rating scale. Thus, we report the correlation analysis on the ratings centered around each participant's mean fatigue / difficulty rating. There was no significant correlation between task difficulty ratings in the self-paced session and the speed-related accuracy decrease either in younger adults, $r(22) = -.25$, $p = .25$, or in older adults, r(22) = .09, p = .68. Neither was there a significant correlation between fatigue ratings in the self-paced session and the speed-related accuracy decrease in younger adults, $r(22) = .27$, $p = .19$, or in older adults, $r(22) = -.05$, $p = .81$. Finally, a two-tailed equal-variances independent-samples *t*-test did not demonstrate a greater speed-related increase in fatigue ratings in older than in younger adults, $t(46) = 1.21$, $p = .23$. However, our original hypotheses about fatigue and difficulty ratings were based on the assumption that they will be higher in older than younger adults. Since the assumption was not met, the hypotheses are no longer quite applicable and the analyses of ratings will not be further discussed.

**Online supplement 2.**

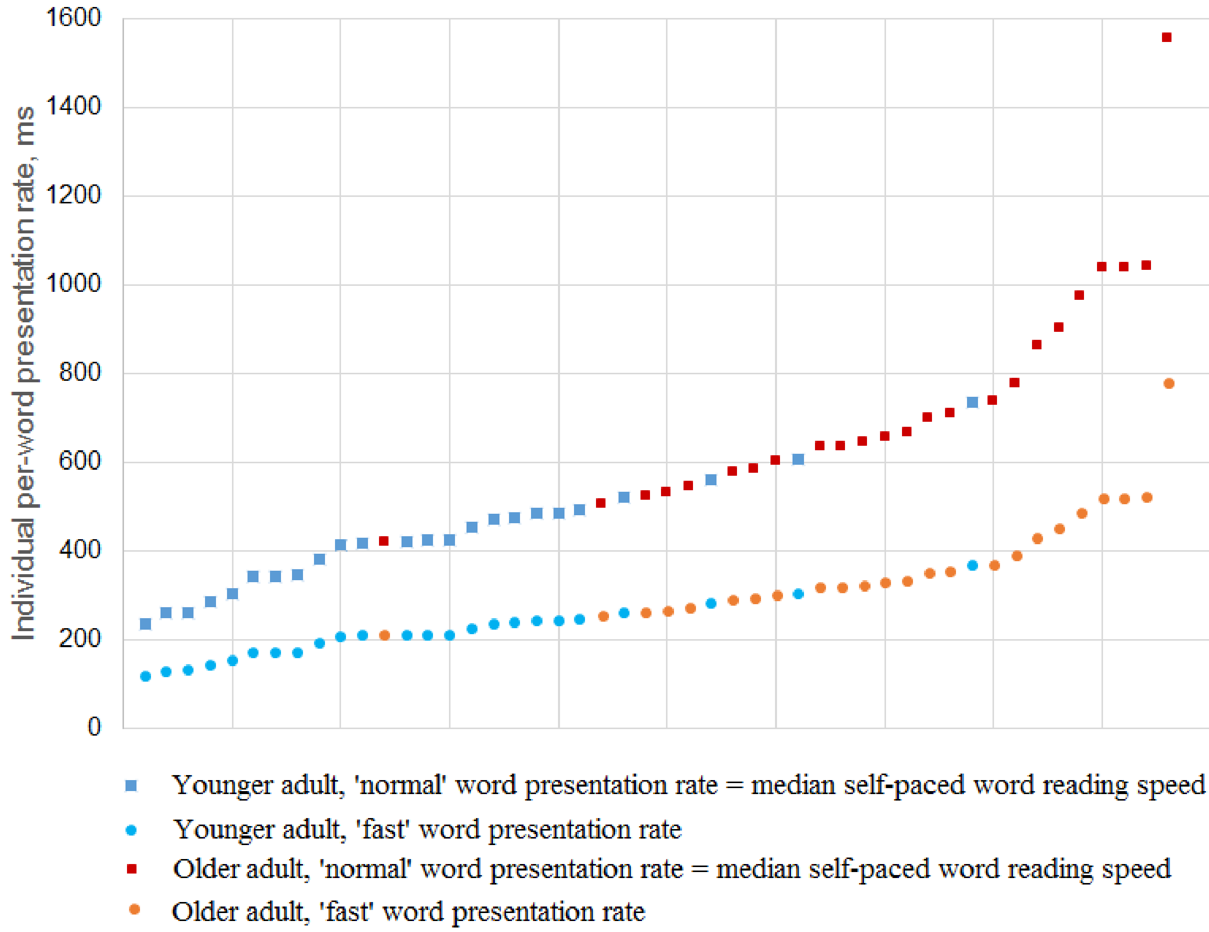


*Figure 1*. Participants' individual word presentation rates across experimental sessions. Each vertical pair of markers represents one participant; older and younger participants are presented together, ordered by speed decrease.

**Online supplement 3.**

**Speed-accuracy tradeoff**

**Statistical analysis**

In addition to the pre-registered analyses, we have also explored the speed-accuracy relation in younger and older adults. In Brébion (2003), the relation was inverse in younger and older adults: more accurate younger participants used faster processing speeds, while more accurate older participants used slower processing speeds. To test whether the dissociation would hold in our data, we used Pearson's correlation to correlate the median reading speed and sentence comprehension accuracy in the self-paced session, in younger and older adults.

**Results**

The exploratory Pearson correlation analysis revealed no correlation between self-paced reading speed and question response accuracy in the younger group, $r(22) = .14$, $p = .51$. In the older group, faster reading speed was associated with higher question response accuracy, $r(22) = -.52$, $p = 0.001$. However, the correlation was largely driven by an outlier participant with the slowest median reading speed of 1558 ms. If this extreme datapoint was removed, the correlation became non-significant, $r(21) = -.28$, $p = .20$. The speed-accuracy relation in younger and older adults is shown in Figure 1.

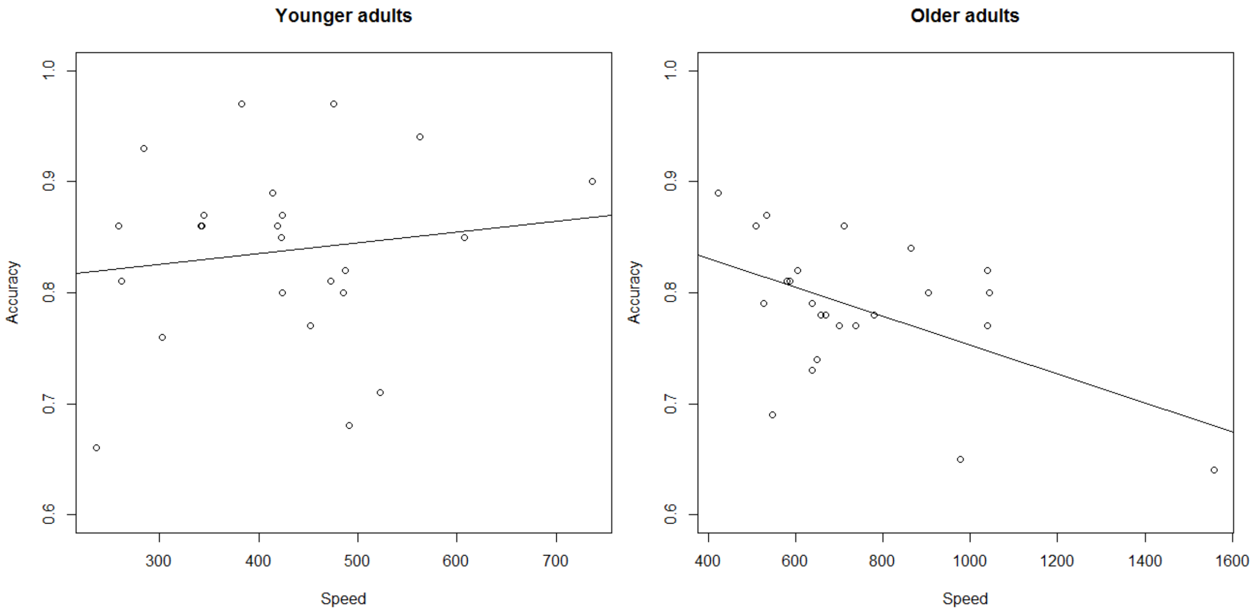


*Figure 1*. The relation between self-paced sentence reading speed (ms) and sentence comprehension accuracy in younger and older adults.

**Discussion**

To explore a compensatory versus maladaptive role of slowing, we correlated individual self-paced sentence reading speed and sentence comprehension accuracy in younger and older adults. The analysis did not reveal any meaningful correlations. In younger adults, there was no significant correlation between speed and accuracy; in older adults, a moderate negative correlation was only driven by one influential datapoint. Thus, we did not replicate an interesting finding by Brébion (2003): in his study, more accurate older participants used slower processing speeds, likely compensatorily, whereas more accurate younger adults used faster processing speeds. Further research is required to examine in-depth whether the age-related slowdown of language processing appears beneficial or maladaptive. Possibly, the effect of age on speed-accuracy relation may interact with additional factors such as educational and socioeconomic background. The mean number of years of education was 14 years in the sample of older adults in Brébion (2003) and 16.5

years in our sample. Thus, our older participants had a higher average educational background, especially given a longer duration of secondary school studies in France than in Russia (typically 10-11 years in Russia and 12 years in France). Speculatively, it seems likely that older individuals with a lower education may need lower processing speeds to ensure successful processing, while individuals with higher education backgrounds may be more diverse in their linguistic processing abilities and strategies. At this stage, this remains a speculation and needs further research.

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