Acute stress impairs visual narrative comprehension in younger but not older adults

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Author Note

Data and syntaxes used to conduct analyses in the statistical package R are openly available at the project's Open Science Framework page (https://osf.io/5q3xc/). We have no conflicts of interest to disclose. The study described in this manuscript was partially presented as an abstract and talk at the conference "Tagung experimentell arbeitender Psycholog:innen (TeaP2024) - Conference of Experimental Psychologists."

Links to preregistrations. For the first experiment see https://aspredicted.org/Y11_CM2; for the second experiment, see https://aspredicted.org/7C2_VBF

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Abstract

Visual narrative comprehension is essential for navigating modern society, where information, rules, and news are frequently communicated through images, diagrams, and visual stories. Encoding a coherent narrative from disparate elements is critical for all age groups. Although recent data indicate that stress levels have risen compared to previous decades, the impact of stress on visual narrative comprehension remains underexplored. This study explored how acute stress affects narrative comprehension in younger (N = 203, 18-57 years; M = 23 years; Experiment 1) and older adults (N = 212, 60-85 years; M = 67 years; Experiment 2). Participants were assessed under both acute stress and neutral conditions. A tool for inducing acute stress online employed mathematical and logical tasks under time pressure, along with elements that simulate social stress. Participants were presented with pictorial stories comprising three panels, where the second panel was intentionally left blank. Their task was to comprehend the stories and determine whether the presented pictorial inference for the missing event was correct or incorrect. Results revealed that acute stress negatively impacted narrative comprehension in younger adults, while the older adults' comprehension remained unaffected by acute stress. Similarly, younger adults demonstrated reduced confidence in their responses under stress, whereas older adults' confidence levels remained unaffected. These findings highlight the relationship between visual narrative comprehension, stress, and aging, suggesting that, with age and experience, comprehenders may develop more differentiated event schemas, which makes their comprehension processes more resilient to stress.

Public Significance Statement

Understanding how cognitive and perceptional processes function under stress is crucial for daily life across all age groups. Our research demonstrates that acute stress leads to a decline in visual narrative comprehension only in younger adults, while older adults' narrative comprehension remains stable despite stress. This finding suggests that older adults may employ more effective coping mechanisms, which helps maintain their cognitive stability in the face of stress. Consequently, narrative comprehension appears to be more resilient compared to other fundamental cognitive skills. These

insights could inform interventions and strategies to support cognitive health across different age groups.

Key-words: Narrative comprehension, age, acute stress, age comparison

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Narrative comprehension is crucial for understanding and processing information in the increasingly visual world. This ability, underpinned by cognitive frameworks such as the Structure-Building Framework (Gernsbacher et al., 1990) and Visual Narrative Grammar (Cohn, 2013; Cohn, 2014), is essential across all age groups. With stress becoming an ever-present factor in modern life, understanding its impact on cognitive functions like narrative comprehension is vital. As stress can significantly impair or facilitate cognitive performance (Sandi, 2013), our study examines how acute stress affects visual narrative comprehension across different ages.

Narrative Comprehension

Narratives are important in many aspects of everyday life as they convey knowledge, information, instructions, and explanations. Understanding narratives is thus crucial for participating in social life and accessing education and knowledge. Making sense of a narrative is known as *narrative comprehension* (Quintero Johnson & Sangalang, 2017), which happens by drawing meaning from incoming information (Lynch et al., 2008) and generating a mental representation of the narrative's components (Bilandzic et al., 2019).

Theoretical frameworks, including the Structure-Building Framework (Gernsbacher et al., 1990), the Scene Perception and Event Comprehension Theory (Loschky et al., 2020) and the concept of Visual Narrative Grammar (VNG) (Cohn, 2014), describe the process of narrative comprehension. According to the Structure-Building Framework, the main goal of comprehension is to create a cohesive mental representation of incoming information. Gernsbacher et al. (1990) describe mechanisms and cognitive processes that might contribute to the comprehension of incoming information. Particularly, the Structure-Building Framework implies that comprehension aims to construct a mental representation of a story, starting by laying a foundation and further categorizing and mapping new information. New substructures are generated if new information is not related to existing structures.

Another important factor in the Structure-Building Framework (Gernsbacher et al., 1990) is a person’s ability to enhance or suppress incoming information. If new information is relevant to the existing structure, it is enhanced and added to the mental model, whereas irrelevant information will be suppressed. Hence, the authors suggest that skilled and less-skilled comprehenders can be differentiated based on the effectiveness of suppression processes. Skilled comprehenders use suppression mechanisms more effectively than less-skilled ones (Gernsbacher et al., 1990). Oakhill et al. (1986) also found that less-skilled comprehenders perform worse when accomplishing working memory tasks. Based on earlier findings, Gernsbacher et al. (1990) concluded that the listening comprehension skill strongly correlates with the reading comprehension skill. As a result, Gernsbacher and Faust (1991) proposed the concept of a general comprehension skill, which they identified as a capacity to comprehend linguistic and nonlinguistic information.

The Scene Perception and Event comprehension Theory (SPECT) (Loschky et al., 2020) offers a nuanced approach to understanding comprehension differences by distinguishing between front-end and back-end processes in visual narrative comprehension. Front-end processes involve attentional selection and information extraction from the visuals. Attentional selection defines what information should be processed, whereas information extraction is important to extract relevant meaning. Both processes are associated with working memory activity. Back-end processes are associated with both working and long-term memory, and serve to construct as well as maintain the representation of the current event model in working memory. The new current event model in working memory receives information from and is impacted by the newly shaped event models in episodic long-term memory. Moreover, existing schemata and executive functions, such as goal setting, attention control, and inhibition, may also impact the current event model (Loschky et al., 2020). SPECT is supported by a study by Magliano et al. (2013), who have also argued that comprehension processes operate either at the "front-end" or at the "back-end" of comprehension. Front-end processes involve extracting information from the visual sequence to compute the event model representing the "now" moment in a narrative. During the first 150 ms of the initial fixation, front-end processes extract the global semantic meaning of the scene, known as scene gist (Fei-Fei et al., 2007; Magliano et al., 2013). This scene gist representation will form the foundation of the event model, which will be further refined by back-end processes. Back-end processes, which are event segmentation, inferencing, and structure building are responsible for comprehension of the dynamic structure of the visual narrative. The product of back-end processes is a mental model. Inferencing as an important process for narrative comprehension involves connecting explicitly experienced story elements and utilizing relevant background knowledge. (McNamara & Magliano, 2009).

Visual narratives, that is, narratives using visual codes (e.g., pictures, comics), are a widespread medium for conveying information. It covers a spectrum starting from children's books and comics for teenagers through its active implementation in the educational system, informational brochures, social media posts, and instruction guides for, for example, furniture construction. The concept of Visual Narrative Grammar (VNG) proposed by Cohn (2014) suggests that consecutive images assume narrative roles comparable to the grammatical roles of words in sentences (Cohn, 2013; Cohn, 2014). VNG posits that the sequence of image follows a hierarchical narrative grammar, and that the processes of updating perceptual-semantic information and grammar interact with each other (Cohn, 2013; Cohn & Kutas, 2017). When understanding visual narrative sequences, the brain utilizes this narrative structure along with more general semantic schemas (Schank & Abelson, 2013) to build global narrative coherence and facilitate the semantic processing of the images (Cohn, 2012a; Cohn, 2012b; Cohn, 2014).

The presented theoretical accounts do not explicitly make statements regarding the influence of age and stress on narrative comprehension. In the following, we present empirical evidence in aging and stress research that is relevant to the research question of the interplay of age and stress during narrative comprehension.

Narrative Comprehension in the Elderly

Research findings on the impact of age on visual narrative comprehension are ambiguous. There is evidence that perception changes with age. For example, older participants perceive event boundaries in narratives and segment events differently than younger participants (Smith et al., 2023). It has been found that young adults demonstrate higher gaze similarity than older adults, both throughout entire videos and at event boundaries. Additionally, older adults segment everyday events in the videos more distinctly than younger adults (Smith et al., 2023).

Moreover, research indicates variations in certain facets crucial to narrative comprehension, such as age-related discrepancy in character tracking abilities during narrative processing. Older readers face distinct challenges in both identifying the initial character after the introduction of a new character and in comprehensively encoding a new character while multiple characters coexist within the discourse context (Noh & Stine-Morrow, 2009). With increasing age, individuals also experience more difficulty comprehending grammatically or lexically complex sentences and text/discourse (Lee et al., 2014). Regarding reading comprehension, however, adults of 70 years and older experience more difficulty compared to younger adults between 55 and 69 years, they still have adequate reading comprehension skills (measured by multiple-choice inferential questions) when compared to normative control scores (comprehension level achieved at the end of 8th-grade compulsory education), indicating basic comprehension skills necessary for everyday life (De Beni et al., 2003). Ulatowska and colleagues (1998) found in a longitudinal study that the ability to generate global inferences remains consistent across different ages. For instance, they assessed 16 healthy older adults in their 80s and 90s at two separate testing times and found no significant age differences in forming global representations of text. However, the small sample size limits the generalizability of these findings. Newer studies with larger sample sizes (N = 1487, N = 142) demonstrate that despite widely known age-related changes in memory and cognitive function, narrative comprehension remains stable in older adults (Huff et al., 2023; Varkentin et al., 2024).

Stress and narrative comprehension

Individuals increasingly confront various physical, functional, and social losses as they age. Consequently, coping with these losses and stress emerges as a central theme in the later stages of life (Martin et al., 2008). Acute stress might influence any cognitive processes related to narrative comprehension, such as working memory (Oakhill et al., 2003), attentional focus (McNamara & Magliano, 2009), and episodic memory (Brookshire & Nicholas, 1993). Thus, narrative comprehension is a cognitive process that can be affected by acute stress experiences (Shields et al., 2016). During acute stress, a complex response of the human body and brain is activated. The fight-or-flight reaction is a well-known response to an acute stressor when the sympathetic nervous system is activated, preparing a person to face or escape a threat (McCarty, 2016). While some studies show negative effects of acute stress on cognitive performance (Oei et al., 2006; Shields et al., 2019; Xin et al., 2020; Schoofs et al., 2008), other studies show reversed effects (Domes & Zimmer, 2019; Shields et al., 2019). Acute stress seems to affect different cognitive domains differently (Shields et al., 2017).

More specific, evidence suggests that stress adversely affects working memory (Oei et al., 2006; Shields et al., 2019; Xin et al., 2020; Schoofs et al., 2008). For example, Oei et al. (2006) and Xin et al. (2020) found evidence of reduced working memory capacity after acute stress induction. Schoofs et al. (2008) showed that exposure to acute stress leads to the impairment of working memory in a numerical n-back test. However, this impairment weakens with task duration. Since working memory is linked to information suppression (Zanto & Gazzaley, 2009), and empirical evidence reveals that acute stress impairs working memory, we assume that acute stressors may consequently inhibit successful information suppression. Information suppression is important in the Structure-Building Framework (Gernsbacher et al., 1990). Thus, working memory impairment due to stress exposure could negatively influence performance in narrative comprehension due to less successful information suppression.

Another important cognitive process for narrative comprehension and inference generation is attention. Domes and Zimmer (2019) found in their study that participants exposed to the Trier Social Stress Test (Kirschbaum et al., 1993) showed an improved identification of emotional cues. It is assumed that this might help detect any threats and also act as a support system in social situations (Domes & Zimmer, 2019). Shields et al. (2019) revealed that exposure to mild acute stressors was associated with increased response speed in two attentional tests without affecting response accuracy. Other authors show similar results, with acute stress enhancing attention (Degroote et al., 2020; Kan et al., 2019). To the best of our knowledge, no research papers investigate the association between acute stress and narrative comprehension or inference generation. Therefore, we intend to investigate whether exposure to acute stress may weaken participants' ability to comprehend narratives and draw correct inferences.

Experimental Overview and Hypotheses

The present study tested the influence of acute stress on visual narrative comprehension in a younger student sample (*N* = 203, 18-57 years; *M* = 23 years; Experiment 1) and in an older sample (*N* = 212, 60-85 years; *M* = 67 years; Experiment 2). Considering the lack of prior evidence about the effect of acute stress on narrative comprehension, we stated a non-directional hypothesis and expected narrative comprehension to differ between the stress condition and the control condition (H1; preregistered here: https://aspredicted.org/Y11_CM2). Anticipating the results of Experiment 1 - acute stress reduced narrative comprehension in younger adults - we formulated a directional hypothesis in Experiment 2 and expected acute stress to affect narrative comprehension negatively in older adults (H2; preregistered here: https://aspredicted.org/7C2_VBF). In addition, we tested the following exploratory hypothesis in each experiment: we explored whether there is a difference in confidence responses between the stress and control conditions (Participants were presented with the question, "How confident are you in your answer?" with six response options ranging from "very uncertain" to "very confident").

The experiments manipulated stress induction as independent variable (between-subjects) with stress-invoking stimuli in the experimental (stress) condition and easy filler tasks in the control condition. We measured narrative comprehension by testing bridging inference generation (i.e., inferences generated to bridge gaps in short pictorial stories) (Huff et al., 2020; Huff et al., 2023; Magliano et al., 2016; Varkentin et al., 2024). Linking consecutive events within a story is essential for comprehension. That is why by measuring this process we can draw conclusions for overall narrative comprehension skills. This method is an established experimental procedure to research inference generation and, thus, narrative comprehension of both textual and pictorial stories. Similar to Huff et al. (2020), Huff et al. (2023), Magliano et al. (2016), and Varkentin et al. (2024), we used a bridging event generation measurement in our study. Bridging events in comics/picture stories are panels depicting information that connects the narrative gap between two elements (panels). In our study, the bridging event of the stories was not presented to the participants and had to be inferred for comprehension after viewing only the stories' beginning and end state. Participants saw a blank white panel instead of the bridging event. If a bridging event is missing in a visual or textual story, it must be inferred from the information presented in the beginning and end states. This process consumes cognitive resources that can be measured in different ways, for example, by answering comprehension questions (Huff et al., 2023; Gernsbacher et al., 1990; Varkentin et al., 2024). Our study applies this method and tests the formation of inferences between the beginning and end state. After each story, participants receive one picture either depicting the correct inference for the missing bridging event or a false inference to be judged for correctness. The confidence in this answer was also assessed.

Methods

Transparency and Openness

Transparency in Data, Analysis, and Materials

We affirm that the de-identified data on which the study conclusions are based are available at the project's Open Science Framework page (https://osf.io/5q3xc/).

We affirm that the syntaxes used to conduct analyses in the statistical package R are available at the project's Open Science Framework page (https://osf.io/5q3xc/). For data analysis we used R (version 4.3.1) and RStudio (version 2023.12.0). We used following packages for R: stringr (version: 1.5.0; Wickham, 2022), sciplot (version: 1.2-0; Morales et al., 2020), lme4 (version 1.1-33; Bates et al., 2015), lattice (version: 0.21-8; Sarkar, 2008), ggplot2 (version 3.4-2; Wickham, 2016), lmerTest (version 3.1-3; Kuznetsova et al., 2017), car (version: 3.1-2; Fox & Weisberg, 2019), sjPlot (version: 2.8.15; Lüdecke, 2023), Hmisc (version: 5.1-0; Harrell, 2023), dplyr (version: 1.1.2; Wickham et al., 2023), tidyverse (version: 2.0.0; Wickham et al., 2019), viridis (Robinson & DeSarla, 2023), hrbrthemes (Rudis, 2023), ez (Lawrence, 2016), ggpubr (Kassambara, 2023), psych (Revelle, 2023), ggthemes (Arnold, 2023).

We present an example of the study materials (see Figure 1). All visual materials employed in this study can be retrieved by contacting corresponding author (e.varkentin@iwm-tuebingen.de). Access to these materials requires prior acceptance of the corresponding copyright and license agreement, as they were developed by a team of researcher in the Leibniz Institut für Wissensmedien (IWM).

Transparency in Research Design

We affirm that we report how we determined our sample size, all data exclusions, all manipulations, and all measures in the upcoming sections Participants. If specific exclusions were required due to missing data in particular values, we have documented such occurrences in the section Results.

Preregistration

Both parts of the study were preregistered (including study design, hypotheses, and analytic plan):

https://aspredicted.org/Y11_CM2; https://aspredicted.org/7C2_VBF.

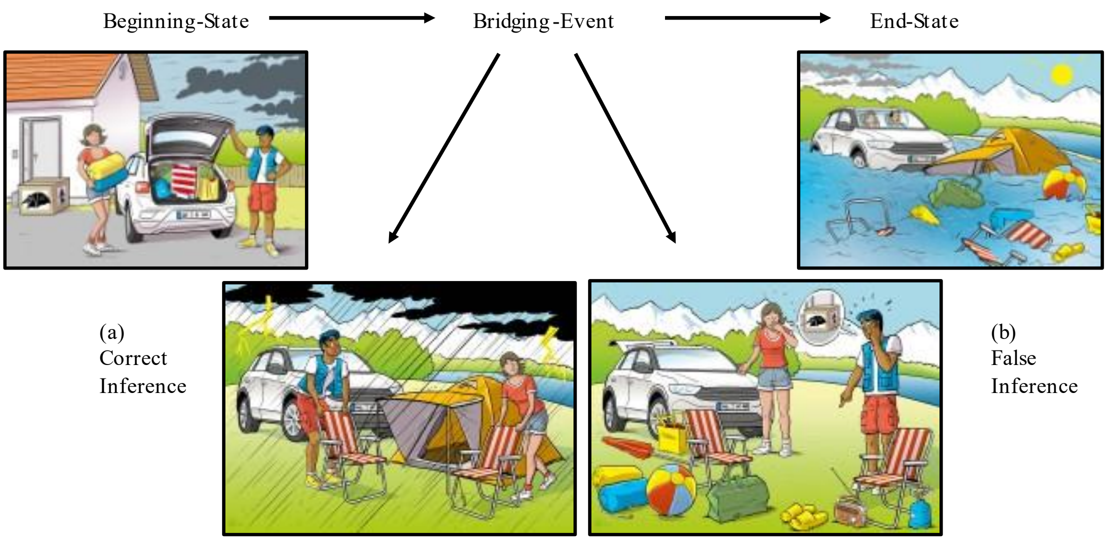
Material test

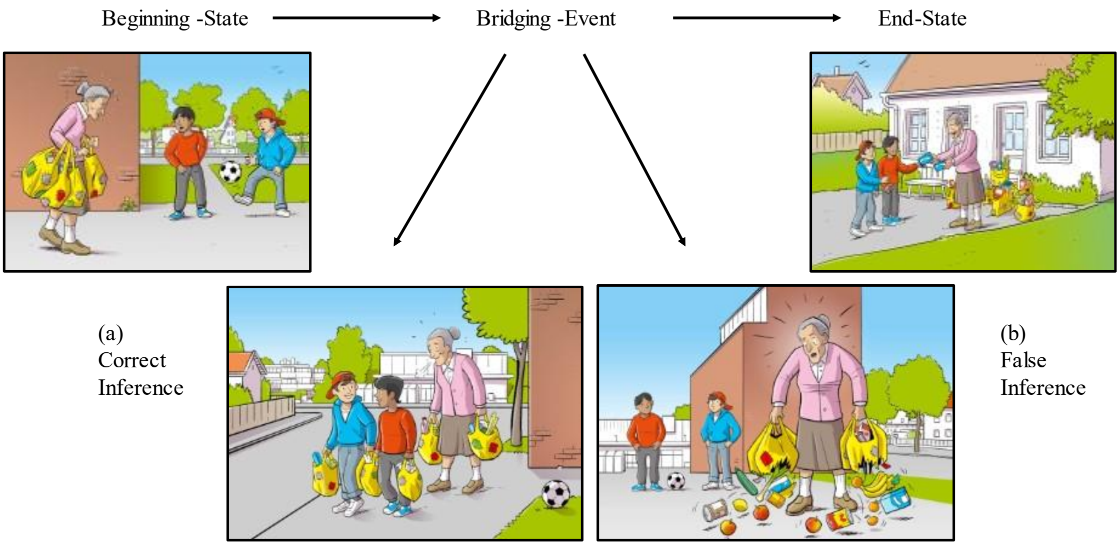
As no standardized materials had been developed yet to measure narrative comprehension, and the existing materials were primarily oriented toward children samples, we first developed a set of textual and pictorial stories to measure narrative comprehension. We conducted a pretest of the stimulus material in a student sample. A total of 28 items were developed, with three difficulty levels in the text form. Difficulty levels were differentiated based on the number of storylines within a story. At level 1 (simplest), there was one storyline, and, in most cases, stories involved a single character. At level 2, there were two storylines and more than one actor. At level 3, there were at least three storylines and even more characters (see Figure 1). Moreover, with increasing difficulty, we had more details in each story, which is why each level had a different number of words, i.e., level 1 had the shortest stories (30-40 words per panel), while levels 2 (40-50 words per panel) and 3 (40-60 words per panel) were consequently longer. Additionally, we made sure to develop both positive (e.g., boys helping an elderly woman) and negative scenarios (e.g., flooded camp site) to counterbalance the sentiment of a story. The text items were tested in a preliminary study with 28 participants, who indicated the stories' difficulty and affect. We fitted a linear mixed model with the help of the lme4 package (Bates et al., 2014). Results showed that, on average, the subjects rated the items' affect as we had planned (OR = 2.58, CI = 2.32 – 2-84, $t(25.48) = 19.50$, $p < 0.05$). In terms of difficulty, there were significant differences between the levels 1 and 2, $t(22.34) = 2.25$, $p = .035$, as well as between the levels 1 and 3, *t*(23.53) = 2.58, *p* = .017. Based on these results, four items that did not provide clear results were excluded. The total amount of final text items included 24 stories.

To create a pictorial version of items, we worked in close collaboration with a comic artist, who created 24 comics for each textual story. The most crucial issue was that the comics were as equivalent to the text version as possible to make measurements in two codalities (pictorial and textual) in future studies possible. Thus, the development of each story involved multiple feedback loops. Two of the stories (in pictorial) are depicted in Figure 1. In the current study, we used only the pictorial version as we are interested in measuring visual narrative comprehension.

Figure 1 *Example of a story from Level 2 (upper story) and 3 (lower story).*

The upper row shows the beginning state and end state, which were presented to the participants with a blank panel between them instead of the bridging event. The lower row shows two possible inferences for the bridging event.





Samples

In Experiment 1, we tested 203 participants (N = 203, M = 23.26 years, range 18-57 years, SD = 5.67, Md = 22 years, 156 female, 44 male, 3 diverse). Participants were recruited via email from the University of Tübingen and the University of Trier. The participants participated in exchange for course credit, or they had a chance to win one of two vouchers from a local bookstore.

In Experiment 2, we recruited a sample of 216 participants over 60 years old (N = 216, M = 67.32 years, range 60-85 years, SD = 5.47, Md = 67 years, 77 female, 135 male) with the online-panel provider bilendi & respondi (bilendi.de), which compensated participants for their participation. We are unable to provide the racial distribution of the sample for both studies, as questions related to ethnical background are not included in the studies conducted in Germany due to legal restrictions.

In *Experiment 1* (younger sample), the following exclusion criteria were applied: participants with a completion time of less than 10 minutes or more than 60 minutes were excluded. However, no participants met this criterion. 24 participants were excluded for having previously participated in an experiment using the same stimuli. Additionally, 2 participants were excluded for not providing consent, and 3 participants requested to withdraw their data. Age-related exclusion criteria were also applied, excluding participants under 18 and over 60 years old, though no participants met this criterion.

In *Experiment 2* (older sample), participants younger than 60 years old were excluded, resulting in the removal of 19 participants. Additionally, 22 participants were excluded for not providing consent, and 2 participants requested to withdraw their data. Another exclusion criterion was applied to participants who reported not having properly viewed more than half of the presented stories. However, no participants met this criterion.

Both studies received ethical approval by the local ethics commission of the Leibniz Institut für Wissensmedien (IWM) (LEK 2022/043).

Procedure

Both experiments were almost identical, with only the level of induced stress and the presentation time in Experiment 2 (older sample) being adjusted due to feedback from the local ethics committee (yet still sufficient for the successful manipulation check, as described in the Results section).

The experiment was programmed and hosted with SoSciSurvey (soscisurvey.de) as an online study, and participants were randomly assigned either to the stress or control condition. The experiment was conducted in German and began with providing general information about the study goals. However, participants were initially not told that stress induction was part of the experimental design. Instead, they were only told that mathematical and cognitive tasks would be presented. Participants who agreed with the conditions provided consent. Afterward, demographic data were collected, including age, gender, education, and stress-coping strategies (based on the Stress Coping Inventar; Satow, 2012). Furthermore, participants provided information about their experience with comics in their adolescence and nowadays (7-point Likert scale).

Stress Induction

In the stress and control conditions, an affect baseline was established using the Positive and Negative Affect Schedule (PANAS; Breyer & Bluemke, 2016). Additionally, we measured acute subjective stress on a range from 1 to 100 (visual analog scale). Moreover, participants completed the Perceived Stress Scale to assess chronic stress (PSS, Cohen et al., 1983). After that, the experimental group was requested to click the displayed link text ("Please, click here"). Thus, the link text covered the name of the website https://stress-plus.herokuapp.com, which was the online tool used to induce acute stress (Richer et al., 2023; www.stress-plus.herokuapp.com). This online tool presents different cognitive tasks of varying difficulty and time limits and provides a quasi-social feedback field regarding the participants' performance (e.g., "unfortunately, your performance in this task was not sufficient. Please try harder."), which may intensify the pressure on the participants while solving the different tasks. Moreover, to intensify stress induction participants saw a fake comparison bar with other participants, which always showed the result "less than average". The current study used a math test, a numerical Stroop task, and a mental rotation task. Each task lasted 110 seconds. The whole stress induction lasted 6 minutes, which resembles studies using similar stressors (e.g., Clamor et al., 2015). All tasks were supposed to be solved under high time pressure but were programmed in a way that it was still possible to reply correctly at least to some of the tasks. This setting was intentional so that participants do not give up too soon and keep on trying to solve the tasks. The difficulty level was set to 'hard' for the younger sample and 'medium' for the older sample due to ethical considerations. The time allowed for providing an answer was 3 seconds for the younger sample and 6 seconds for the older sample. Between the tasks, participants had a ten-second break and received negative visual feedback that requested them to try harder or that their performance was not good enough.

After completing the tasks, participants should memorize a password, given on the last page of the stress online tool. The password was given to verify that participants had clicked the link text and stayed attentive on the website for six minutes. Moreover, participants were not able to move forward with the experiment on the main experimental website, as we had adjusted the waiting screen for six minutes. After memorizing the password, participants were requested to return to the main experimental website (https://sosci.iwm-tuebingen.de/) and proceed with the experiment. The control condition had no stress induction, instead, they received the filler matching tasks. In this simple task, participants matched categories such as fruits and vegetables, animals and their offspring, edible and inedible items, and living versus non-living things. For example, participants were asked to classify whether an orange is a fruit or a vegetable.

After stress induction in the stress condition and the filler tasks in the control condition, PANAS and subjective stress assessment were recorded again in both conditions. Next, participants in both conditions performed the narrative comprehension measurement, which will be described in the next section.

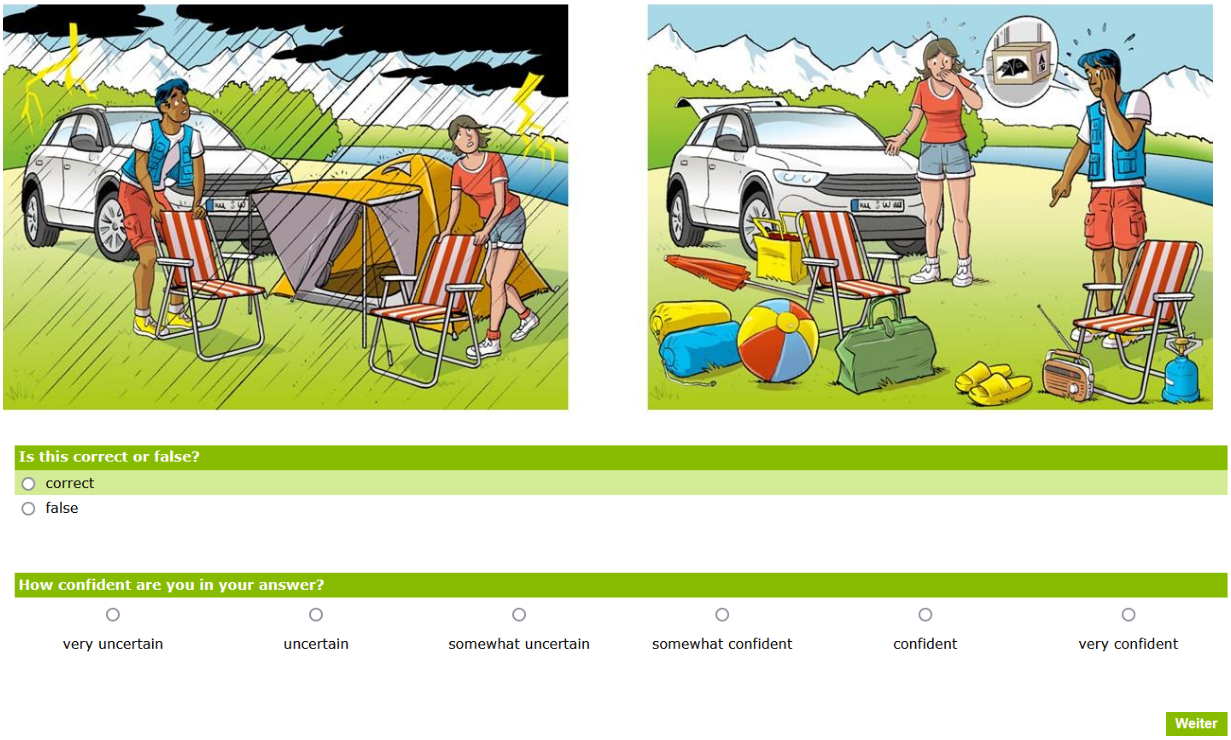
Narrative comprehension task

In this task, participants were instructed to comprehend the pictorial stories with a missing middle part (i.e., the bridging event). They could see only the beginning- and end-states of each of the 24 stories. Before the main experiment, we presented two exercise stimuli, demonstrating the experimental manipulations. For presentation, the pictures were shown simultaneously in a row while the middle picture (bridging event) of each story was replaced by an empty frame (see Figure 1, upper row).

We set the viewing time of each story to nine seconds for the younger sample and to eleven seconds for the older sample. Upon the time expiry, participants were automatically forwarded to the next page. Here, they received either a correct or a false inference presented as a picture and had to indicate if it fit the story they were presented with. Moreover, the confidence in this answer was also assessed. Participants were presented with the question, "How confident are you in your answer?" with six response options ranging from "very uncertain" to "very confident." Figure 2 illustrates both inference options (false on the left and true on the right) for the story presented in Figure 1, upper row, and portrays the questions in the presentation mode, replicating the participants' perspectives.

Figure 2 *Examples of inferences and questions following the inference recognition task. The left picture shows the correct inference and the right picture shows the false inference for the story depicted in Figure 1 (upper row). For each story, only one of the pictures was shown in the actual task.*

The lower row represents the questions in the presentation mode exactly as they were seen by the participants.



The correct inference contains the bridging event, that is, the plot that connects the beginning- and end-states, while the false inference includes the same characters and same surroundings, but the plot is changed and does not connect the beginning- and end-states, but rather is a parallel hypothetic storyline. Each clip was paired with either a true or a false inference picture regarding the blank frame. For each of the 24 experimental clips, we presented either a true (12 trials) or a false (12 trials) inference. The selection of the 24 clips and the combination with true/false inferences was counterbalanced across participants (Huff et al., 2023).

After finishing the bridging-inference generation measurement for the 24 stories, participants in Experiment 2 (older sample) were asked whether they could sufficiently see most of the stories in the given time. At the end of Experiments 1 and 2, all study participants were debriefed regarding the study aims. Thus, we could reduce their distress level, which should have been induced in the experimental group.

Results

First, we will describe the results of Experiment 1 conducted with the younger adults. Second, we will present the findings from Experiment 2, conducted with the older adults. Finally, we will statistically compare the two datasets.

Experiment 1 (younger sample)

Manipulation check

To validate the results of the stress induction, PANAS, and subjective stress measurement took place twice during the experiment in both conditions (control, stress), before and immediately after the stress induction in the experimental condition, and filler matching tasks in the control condition (see Table 1).

Table 1 *Stress assessment for the younger sample as a function of condition (stress, control) and measurement time (t1: before induction, t1: after induction).*

Condition	Scale	t1		t2	
		M	*SD*	*M*	*SD*
Stress	PANAS (positive affect)	26.54	6.52	22.74	6.73
	PANAS (negative affect)	14.88	5.96	18.93	8.09
	Subjective stress	37.19	27.57	54.44	28.48
Control	PANAS (positive affect)	26.27	6.50	24.38	7.37
	PANAS (negative affect)	13.99	4.22	13.66	4.44
	Subjective stress	37.89	24.84	34.72	23.72

Note. t1: before stress induction or filler matching task, t2: after stress induction or filler matching task

A t-test for dependent samples revealed a significant increase in the negative affect in the stress condition, $t(100) = -6.11$, $p <.001$, $d = 0.61$**.** Those participants also showed a significant decrease in their positive affect, $t(100) = 7.68$, $p <.001$, $d = 0.76$. The participants in the control condition showed no significant differences in the negative affect scale, $t(101) = 0.99$, $p = .322$, $d = 0.10$. However, there was a significant decrease in the positive affect scale in the control condition,

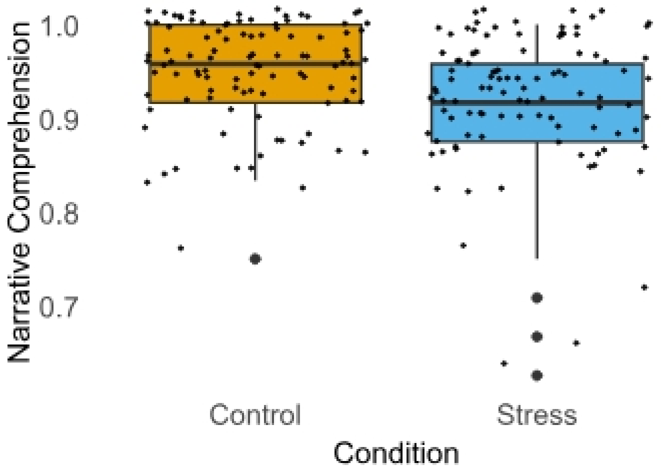
$t(101) = 4.58$, $p <.001$, $d = 0.45$. The participants in the stress condition assessed their subjective stress level as significantly higher after the induced stress, $t(100) = -6.53$, $p < .001$, $d = 0.65$. Participants in the control condition showed no significant difference in their subjective stress level, $t(101) = 2.04$, $p = .978$, $d = 0.20$. Furthermore, we compared with the t-test for independent samples the negative affect between both conditions and found that participants in the stress condition had a significantly higher negative affect after the stress induction than participants in the control condition after solving the alternative filler tasks, $t(154.9) = -5.74$, $p < .001$, $d = -0.80$. Further, participants in the control condition showed a significantly higher positive affect than the experimental group with $t(199.67) = 1.66$, $p = .049$, $d = 0.23$. The subjective stress level in the stress condition was found to be higher than in the control condition at the timepoint two (after the stress manipulation or filler task), $t(193.94) = -5.36$, $p < .001$, $d = -0.38$.

Pre-registered analysis

To test H1 (group difference in narrative comprehension task performance), we calculated proportion of correct inferences and then tested the variance homogeneity. An *F*-test revealed a significant difference between the two variances, $F(101, 100) = 0.59$, $p = .008$. Therefore, we conducted a Welch two-sample t-test confirming a significant difference between the experimental and control conditions, $t(187) = 2.96$, $p = .004$, $d = 0.22$. Compared to the control condition, $M = 0.95$ ($SD = 0.05$), narrative comprehension was significantly impaired by acute stress, $M = 0.92$ ($SD = 0.07$) (see Figure 4).

We additionally calculated a Bayesian t-test with a non-informative Jeffrey's prior, enabling the explicit testing of the null hypothesis, thus complementing our frequentist approach. We followed Jeffreys' (1961) heuristic: Bayes Factors (BF) between 1-3 are anecdotal, 3-10 substantial, 10-30 strong, 30-100 very strong, and BFs >100 extreme evidence for the alternative hypothesis. Fractions (1/3, 1/10, etc.) represent evidence strength for the null hypothesis. This Bayes t-test showed substantial evidence for the alternative hypothesis ($BF = 8.47$), which assumes a difference between experimental conditions.

Figure 4 *Boxplot depicting the distribution of narrative comprehension as a function of condition (control, stress) for the younger sample.*

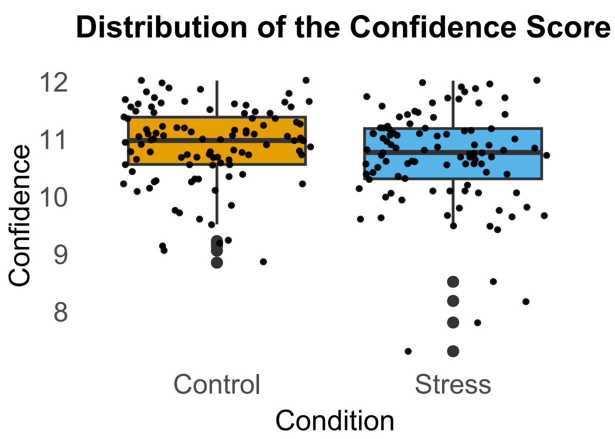


Exploratory analyses

We first explored whether there is a between-group difference in participants' confidence in their responses. Participants in the control condition were more confident than participants in the stress condition, as shown by a t-test for independent samples, $t(201) = 2.06$, $p = .041$, $d = 0.41$ (see Figure 5).

We additionally calculated a Bayesian t-test with a non-informative Jeffrey's prior. This Bayes t-test showed indecisive evidence for neither the null and the alternative hypothesis ($BF = 1.10$).

Figure 5 *Boxplot describing the distribution of confidence in response in both conditions (control, stress) for the younger sample*



Experiment 2 (older sample)

Manipulation check

To validate the results of the stress induction, PANAS and subjective stress measurement took place twice during the experiment in both conditions (stress and control): once before and once immediately after the stress induction in the stress condition and alternative filler tasks in the control condition (see Table 5).

Table 5 *Stress assessment for the older sample as a function of condition (stress, control) and measurement time (t1: before induction, t1: after induction).*

Condition	Scale	t1		*t2*	
		M	*SD*	*M*	*SD*
Stress	PANAS (positive affect)	30.44	8.04	27.53	7.5
	PANAS (negative affect)	12.51	4.73	16.41	7.15
	Subjective stress	13.26	18.49	37.23	29.17
Control	PANAS (positive affect)	29.70	7.55	29.69	8.01
	PANAS (negative affect)	12.94	5.2	12.22	4.59
	Subjective stress	11.71	18.14	12.39	16.82

Note. t1: before stress induction or alternative task, t2: after stress induction or alternative task

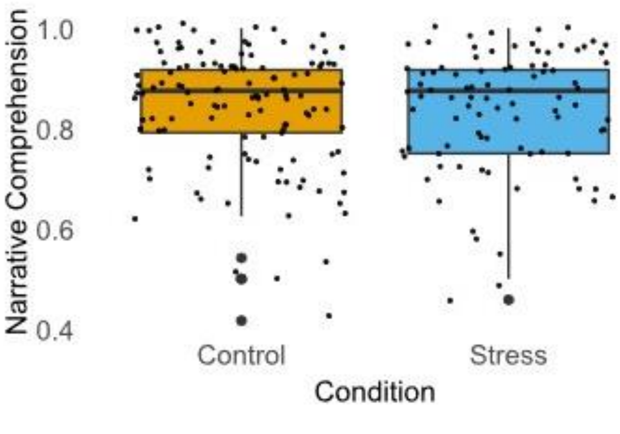
A t-test for dependent samples was conducted to run the manipulation check. Firstly, we compared the negative affect scores at time point 1 and time point 2 in the stress condition. A t-test revealed a significant increase in the negative affect in the stress condition, $t(89) = -5.58$, $p < .001$, $d = 0.46$. There was also a significant decrease in positive affect in the stress condition, $t(89) = 5.67$, $p < .001$, $d = 0.59$. A paired samples t-test was conducted to compare negative affect scores at timepoint 1 and timepoint 2 in the control condition. There was no significant difference in the negative affect scale, $t(121) = 1.92$, $p = .057$, $d = 0.17$. These results suggest that there was no significant change in negative affect over time in the control condition. The control condition showed also no significant differences in the positive affect, $t(121) = 0.018$, $p = .986$, $d = 0.00$.

The participants in the stress condition assessed their subjective stress level as significantly higher after the induced stress, $t(89) = -8.62$, $p < .001$, $d = 0.91$. This indicates a substantial difference between the two measurements in the stress condition. The participants in the control condition showed no significant difference in their subjective stress level $t(121) = -0.77$, $p = .222$, $d = 0.07$. Furthermore, a t-test for independent samples was conducted to compared the negative affect between both conditions and found that participant in the stress condition had a significantly higher negative affect after the stress induction than the participants in the control condition after solving alternative filler tasks, $t(141.6) = -4.87$, $p < .001$, $d = 0.68$. This suggests that there is a substantial difference in negative affect at timepoint two between the control and stress conditions, with the stress group exhibiting higher negative affect. The control condition showed a significantly higher positive affect than the stress condition, $t(198.5) = 2.01$, $p = .046$, $d = 0.40$. This indicates that there is a moderate difference in positive affect at timepoint two between the control and stress conditions. The subjective stress level in the stress condition was higher than in the control condition at timepoint two (after the stress manipulation or filler task), $t(132.18) = -7.24$, $p < .001$, $d = 1.09$.

Pre-registered analysis

To test H2 (group difference in narrative comprehension task performance; the stress condition exposed to acute stress has lower narrative comprehension performance than the control condition in the older sample), we first tested for variance homogeneity. The *F*-test revealed no significant difference between the two variances, $F(2927,2159) = 0.98$, $p = .611$. Therefore, we conducted a standard t-test, which showed no significant difference between the stress and control conditions, $t(210) = 0.25$, $p = .805$, $d = 0.03$. Whereby the control condition had an average performance of $M = 0.84$ ($SD = 0.12$) and the stress condition $M = 0.84$ ($SD = 0.12$) (see Figure 7). We additionally calculated a Bayesian t-test with a non-informative Jeffrey's prior, enabling the explicit testing of the null hypothesis, thus complementing our frequentist approach. We followed Jeffreys' (1961) heuristic: Bayes Factors (BF) between 1-3 are anecdotal, 3-10 substantial, 10-30 strong, 30-100 very strong, and BFs >100 extreme evidence for the alternative hypothesis. Fractions (1/3, 1/10, etc.) represent evidence strength for the null hypothesis. This Bayes t-test showed substantial evidence for the null hypothesis ($BF = 0.16$), which assumes no difference between experimental conditions.

Figure 7 *Boxplot describing the distribution of narrative comprehension test performance in both conditions (older sample)*



Explorative analyses

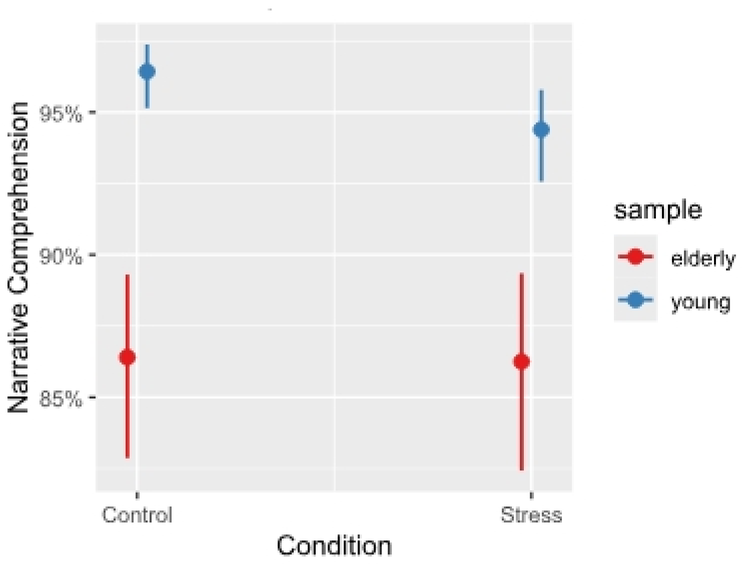
Further exploratory analysis investigated whether there is a between-group difference in participants' confidence in their responses and showed that there is no effect of stress on confidence in the older sample. The control condition did not significantly differ from the stress condition in submitting their confidence rating for the correctness and falseness of depicted inferences with M = 9.06 (SD = 1.22), whereby the stress condition had M = 9.23 (SD = 1.11). The conducted t-test for independent samples revealed no significant between-group difference, $t(210) = -1.029$, $p = .305$, $d = -0.14$.

We additionally calculated a Bayesian t-test with a non-informative Jeffrey's prior. This Bayes t-test showed substantial evidence for the null hypothesis (BF = 0.25), which assumes no difference between experimental conditions.

Cross-experimental analysis: Comparison of two samples

We conducted a cross-experimental analysis comparing the two experiments to test for the interaction effect of age (younger vs. older sample) and condition (stress vs. control). We fitted a GLMM (generalized linear mixed models) with condition (stress, control) and age group (younger vs. older sample) as fixed effects (main effects and interaction), and participants and item as random effects. We submitted the resulting model to a type 2 Anova using the Anova function of the car package (Fox & Weisberg, 2019). Besides a significant main effect of condition (lower performance in stress condition, $\chi^2(1) = 3.78$, $p = .052$), and a significant effect of age group (lower performance for the older participants, $\chi^2(1) = 128.6$, $p < .001$), we observed a significant interaction effect of condition (stress, control), and age (younger, older), $\chi^2(1) = 4.62$, $p = .032$. Whereas narrative comprehension was not influenced by acute stress in the older sample, we found a substantial impairment in the younger sample (see Figure 9). This cross-experimental analysis confirms the results of Study 1 and 2.

Figure 9 *Predicted probabilities in the interaction model of condition and age*



Discussion

In this study, we examined narrative comprehension of pictorial stories in younger and older groups under stress and in a control condition. While stress affected narrative comprehension negatively in the younger group (supporting H1), narrative comprehension remained unaffected by stress in older adults (not supporting H2). This finding supports research, indicating the general stability of narrative comprehension skills in the elderly (Huff et al., 2023, Varkentin et al., 2024, Ulatowska et al., 1998). Comprehension of pictorial and textual narratives, measured with bridging inference generation remains stable and unaffected by age progression, even though cognitive skills and working memory are generally understood to show signs of decline as people age (Huff et al., 2023, Varkentin et al., 2024). The previous studies by Huff et al. (2023) and Varkentin et al. (2024) also employed a bridging event generation task to measure narrative comprehension. However, a key limitation in their research lies in the materials they used, which comprised only eight stories primarily tailored for the multilingual assessment of children. The consistency of our findings, using new and improved materials, with the previous results of Huff et al. and Varkentin et al. reinforces the idea that narrative comprehension remains stable with age (Huff et al., 2023; Varkentin et al., 2024).

The stability of narrative comprehension across age can be explained by a shift in comprehension processes. For instance, older adults may develop more differentiated event schemas or event model through age and experience. The structure-building framework (Gernsbacher et al.

1990) posits that when new information is related to previously acquired knowledge, it is integrated into pre-existing structures and schemas. It can be assumed that older individuals possess a greater number of schemas, which are more differentiated, allowing them to be more resilient to stress during comprehension. Also SPECT theory (Loschky et al., 2020) emphasize that current event model is influenced by formed event models stored in episodic long-term memory. Maybe amount of stored event models can compensate for the negative effect of stress. The idea of stability of narrative comprehension in age is also supported by the psychometrically-based theory of fluid intelligence and crystallized intelligence (Cattel R., 1963). Cattel describes (1963 & 1971) fluid intelligence, which refers to the capacity to solve new reasoning challenges. In contrast, crystallized intelligence refers to the ability to apply fundamental relational concepts acquired earlier (Cattell, 1987), involving accumulated experience, gained knowledge, and the capacity to use that knowledge and skills in appropriate situations. Interestingly, both types of intelligence have their peaks. It is commonly assumed that peak of the fluid intelligence development happens at a young age, typically around the age of 20 (Schubert et al, 2019), while crystallized intelligence typically increases gradually and stays relatively stable across most of adulthood, and then begins to decline only after age 65 (Cavanaugh et al., 2006).

The unexpected finding that older adults' performance in narrative comprehension remains unaffected by stress could be partially attributed to their more efficient coping mechanisms. Applying effective and active coping mechanisms is essential for functional health and social relations. Older adults apply a combination of coping and defense strategies, suggesting enhanced impulse control and a propensity to view conflict situations positively. In contrast, adolescents and younger adults tended to utilize strategies characterized by outward aggression and more psychological undifferentiation (Diehl et al., 1996). Coping capacities, exemplified by support-seeking, problem-solving, and distraction increase with age; moreover studies could find advancements in the utilization of various coping strategies based on their effectiveness in different situations (Zimmer-Gembeck & Skinner, 2011). Also, in the working context older workers utilize greater active problem-focused and active emotion-focused coping strategies compared to their younger colleagues (Hertel et al., 2015). However, there are also controversial findings, showing opposite results, for example, Chen and colleagues found that older adults were less likely than younger adults to use problem-focused coping and showed lower levels of positive affect (Chen et al., 2018). Even while aging may be associated with declines in memory, processing speed, and executive functioning (Harada et al., 2013), older individuals continue to discover methods to compensate for age-related deficits and remain active physically and cognitively. It was found that the use of compensation strategies (mental imagery, greater concentration or slowing down while doing cognitive tasks or including external aids) is associated with higher levels of functioning in daily life among older adults (Tomaszewski Farias et al., 2018). Compensation strategies are typically used proactively to postpone or reduce the decline in functionality, and in certain instances, they may also reflect an amplification of long-term habits (Tomaszewski Farias et al., 2018).

The heightened impact observed in the younger group may be linked to their perception of difficulties. Our study revealed that the younger group began the study with already notably higher levels of perceived stress, as measured by PSS (M = 29.99 in the younger group compared to M = 23.05 in the older group) and by subjective stress assessment using the visual analog scale (M = 37.54 in the younger group compared to M = 12.37 in the older group). Additionally, stress was found to significantly decrease confidence in responses among younger adults, while the confidence levels of older adults remained unaffected. This finding highlights the broad negative impact of stress on the younger sample. Stress not only impaired comprehension in younger adults but also led to increased feelings of insecurity. Our findings are in line with previous research (Heereman & Walla, 2011), which shows that stress results in reduced decision confidence when decisions involve moderate levels of uncertainty but has no effect in cases of either high or low uncertainty. Furthermore, ambiguity is less accurately assessed under stress conditions (Heereman & Walla, 2011). The APA's 2023 Stress in America survey found that young adults (ages 18 to 34) reported higher stress levels than those aged 65 and older. Young adults rated their average stress level as 6 out of 10, compared to 3.4 among the older generation (American Psychological Association; 2023). Similar patterns have been observed in previous studies, for instance, Aldwin et al. (1996) found that middle-aged men were more likely to view their problems as both challenges and annoyances compared to older men. Moreover, older people showed a lower stress-induced cortisol response than young people (Hidalgo et al., 2015). This can explain why the younger group was more negatively affected by stress in their narrative comprehension. Interestingly, in her study, Hidalgo and colleagues (2015) found a similar effect of stress, but in a memory recall task. Stress impaired the free recall of emotional (both positive and negative) and neutral pictures the next day after encoding, but only in the group of young men. This negative impact of stress was not observed in older adults. These findings, along with our results, indicate that the younger generation may be more sensitive to the negative effects of stress.

Limitations

One of the limitations of the current study is the lack of a broader variance. Especially for the sample of young people who were mainly university students, we can assume that they have above average cognitive skills (e.g., IQ, reading skills). Thus, they were probably more efficient in extracting relevant and suppressing irrelevant information (Gernsbacher et al., 1990). In future studies, it would be interesting to manipulate education as one influencing factor (Huff et al., 2023). Furthermore, having pictorial stimuli makes it possible to investigate possible between-group differences with persons with low-literacy (Grotlüschen et al., 2019).

Another limitation is the absence of measurement of a physiological stress marker. For example, salivary cortisol, as a marker of hypothalamus-pituitary-adrenal activity, can be used to test whether participants are stressed (Noack et al., 2019). Thus, more replications of the current study with additional cortisol measurements are needed. By doing this it would be possible to cover not only subjective but also objective stress assessment.

Another limitation is that the two age groups were tested in two separate experiments (including slightly different stress inductions). While this was a prerequisite of the local ethics committee, future research should aim to test the different age groups within a single experiment or even aim to test a representative sample.

Moreover, the method used in this study explores only one aspect of narrative comprehension – bridging inference generation. While understanding the narrative and inferencing is crucial, it is not the sole process occurring during story comprehension. Therefore, future studies should employ different methods to measure narrative comprehension or explore alternative ways to test inference generation to support our findings. For example, open-ended questions or recall of the narrative instead of judging for correctness pre-determined inference would be one possible alternative to test narrative comprehension. By doing this, more insights into how inferences are generated and how visual narrative comprehension works in different groups could be gained.

The aim of this study was to investigate the process of narrative comprehension and the impact of stress on it in older and younger adults. In summary, our findings indicate that stress negatively affects both narrative comprehension and confidence in responses among younger adults, supporting Hypothesis 1 (H1). In contrast, narrative comprehension and response confidence in older adults remain unaffected by stress, which does not support Hypothesis 2 (H2).

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