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The Psycholinguistic and Affective Processing of Framed Health Messages Among Younger and Older Adults

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How health-related messages are framed can impact their effectiveness in promoting behaviors, and messages framed in terms of gains have been shown to be more effective among older adults. Recent findings have suggested that the affective response to framed messages can contribute to these effects. However, the impact of demands associated with psycholinguistic processing for different frames is not well understood. In this study, exercise-related messages were gain or loss framed and with a focus on either desirable or undesirable outcomes. Participants read these messages while their eye movements were monitored and then provided affective ratings. Older adults reacted less negatively than younger adults to loss-framed messages and messages focusing on undesirable outcomes. Eye-movement measures indicated both younger and older adults had difficulty processing the most complex messages (loss-framed messages focused on avoiding desirable outcomes). When gain-framed messages were easily processed, they engendered more positive affect, which in turn, was related to better recall. These results suggest that affective and cognitive mechanisms are interdependent in comprehension of framed messages for younger and older adults. An implication for translation to effective health communication is that simpler message framing engenders a positive reaction, which in turn supports memory for that information, regardless of age.

Public Significance Statement

Linguistically simple health messages that focus on the positive outcomes of behavioral engagement, relative to the negative consequences of not doing something, are processed more fluently, which contributes to a more positive affective response. Positive affect, in turn, produces more robust memory for health information. These principles held regardless of age. These findings may inform recommendations for conveying health information to the public.

Keywords: aging, message framing, physical exercise promoting, affective processing, psycholinguistic processing

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People are routinely bombarded with health messages. The way in which these health messages are framed can impact their effectiveness in promoting health behaviors. Message framing may influence the way in which information is encoded through both affective and cognitive-linguistic pathways (Updegraff & Rothman, 2013), though the roles of these mechanisms for comprehension, memory, and adherence are not well understood. Framing effects may differ depending on one's age (Notthoff & Carstensen, 2014), which impacts both language (Stine-Morrow & Radvansky, 2017) and affective (Mikels et al., 2016) processing. We report a study in

which we used eye tracking to examine age differences in the ongoing comprehension of health messages framed in different ways and the relationship of processing difficulty to affective response. Our focus was on messages about physical activity given its well-replicated status as a pathway to physical, cognitive, and mental health (Febbraio, 2017).

Message Framing

In health communication, message framing is a theoretically grounded approach to encourage healthy behaviors by emphasizing particular consequences of adopting or not adopting the behaviors (Rothman & Salovey, 1997). As shown in the upper panel of Figure 1, health messages can be framed in terms of the benefits of engaging in healthy behaviors (i.e., gain-framed, GF) or the costs of not doing so (i.e., loss-framed, LF). Framing of the outcomes can also vary so that GF messages can be expressed in terms of attaining desirable health outcomes (GF-D) or avoiding undesirable ones (GF-U), and LF messages can focus on the loss of desirable health outcomes (LF-D) or the attainment of undesirable outcomes (LF-U).

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Generally, GF messages, particularly those that encourage behaviors that promote health, have been shown to produce an advantage in terms of the ease of processing and effectiveness in stimulating behavior change. For instance, based on a meta-analysis, O'Keefe & Jensen (2008) reported that GF messages were more engaging, as measured by differences in memory and in stimulating related thoughts. Latimer et al. (2008) studied the differential effectiveness of framed messages in motivating physical activities by randomly assigning sedentary participants to one of the three conditions: GF only, LF only, or a mixed-framed control groups in which more than 80% of the messages were unframed. Messages were delivered to participants through the mail during the program. Participants who received only GF messages indicated stronger behavioral intentions than those who received only LF messages. A follow-up survey showed that those in the GF-only condition had greater self-reported physical activity engagement compared to those in the other conditions. In a meta-analysis of almost 100 published articles, Gallagher and Updegraff (2012) found that GF messages were more effective than LF messages in promoting prevention behaviors, particularly in the domain of physical activity, smoking cessation, and skin cancer prevention. The current literature suggests two accounts for the GF advantage.

First, Rothman and Salovey (1997) provided a theoretical analysis of GF and LF messages in terms of their differences in implied risk. GF messages, which speak to benefits of engaging in certain behaviors (e.g., provide protection from illness and maintenance of good health), do not suggest any risk (e.g., If you exercise, you will have a healthy heart), while LF messages, which focus on possible consequences of neglect, highlight risk (e.g., If you do not exercise, you may have an unhealthy heart). Based on the framing postulate of Prospect Theory (Tversky & Kahneman, 1981), suggesting that decision makers are risk averse when considering potential gains or benefits, Rothman and Salovey argued that GF messages are more effective than LF messages because they are more compatible with decision makers' risk aversion when considering gains.¹

Another, related, account is that GF messages evoke more positive affect than LF messages, in part, because the activation of risk would be expected to dampen positive affect in LF messages. Based upon the *risk-as-feelings* hypothesis (Loewenstein et al., 2001), people react to the prospect of risk not only cognitively but also emotionally. It is suggested that when faced with risky situations, decision makers can experience negative affect, such as worry, fear, or anxiety, and that this affect can play an informational role in decision making. In fact, several studies have found that messages framed in terms of gain evoke more positive affect, whereas those framed in terms of loss evoke more negative affect (Liu et al., 2019; Mikels et al., 2016; van't Riet et al., 2010). van't Riet et al. (2010) examined the effect of GF and LF messages describing health consequences of salt intake on message persuasiveness, as measured by the ratings of information acceptance, attitude toward the health behaviors, and behavioral intention. They found that GF messages were rated as more persuasive than LF messages in promoting prevention behaviors like physical exercise and reducing salt intake, and this effect was in fact mediated by the differential positive and negative affective responses evoked from GF and LF messages. In addition, Liu et al. (2019) found that for GF messages promoting physical exercise, the more positively people felt about the messages, the more effective people perceived them to be. On the other hand, the relationship was in the opposite direction

for LF messages, such that the more negative reactions people had toward the LF messages, the more effective they perceived them to be. In a field experiment, Mikels et al. (2020) showed that older adults solicited for a senior wellness program rated messages as more positive when framed in terms of gain relative to loss, which in turn predicted the likelihood of following up with an inquiry about joining the program. Collectively, these results suggest that affect evoked from framed messages can contribute to the framing effects on message effectiveness.

Thus, this literature is fairly clear in showing some advantages of gain-over loss-framing of messages promoting healthy lifestyles, with growing evidence that a central mechanism of communicative effectiveness has to do with the affective response to the messages. Less clear is the source of these differences in affective response. The dominant account has to do with the implicit activation of risk, but largely neglected is an important confound—differences between GF and LF messages in cognitive and psycholinguistic demands for the comprehender.

Cognitive and Psycholinguistic Demands of Comprehending Framed Health Messages

Comprehension of health messages is fundamentally language comprehension, which is widely conceptualized as depending on the construction of a mental representation at multiple levels. The *surface form* reflects the exact wording and syntactic form of the text. The *textbase* is the semantic representation, or the meaning, of a text as given. This representation can be modeled as a network of idea units, or "propositions," that describes the interrelationships among concepts described by the text. The *situation model*, on the other hand, is a mental representation of the state of affairs implied by the text (van Dijk & Kintsch, 1983). Language comprehension and memory are thought to rely on these different levels of representation, with their relative contributions depending in part on the affordances of the text, and the goals and abilities of the reader (Kintsch, 1994; Stine-Morrow et al., 2006). Relative to the surface form and textbase, the situation model is relatively resistant to memory decay (Radvansky et al., 2001), and it is thought to be the highest level of memory representation, which is the hallmark of comprehension (Zwaan & Radvansky, 1998). Comprehension of health messages and memory to support self-care, then, would be expected to depend on these levels of representations, though the ultimate effectiveness of the message for promoting decision making leading to behavior change should hinge on the construction of a situation model (O'Keefe & Jensen, 2008). As we will argue, framing can influence how the mental representation of a health message is constructed during comprehension.

Message framing varies in the use of negation, which can be a local operator like "not" or an action that expresses a negated situation. As discussed later in detail, the different number of negations in GF and LF messages can lead to differences in psycholinguistic processing (e.g., processing time). Research has shown that negations can slow processing and compromise

¹ This effect can actually be reversed for messages advocating detection behavior, such as mammogram screening, which put the decision maker at risk of discovering illness, in which case LF messages may be more effective than GF messages because decision makers are risk seeking when considering potential losses.

comprehension accuracy, effects that can be localized to both textbase and situation model processing (Kaup & Zwaan, 2003). Negation at the textbase level (e.g., “not doing exercise”) is thought to increase sentence processing demands in adding a proposition. Kaup and Zwaan proposed a two-step simulation hypothesis for comprehending negation at the situation level, such that readers first create a representation of the state of affairs that is negated in the situation model, and then, shift attention toward the actual state of affairs described in the text. In other words, the comprehension of the absence of a situation requires that a mental representation of the situation itself first be created and then suppressed (e.g., “not doing exercise” implies a situation in which *doing exercise* does not exist).

Figure 1 shows the typical of demands on comprehension as a function of framing conditions at the levels of the textbase (middle panel) and situation model (bottom panel). Framed messages can be thought as consisting of three major regions: a behavior region that depicts engaging in or not engaging in a behavior; an outcome region describing a desirable or undesirable outcome; and linking the two, a verb region that affirms or negates the outcome. Thus, the behavior region and the verb region can each vary in their requirements for the processing of negations, placing differential demands in creating the textbase and situation model representations. Generally speaking, the negation in LF messages adds a proposition (regardless of outcome) as shown in the example in Figure 1.

Figure 1

Textbase and Situation Model Representations of a Sample Health Messages in Different Framing Conditions

SAMPLE MESSAGE VARYING IN FRAME AND OUTCOME

Gain-Frame/Desirable (GF-D):	Doing exercise can lead to good cardiovascular function.
Gain-Frame/Undesirable (GF-U):	Doing exercise can prevent bad cardiovascular function.
Loss-Frame/Desirable (LF-D):	Not doing exercise can hinder good cardiovascular function.
Loss-Frame/Undesirable (LF-U):	Not doing exercise can lead to bad cardiovascular function.

TEXTBASE

Proposition		GF-D	GF-U	LF-D	LF-U
P0 (NOT P1)	“not”			√	√
P1 (EXERCISE \$)	“doing exercise”	√	√	√	√
P2 (LEAD-TO P1 P3)	“can lead to”	√			√
P2 (AVOID P1 P3)	“can prevent/hinder”		√	√	
P3 (GOOD CVF)	“good CVF”	√		√	
P3' (BAD CVF)	“bad CVF”		√		√

SITUATION MODEL

Condition		Region		
Frame	Outcome	Behavior	Verb	Outcome
Gain	Desirable (GF-D)	Doing exercise 	can lead to 	good cardiovascular functions. 
	Undesirable (GF-U)	Doing exercise 	can prevent 	bad cardiovascular functions. 
Loss	Desirable (LF-D)	Not doing exercise 	can hinder 	good cardiovascular functions. 
	Undesirable (LF-U)	Not doing exercise 	can lead to 	bad cardiovascular functions. 

Note. See the online article for the color version of this figure.

By contrast, differential demands for situational representation as a function of frame are not as intuitive. In comprehending GF messages, the reader must construct a representation of the situation model (“doing exercise”) for the health behavior. However, in processing LF messages, readers first create that same representation and then mentally reject it. Similarly, when the message describes avoiding certain outcomes (as in GF-U and LF-D conditions), readers must first create the representation of “good (or bad) cardiovascular functions” and then suppress it. Thus, the construction of the mental representations for LF-D messages would be expected to be uniquely difficult in requiring the creation and suppression of situation models for both the health behavior and the outcome.

To the extent that readers attend to the textbase in comprehending such messages, one would expect different processing time between GF and LF messages as shown in Figure 1, with no effect of the outcome. If, on the other hand, comprehension were more oriented toward the situation model, one would expect relatively fast processing of GF messages describing the attainment of desirable outcomes (GF-D), as they require the simple construction of situation models of the behavior and of the outcome, with one leading to the other. By contrast, the processing of LF messages describing the avoidance of a desirable outcome (LF-D) should be especially difficult (i.e., has longer processing time) as they require the construction of the two situation models, each of which must be deleted (thus, requiring two two-step simulations). Finally, the processing time of other two conditions (GF-U and LF-U) should be in between GF-D and LF-D messages.

Furthermore, these differences in psycholinguistic processing may contribute to the different affective responses evoked from framed messages. Research has shown that processing fluency (i.e., the ease of processing) can produce positive affect (for a review, see Schwarz, 2004). For instance, in the study by Reber et al. (1998), participants were presented with images varying in perceptual difficulty and were asked to provide affective ratings. Images that were easier to process (e.g., higher figure-ground contrast or longer presentation time) were rated as more positive and prettier than images with lower perceptual fluency. Song and Schwarz (2008) found that exercise instructions printed in an easy-to-read font produced higher levels of motivation to engage in the exercise than those printed in a difficult-to-read font. Thus, GF messages may lead to more positive affective responses relative to LF messages, in part, simply because they are easier to understand.

Age Differences in the Effects of Framed Messages

Several studies have documented age differences in response to framed health messages. Particularly, GF messages have been found to be differentially more effective than LF messages in promoting a prevention behavior (i.e., walking) among older adults relative to younger adults (Notthoff & Carstensen, 2014). Shamskin et al. (2010) also found that, relative to younger adults, older adults rated positively framed health messages as more informative than negatively framed messages, and showed a corresponding recall advantage. Mikels et al. (2016) found older adults responded less negatively to LF health messages relative to younger adults, while both age groups had similar affective responses to GF messages. In addition, Liu et al. (2019) found that younger and older adults differentially used affective cues to gauge perceived effectiveness of

framed messages, such that relative to younger adults, older adults were more likely to find GF messages that made them feel good to be more effective.

From the affective perspective, researchers have argued that one of the mechanisms that contributes to the age differences in message-framing effects is the age-related positivity effect (Mikels et al., 2015), which is characterized as an increased preference with aging to process positive information over negative information (Carstensen & Mikels, 2005). This effect has been well demonstrated in a variety of tasks in which older adults are more likely than younger adults to attend to and recall positive stimuli relative to negative stimuli (Reed et al., 2014). The explanation of this positivity effect is derived from the Socioemotional Selectivity Theory (SST; Carstensen et al., 1999), which suggests a developmental shift in motivation toward emotionally meaningful goals as people age due to a shift toward more limited future time horizons. Thus, SST suggests that with aging, emotional satisfaction is prioritized resulting in a tendency to avoid negative information, and to seek positive information (Carstensen & Mikels, 2005).

From the cognitive-linguistic perspective, older adults generally show disadvantages in memory for text, which has been linked to deficits in textbase processing (Radvansky et al., 2001; Stine-Morrow et al., 2006), but the ability to construct situation models during reading comprehension can be relatively preserved with aging (Radvansky & Dijkstra, 2007; Radvansky et al., 2001; but see Noh & Stine-Morrow, 2009). For example, in the study by Soederberg and Stine (1995), younger and older adults read narratives containing a critical sentence directly stating the emotional disposition of a character that was either consistent or inconsistent with the implied emotional state of the character. Both age groups showed increased reading time on the critical sentences in the inconsistent condition relative to the consistent condition, suggesting an age-related preservation in building situation models containing emotional information.

Although few studies have investigated the effect of aging on processing negated texts, in a study by Margolin and Abrams (2009), participants read sentences that contained target words that were either preceded by negative modifiers or not (e.g., *the room was noisy* vs. *the room was not noisy*). After reading each sentence, participants were asked to name probe words related to the target words (e.g., *loud*). Naming time was increased and the comprehension accuracy was lower for sentences in which concepts were negated. This negation effect was similar among younger and older adults, suggesting age constancy in the two-step simulation process required to represent negation in the situation model (Kaup & Zwaan, 2003).

Current Study

The goal of this study was to examine the cognitive processing of framed health messages promoting physical exercise, and its relationship to affective response among younger and older adults. Eye tracking was used to investigate the cognitive effort involved in online processing. Eye movements have been widely used to study the moment-to-moment cognitive processing during reading comprehension (Rayner, 2009). They can reveal not only early-stage processing that is sensitive to basic word characteristics such as length but also, important to our research question, late-stage processing reflecting message integration and reanalysis. We also

examined subsequent memory for the messages. As outlined above, to the extent that comprehension of health messages depends on propositional coding, LF messages should take longer to read than GF messages, and because relative to younger adults, older adults have more difficulty in propositional coding, which is heavily dependent on working memory (Stine & Hindman, 1994), their reading times should be differentially longer in the LF condition. To the extent that comprehension of health messages depends on a situation model representation, readers would be expected to show relatively faster processing for GF-D messages and relatively slower processing for LF-D messages, with GF-U and LF-U falling in between (cf., Figure 1). Theories suggesting that situation model processing is preserved with aging (e.g., Radvansky & Dijkstra, 2007) would predict comparable effects for younger and older readers.

Subjective ratings were used to assess affective reactions to framed messages. Based on the SST, we predicted that older adults would show reduced negativity to LF messages relative to the young, and would show relatively better memory for GF messages (e.g., Mikels et al., 2016). We also examined whether the differential affective responses of framed messages were related to message memory as motivated by previous findings on affective response and perceived effectiveness (Liu et al., 2019).

Finally, we were interested in whether processing fluency was related to affective response (Reber et al., 1998; Schwarz, 2004; Song & Schwarz, 2008). To the extent that older readers might experience more processing difficulty with the more complex negations of LF messages (Margolin & Abrams, 2009; Stine & Hindman, 1994), one would expect a more exaggerated effect of processing difficulty on the affective response to messages among older adults.

Method

Participants

Forty younger (18–35 years old) and 40 older adults (64–80 years old) were recruited from the Champaign-Urbana community in the U.S. The sample size was estimated based on a power analysis using G*Power 3 (Faul et al., 2007) to test the differences of processing different types of messages between younger and older adults. With an α of .05 and a small-to-medium effect size (Cohen's $f = .15$), to achieve a power of .8, a total sample of $N = 62$ with two equal-sized groups of $n = 31$ was required. Thus, our sample size was adequate to detect the effects of interest. Two additional younger adults and four additional older adults came to the laboratory for testing but their sessions were discontinued because their eye movements cannot be tracked due to thick eyelashes or thick corrective lenses.

All participants were native speakers of English and were screened for severe neurological or medical conditions, such as Parkinson's, Alzheimer's Disease, stroke within the last 5 years, and severe visual impairments sufficient to affect reading the display based on self-reports. During scheduling, participants were reminded to wear any corrective lenses needed for reading. As shown in Table 1, the two age groups were matched in years of education, socioeconomic status (Barratt, 2006), and self-reported physical activity level (Washburn et al., 1993). Younger adults had higher levels of processing speed, as measured by letter and pattern comparison tasks (Salthouse, 1991) and digit-symbol coding task

Table 1
Mean Values (SEs) of Participant Characteristics

Measures	Younger adults	Older adults	<i>t</i> test <i>p</i> value
Age	24.50 (0.79)	71.50 (0.77)	
Education	15.49 (0.24)	15.50 (0.33)	n.s.
SES	45.64 (2.08)	44.27 (1.41)	n.s.
Positive affect	2.88 (0.11)	3.39 (0.11)	<.01
Negative affect	1.19 (0.04)	1.17 (0.04)	n.s.
PASE	151.22 (14.41)	151.09 (9.64)	n.s.
Promotion focus	7.29 (0.24)	6.01 (0.31)	<.01
Prevention focus	5.57 (0.23)	4.28 (0.31)	<.01
Vocabulary	9.70 (0.67)	13.89 (0.86)	<.01
Speed	0.51 (0.13)	−0.51 (0.10)	<.01
WM	0.28 (0.17)	−0.28 (0.09)	<.01

Note. SES = Socioeconomic Status, measured by Barratt Simplified Measure of Social Status; PASE = Physical Activity Scale for the Elderly; Promotion and Prevention Focus are measured by General Regulatory Focus Measure; Speed is a composite of standardized scores of letter comparison, pattern comparison, and digit-symbol coding task from the Wechsler Adult Intelligence Scale, with Cronbach's $\alpha = .85$; WM = Working memory, which is a composite of standardized scores of reading span and counting span, with Cronbach's $\alpha = .78$; n.s. = not significant.

(Wechsler, 2008), and working memory, as measured by counting span (Case et al., 1982) and reading span tasks (Stine & Hindman, 1994). In contrast, older adults had a higher level of vocabulary, as measured by the extended range vocabulary test (Ekstrom et al., 1976). The two age groups did not differ in their self-reported baseline negative affect levels, but older adults showed higher ratings on their positive affect levels than younger adults, as measured by the Positive Affect and Negative Affect Schedule (Watson et al., 1988) at the beginning of the study.² Participants scored higher on the promotion subscale than the prevention subscale of the General Regulatory Focus Measure (Lockwood et al., 2002), and this difference did not vary with age.³

Materials

Stimuli were 48 exercise-related messages. Four versions of each message were constructed according to Rothman and Salovey's framework (cf., Figure 1) in terms of two frame types (Frame: GF vs. LF) and two types of behavioral outcomes (Outcome: desirable vs. undesirable). GF messages were expressed such that engagement in exercise-related behaviors would result in the attainment of desirable outcomes (GF-D) or avoidance of undesirable outcomes (GF-U). LF messages were expressed such that the lack of engagement in exercise-related behaviors would result in the avoidance of desirable outcomes (LF-D) or attainment of undesirable outcomes (LF-U). So, messages had three regions: a behavior region (i.e., engaging vs. not engaging), verb region (i.e., attain vs. avoid certain

² Levels of positive and negative affect at baseline and self-reported level of physical activities had no effects on any of the dependent measures for affect rating, reading time, and memory recall of framed messages.

³ Regulatory focus (promotion vs. prevention) was measured as motivated by the literature suggesting that a person's motivational orientation of goal achievement can moderate the message framing effect (Updegraff & Rothman, 2013). However, the levels of promotion and prevention focus did not have significant effects on any of the dependent measures. Therefore, this was not further discussed in the article.

outcomes), and outcome region (i.e., desirable vs. undesirable). For about half the items, the propositional form was as in the example shown in Figure 1, such that LF entailed negation (requiring an additional proposition relative to the GF condition), and for the other items, LF described the lack of engagement without negation (e.g., “Engaging in routine exercise” vs. “A lack of routine exercise”). An analysis of propositional content showed that LF messages had a mean of .50 ($SE = 0.09$) more propositions than GF messages, $F(1, 47) = 130.4$, $p < .01$. There was no effect of outcome or an interaction, $F < 1$. The complete set of stimulus materials was presented in the Supplemental Materials online.

Each participant read a version of each of the 48 messages, with 12 from each of the 4 message framing conditions. Materials were counterbalanced across framing conditions to create four stimulus lists so that across the study, each message appeared approximately equally often in each condition. Thus, the effects of Frame and Outcome were examined as within-subject variables, such that each participant received all message conditions, and no participant was presented the same message in more than one condition. Messages were presented in a single random order for all four lists, and participants were assigned to one of the four lists using block randomization.

Procedure

This study was approved by the University of Illinois at Urbana-Champaign Institutional Review Board. The duration of the study was about 2 hr. After consenting, participants were interviewed to collect demographic information. Afterward, they completed the measure for positive and negative affect and then the exercise-related message reading task on a computer. Following the reading task, measures of processing speed (i.e., letter comparison, pattern comparison, and digit-symbol coding) were administered, which took approximately 8–10 min. Then, participants were given a surprise cued-recall task, followed by a recognition task about the messages they read. Finally, the rest of questionnaires and cognitive measures were administered.

During the reading task on the computer, participants' eye movements were monitored with a head-mounted SR Research Eye-Link II (500 Hz) eye-tracking system. Sentences were presented in white 20-point Courier New font on a black background on a 19-in. ViewSonic monitor set to a resolution of $1,024 \times 768$, with a refresh rate of 120 Hz. Participants were seated approximately 70 cm from the monitor, such that three letters subtended less than one degree of visual angle. None of the participants reported any difficulties to read messages on the display. Some sentences did not fit on one line, but words belonging to the same region were never separated. All sentences fit within two lines. Participants were asked to place their heads in a chinrest to minimize head movement. After the tracker was aligned and calibrated, the participant pressed the spacebar on the keyboard to begin reading. Calibration was checked and corrected between trials. When a minor drift occurred, the system autocorrected before beginning the trial. In cases where calibration was lost, the system was completely recalibrated by the experimenter before moving forward.

Participants were instructed to provide their affect ratings after reading each message. When they finished reading each message, they pressed the spacebar, and then were presented with the question

“How does this statement make you feel?” and a 6-point Likert rating scale from *very negative* (–3) to *very positive* (+3). Participants indicated their ratings by pressing numbered keys on the keyboard, and then were automatically directed to read the next message. Instructions and practice trials were given at the beginning so that participants were familiar with the keyboard to provide responses and did not need to look down at the keyboard, which minimized participants' head movements and reduced the probability to recalibrate the system during the reading task.

The cued-recall task aimed to assess the memory for the content of framed messages. Participants were presented with a piece of paper with designated columns to write down the benefits of doing physical activities and the consequences of not doing physical activities that they learned from reading the messages. To further assess memory for the surface form of messages (i.e., framing), a recognition task was developed and administered immediately after the cued-recall task based on the paradigm used in Radvansky et al.'s (2001) study. The instruction was to indicate whether a message was exactly the same one that they read earlier during the eye-tracking reading session by rating their confidence level on a 6-point Likert scale from *very confident that I did not read this item before* (1) to *very confident that I read this item before* (6). The list of messages contained 60 items in total, among them were 12 identical items that matched the ones presented at the earlier reading session, 36 items that expressed the same content but were framed differently from what participants read before and equally distributed among the remaining framing conditions, and 12 foils that expressed false information about the consequences of doing exercises (i.e., “Exercisers are more likely to have a poor circulatory system”). Thus, participants were presented with an equal number of messages across the four different framing conditions in the task.

Results

Unless otherwise specified, continuous variables were analyzed with linear mixed-effects models (Bates et al., 2015) to account for subject and item variability simultaneously. These models were fit using the MIXED procedure in SAS software (version 9.4) with maximum likelihood estimation. Dichotomous variables were analyzed with mixed-effects logistic models using the GLIMMIX procedure in SAS software (version 9.4), and the LaPlace algorithm was used to approximate maximum likelihood estimation. Models included the fixed effects of Age Group, Frame, Outcome, and their interactions, and random effects of intercepts for subjects and items. The final model for each dependent variable was selected by starting with the most complex model and deleting effects that were not significant based on likelihood ratio tests, using a criterion of $p < .05$. Following the standard statistical principle with respect to main effects and interactions (Bates et al., 2015), model reduction started with removing nonsignificant higher-order terms and then any nonsignificant lower-order terms that were nested under nonsignificant interactions. Therefore, the final models included significant fixed main effects, significant interactions, nonsignificant terms if they were nested under significant higher-order terms, and significant random effects of intercepts for subjects and items. Post hoc Tukey tests were conducted to compare least squares means of significant interaction effects in the final models.

Affect Ratings

Significant main effects of Frame, $c^2(1, N = 80) = 275.3$, $p < .01$, and Outcome, $c^2(1, N = 80) = 11.9$, $p < .01$, indicated GF messages were rated as more positive than LF messages ($M_{GF} = 1.63$, $SE = 0.09$; $M_{LF} = -0.16$, $SE = 0.09$), and messages with desirable outcomes were rated as more positive than those with undesirable outcomes ($M_{DES} = 0.86$, $SE = 0.09$; $M_{UND} = 0.61$, $SE = 0.09$). As shown in Figure 2a, these two factors interacted, $c^2(1, N = 80) = 10.3$, $p < .01$, such that GF-D messages were rated as more positive than GF-U messages, $t(188) = 4.86$, $p < .01$, whereas LF messages did not differ in terms of the Outcome, $t < 1$.

In general, older adults' ratings were more positive than those of younger adults, $c^2(1, N = 80) = 6.9$, $p < .01$ ($M_O = 0.95$, $SE = 0.12$; $M_Y = 0.51$, $SE = 0.12$). Importantly, this age difference varied as a function of both Frame, $c^2(1, N = 80) = 27$,

$p < .01$, and Outcome, $c^2(1, N = 80) = 7.3$, $p < .01$. Specifically, as shown in Figure 2b, the age difference for GF messages was not significant, $t(93) = 1.2$, $p > .1$, but older adults had less negative affect to LF messages than younger adults, $t(93) = 3.98$, $p < .01$. Figure 2c shows that the affective response to messages describing desirable outcomes did not differ across age groups, $t(93) = 1.87$, $p > .1$, but for messages describing undesirable outcomes, older adults responded more positively than younger adults did, $t(93) = 3.31$, $p < .01$. The three-way interaction was not significant, $c^2 < 1$. In short, older adults had more positive reactions, an effect that was primarily due to a diminished negative reactivity to loss frames and to undesirable outcomes.

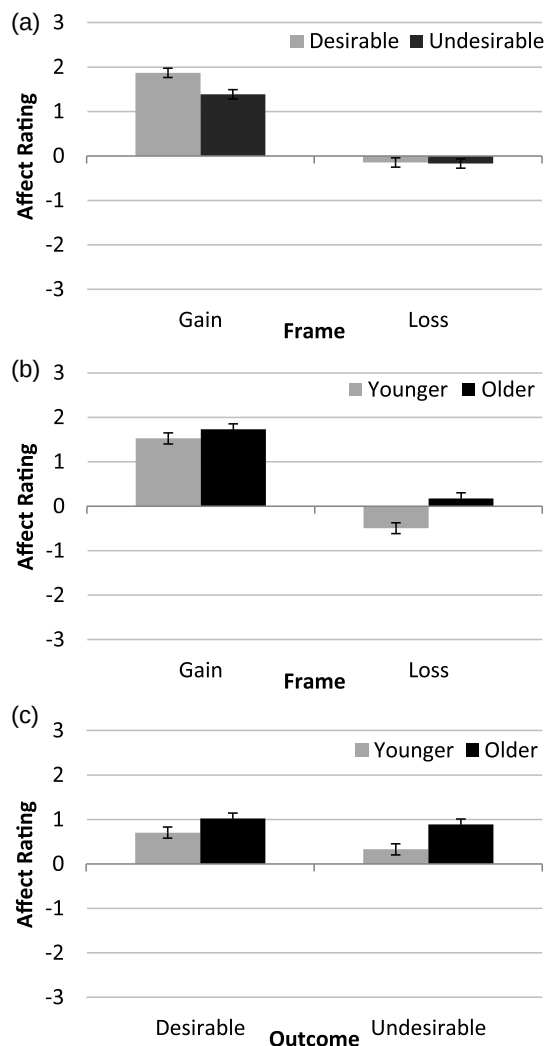
Eye-Tracking Measures

Because we were interested in the integrative processes of comprehension, we report late-stage measures, separately by region. This included total fixation time (TFT) of all three regions (i.e., behavior, verb, and outcome region), regression path duration (RPD) for the last region (i.e., outcome region), and probability of regressing in (pRI) to the first region of a message (i.e., behavior region). TFT is the sum of all fixation durations on a region, reflecting the total time spent processing the region. RPD is the sum of fixation durations on a region and all prior regions before eyes move to the right, which specifically reflects the time spent rereading and reanalyzing the region. pRI is the probability that the eyes moved back to a region from later regions, which reflects the likelihood to reread the region rather than time. We also report whole-sentence reading time as it reflects overall level of processing. All measures were analyzed controlling for character length.

About 0.5% of trials were excluded from analysis due to participants' accidental skipping of the trials and technical problems during recording. Of the remaining trials, fixations were trimmed such that two fixations with durations less than 80 ms and within a half a degree of visual angle were combined, and single fixations shorter than 80 ms (with no close neighboring fixations) and longer than 1000 ms were excluded from analyses. Fixation durations were log transformed to normalize their distribution. The data were further trimmed for outliers for each reading measure on different regions, so the trimming criteria were adjusted so that the data exclusion rate was similar across the four framing condition and two age groups.⁴ The overall trimming procedure resulted in less than 2% of the fixation data being excluded from analysis.

As shown in Figure 3, processing was generally facilitated for GF relative to LF messages as indicated by most of the eye-tracking measures for individual sentence regions and the whole sentence. Gain frames engendered more fluent processing than loss frames, as evidenced by shorter total reading times [at the Behavior region, $c^2(1, N = 80) = 40.5$, $p < .01$; at the Outcome region, $c^2(1, N = 80) = 3.8$, $p = .05$; and for the sentence as a whole, $c^2(1, N = 80) = 28.3$, $p < .01$], less rereading time [RPD at the Outcome region, $c^2(1, N = 80) = 27$, $p < .01$], and a lower probability of regressions [pRI to Behavior region, $c^2(1, N = 80) = 16.88$,

Figure 2
Mean Ratings for Affect as a Function of (a) Message Framing and Outcome Desirability, (b) Age Group and Message Framing, and (c) Age Group and Message Outcome Desirability

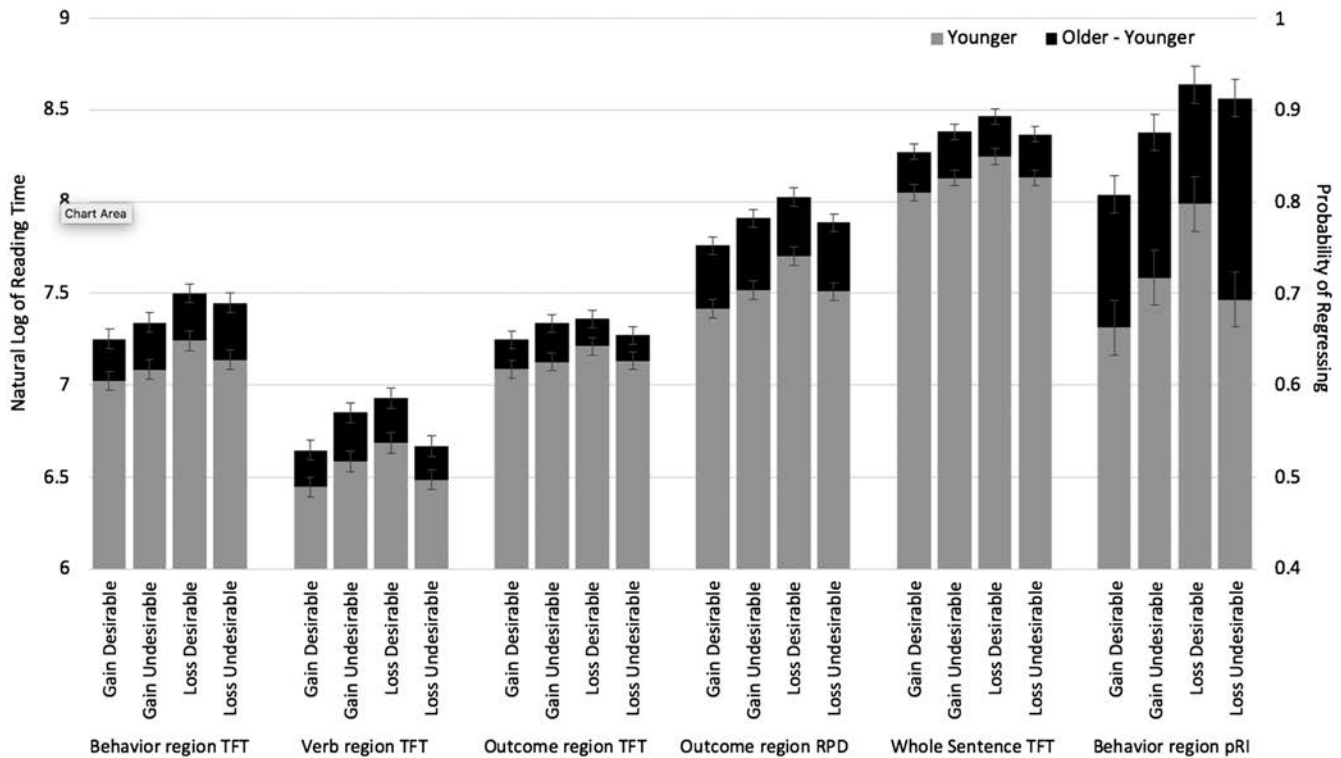


Note. Error bars represent standard error of the mean.

⁴ Mean values and standard deviations of the natural logarithm of transformed reading time measures of interests on the three individual message regions were calculated for each frame by outcome conditions among younger and older adults. Data were trimmed by condition mean ± 2.5 times its standard deviation, such that extreme values were excluded.

Figure 3

The Effects of Message Frame and Outcome Desirability on Natural Logarithm Transformed TFT (Total Fixation Time) in Behavior, Verb, and Outcome Region, RPD (Regression Path Duration) in Outcome Region, Whole-Sentence TFT, and Also pRI (Probability of Regressing In) to Behavior Region



Note. Error bars represent standard error of the mean.

$p < .01$]. There was also a numerical trend for reduced TFT on the Verb region for GF relative to LF messages, $c^2(1, N = 80) = 3.1, p = .08$.

Although desirability of outcome did not show a significant main effect on any of the reading time measures, $c^2 < 1$, it moderated the effect of Frame on all measures, including TFT on Behavior region, $c^2(1, N = 80) = 47, p < .01$; TFT on Verb region, $c^2(1, N = 80) = 38.2, p < .01$; TFT on Outcome region, $c^2(1, N = 80) = 11.2, p < .01$; RPD on Outcome region, $c^2(1, N = 80) = 40.5, p < .01$; pRI to Behavior region, $c^2(1, N = 80) = 12.4, p < .01$; and whole-sentence reading time, $c^2(1, N = 80) = 38.3, p < .01$. Specifically, comparing the effects of framing when outcomes were desirable, GF-D messages were processed relatively faster and with fewer regressions to the Behavior region compared to LF-D messages, $t > 3.8, p < .01$. However, comparing the effects of framing when outcomes were undesirable, GF-U and LF-U messages did not differ significantly, $t < 2.5, p > .06$, with the exception of TFT on the Verb region, $t(183) = 3.21, p < .01$ in which processing time was greater in the GF-U than in the LF-U condition. It was also the case that messages in the Undesirable conditions were generally more difficult to process than the GF-D messages, $t > 2.6, p < .058$, but easier to process than the LF-D messages, $t > 2.7, p < .057$ (the one exception was the TFT on the Verb region). Generally, then, the GF-D messages were relatively easy to process, shown by faster overall processing time, less time rereading, and lower likelihood of rereading, whereas the LF-D messages were

most difficult, and the processing of GF-U and LF-U messages was in between. Collectively, the results are consistent with the pattern suggesting that readers were allocating more attention to the situation model than to the textbase.

A significant main effect of Age was found in all eye-tracking measures [TFT on Behavior region, $c^2(1, N = 80) = 14.6, p < .01$; TFT on Verb region, $c^2(1, N = 80) = 11.5, p < .01$; TFT on Outcome region, $c^2(1, N = 80) = 7.6, p < .01$; RPD on Outcome region, $c^2(1, N = 80) = 25.6, p < .01$; pRI to Behavior region, $c^2(1, N = 80) = 16.92, p < .01$; whole-sentence reading time, $c^2(1, N = 80) = 15.4, p < .01$], indicating that older adults had longer reading times and were more likely to reread, relative to the younger adults. With one exception, age differences did not interact with message frame or the desirability of outcome for the rest of eye-tracking measures (i.e., TFT, RPD, and overall sentence reading time), $c^2 < 3, p > .08$. The exception was that regressive eye movements to the Behavior region (pRI, reflecting rereading) showed a significant Age by Frame interaction, $c^2(1, N = 80) = 6.81, p < .01$. Among older adults, the odds of rereading the Behavior region for LF messages was 2.18 times that of GF messages, $p < .01$, 95% CI [1.46, 3.27]; among younger adults, there was no difference, $OR = 1.33, p > .1, 95\% CI [0.95, 1.85]$. Note that although older adults were more likely than younger adults to go back to reread the Behavior region of LF messages relative to GF messages, they did not have differentially longer rereading or

overall processing time. Generally, then, framing did not differentially impact processing time with aging, though there was some indication that LF messages, which typically included a negation (e.g., *Not exercising...*) may have been more difficult for older adults, as indicated by a tendency to look back at this phrase.

Memory Performance

Cued Recall

The accuracy was scored binarily such that “1” was given if a message was correctly recalled given the cue, and “0” was given if it was incorrectly recalled, with an interrater reliability of .95. On average, younger adults recalled a total of 9.65 messages ($SE = 0.52$), and older adults recalled a total of 9.33 messages ($SE = 0.42$). This difference was not significant, $c^2 < 1$, and none of the age-related interactions was significant, $c^2 < 2.3$, $p > .1$. Nor did Frame or Outcome has an impact on the probability of recalling the content of a message, $c^2 < 1.3$, $p > .1$.

Recognition

The confidence ratings were coded to a binary variable such that ratings of 4–6 were coded as “yes,” and ratings of 1 to 3 were coded as “no.” Then, measures of discrimination were calculated for each message framing condition for each participant (Davison & Nevin, 1999) from two perspectives: (a) recognition of the content of messages presented in different framing conditions during reading (i.e., GF-D, GF-U, LF-D, or LF-U) relative to foil items and (b) recognition of the surface form of type of message framing relative to the other three message framing conditions. These variables were natural logarithm transformed for normalization and analyzed with 2 (Frame: GF vs. LF) $\times$ 2 (Outcome: desirable vs. undesirable) $\times$ 2 (Age: young vs. old) mixed-model analysis of variance using the GLM procedure in SAS software (version 9.4).

As shown in the left panel of Figure 4, participants were generally able to discriminate the content of messages from the false information in the foil items, as indicated by a grand mean that was significantly higher than zero, $M = 1.7$, 95% CI [1.51, 1.88]. The discrimination of message content did not differ by Frame, $F < 1$,

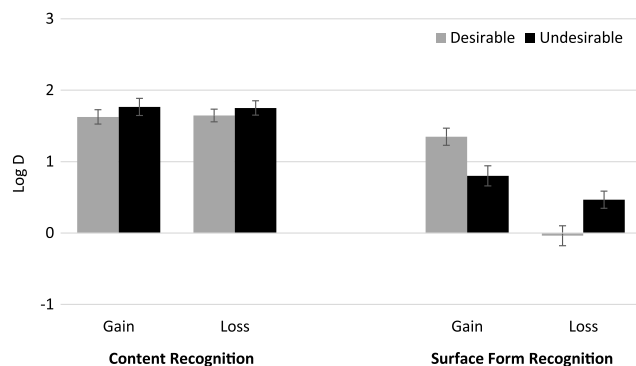
$p > .1$, but participants showed better discrimination of content that was conveyed in messages focusing on undesirable outcomes ($M = 1.76$, $SE = .1$) compared to those with desirable outcomes ($M = 1.64$, $SE = .09$), $F(1, 78) = 7.14$, $p < .01$, $\eta_p^2 = .08$. Other effects were not significant, $F < 1.7$, $p > .1$. On the other hand, as shown in the right panel of Figure 4, participants had better discrimination of the surface form of GF ($M = 1.07$, $SE = .09$) than LF messages ($M = 0.21$, $SE = .09$), $F(1, 78) = 46.01$, $p < .01$, $\eta_p^2 = .37$. The main effect of outcome was not significant, $F < 1$, but there was a significant interaction between Frame and Outcome, $F(1, 78) = 16.78$, $p < .01$, $\eta_p^2 = .18$. Post hoc comparisons revealed that for GF messages, discrimination of the surface form was better for desirable than undesirable messages, $p < .01$; however, the pattern was reversed for LF messages, $p < .01$. As a matter of fact, discrimination of the surface form of LF-D messages did not differ from zero, $M = -0.04$, 95% CI [-0.32, 0.25]. There was a nonsignificant numerical trend for younger adults ($M = 0.77$, $SE = .09$) to show a better discrimination of surface form than older adults ($M = 0.52$, $SE = .09$), $F(1, 78) = 3.69$, $p = .058$, $\eta_p^2 = .045$. Age did not interact with other effects, $F < 1$. Collectively, these data suggested that in terms of promoting recognition of the message content, there was no particular advantage for GF over LF messages, but the findings with respect to discriminability for the surface form (i.e., the Frame by Outcome interaction) followed the same pattern as that of the eye-tracking measures, such that frames that were more easily processed were also better recognized.

The Relationship between Message-Evoked Affect, Processing Time, and Recall

Motivated by the previous research on processing fluency (Schwarz, 2004), we explored the relationship between affective response and the ease of processing by fitting linear mixed-effects models to examine the effect of affective ratings (at the item level) on message reading time. In addition, because Liu et al. (2019) showed that the variation in affective response contributed to perceived effectiveness of framed messages, we wondered whether positive affect from gain framing would translate to better memory. The relationship between affective response and message memory was examined by fitting mixed-effects logistic models for the effect of affective ratings on the probability of cued recall. All models were controlled for the fixed effects of message framing.

As shown by the solid lines in Figure 5a, more positive affect was related to decreased processing time (i.e., greater processing fluency), $c^2(1, N = 80) = 35.3$, $p < .01$. Critically, this effect varied with Frame, $c^2(1, N = 80) = 60.7$, $p < .01$, such that the effect of affective rating on processing time was larger for GF messages, $\beta = -0.65$, $p < .01$, compared to that for LF messages, $\beta = -0.27$, $p < .01$. These effects did not interact with Age, $c^2 < 2.5$, $p > .1$. Recall that framing had no effect on cued recall. However, framing had clear effects on affect, which is known to impact memory (Carstensen & Turk-Charles, 1994), so we explored whether items rated more positively would be better recalled. In fact, the likelihood of recalling the content of a message increased with more positive affect, $c^2(1, N = 80) = 3.84$, $p = .05$. Importantly, as shown by the dashed lines in Figure 5b, this effect was moderated by Frame, $c^2(1, N = 80) = 9.16$, $p < .01$, such that for among GF messages, the probability of recalling a message increased with positive affect, $OR = 1.2$, $p < .01$, 95% CI [1.08, 1.32], whereas for LF messages,

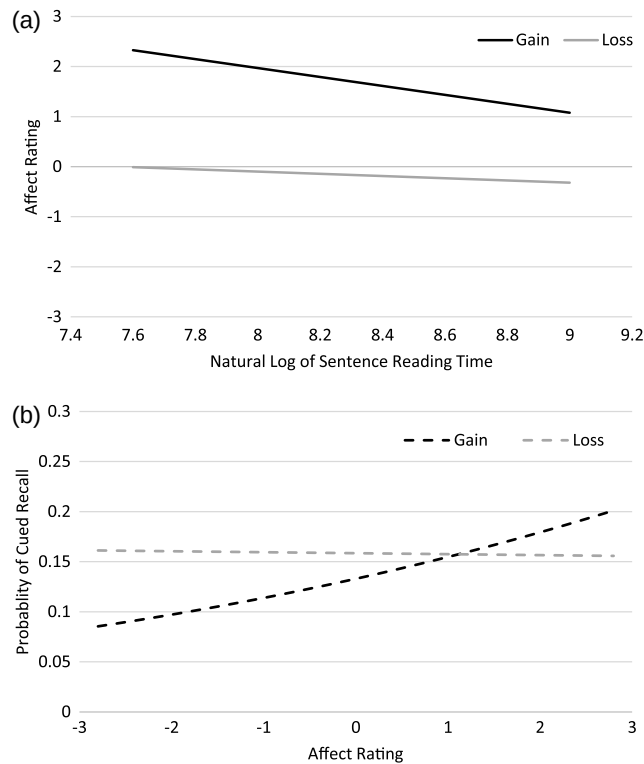
Figure 4
Discriminability (Log D) as a Function of Message Frame and Outcome Desirability for Message Content Recognition and Message Surface Form Recognition



Note. Error bars represent standard error of the mean.

Figure 5

The Effect of (a) Whole-Sentence Reading Time (Natural Logarithm Transformed, Solid Lines) on Affect Rating Score and (b) Affect Rating Score on Probability of Cued Recall (Dashed Lines) for Gain- and Loss-Framed Condition



affect was not related to recall, $OR = 0.92$, $p > .1$, 95% CI [0.66, 1.29].

Discussion

We investigated the cognitive processing demands underpinning the comprehension, as well as affective response, for messages about physical activity, which varied in how the information was framed. When information was expressed as benefits accrued from behavioral engagement (GF messages), especially when framed in terms of positive outcomes (rather than failing to avoid negative ones), the message was more easily processed, evoked more positive affect, and was better recognized. On the other hand, when information was expressed in terms of the negative consequences of nonengagement (LF messages), messages were generally more difficult to process, especially when framed in terms of missing out on positive outcomes (rather than leading to negative ones). Messages framed in terms of loss generally evoked more negative affect, and were less recognizable, regardless of how the outcome was framed.

We explain these findings in terms of differential demands for situational simulation during comprehension. Thus, one of the important contributions of this study is to provide evidence on the psycholinguistic processes involved in understanding framed messages, which systematically vary in their requirements for the

suppression of mental simulations of events (Kaup & Zwaan, 2003). The replicable pattern found across multiple reading time measures ($GF-D < GF-U \sim LF-U < LF-D$; cf., Figure 3) was consistent with a situation model account in which difficulty is increased with the number of event simulations that must be deleted from the mental representation for message comprehension.

Largely, reading time patterns did not differ with age, and were consistent with literature showing a preserved ability to represent and use situation models with aging (Radvansky & Dijkstra, 2007; Stine-Morrow & Radvansky, 2017). The one exception was older adults' greater likelihood of regressive eye movements to the behavior region for LF messages. Because LF messages were, on average, slightly more complex in terms of propositional content, this might reflect age-related deficits in propositional coding of the textbase (cf., Hartley et al., 1994; Stine & Hindman, 1994; Stine & Wingfield, 1988). Nevertheless, although older adults read somewhat more slowly and showed more regressions overall, they showed a very similar responsiveness to the demands for situation model construction.

These findings of differences in cognitive/psycholinguistic processing with message framing inform earlier work on the affective response to framed health messages. We replicated the finding (Liu et al., 2019; 2016, van't Riet et al., 2010) of a more positive affective response to GF than to LF messages. The prevailing account of this effect is that exposure to loss activates feelings of risk that engender negative affect (Loewenstein et al., 2001; Rothman & Salovey, 1997). Our findings suggest an alternative, or complementary, route for the activation of emotion information. Using reading time as a diagnostic for processing fluency, we found some evidence that affective response may be related to difficulty in comprehension. First, there was a loose correspondence between patterns of affective response and patterns of reading time (cf., Figure 2a vs. Figure 3), such that conditions in which messages were processed more easily (reduced reading time and fewer regressions) engendered more positive affect. Perhaps, more interesting relative to identifying causal pathways, variation in reading time among items within condition was also related to variation in affective reaction (cf., Figure 5a). So even within GF (or LF) messages in which implications of risk would not be expected to vary, greater processing fluency was related to more positive affect. This is consistent with the findings of Schwarz and his colleagues on processing fluency and affective response using visual stimuli like images (Reber et al., 1998; Schwarz, 2004). The relationship between processing fluency and affect was stronger for GF than LF messages. It is somewhat puzzling that this relationship varied by message frames, but this may be simply due to less variation in affective response to LF, relative to GF, messages (cf., Figure 2a), which might make the effect more difficult to detect. We note that the correlational evidence in current study is far from definitive. Even though reading time was measured prior to affective response, it is possible that an ongoing affective response during comprehension could lead to different cognitive/psycholinguistic processing. Future studies should be conducted to further probe this relationship.

Older adults generally had longer reading time. They had more positive feelings about the health message, particularly when the information was framed in terms of loss and focused on undesirable outcomes, which have been also found in previous studies (Liu et al., 2019; Mikels et al., 2016). Based on the SST (Carstensen et al., 1999), Charles (2010) proposed an emotional development

model suggesting that older adults improved and maintained their emotional well-being by avoiding or limiting the elicitation of negative emotions when encountered a negative situation. Thus, the reduced negativity to loss frames and to undesirable outcomes among older adults may indicate that they regulated their emotional responses by de-escalating negative affect as the messages focused on consequences of not engaging in healthy behaviors or negative health outcomes. However, there were no age differences in the relationship between processing fluency and affective reaction. This may suggest a lack of an age difference in the effects of fluency on affect, but on the other hand, in an absolute sense, the texts were not terribly difficult. Given recent theoretical perspectives in the literature suggesting differential avoidance of effortful tasks with aging (Hess, 2014), age differences in affective reaction across a broader range of text processing demands would be worthwhile.

We found no direct effects of framing on recall of message content. However, there was an indirect effect through message-evoked affect, such that affective responses predicted message memory, particularly among GF messages. This effect of message-evoked affect on recall did not vary with age. This is somewhat surprising given earlier work suggesting that older adults may have differential recall for positively valenced information (Reed et al., 2014).

Generally, the recognition of message content (i.e., the ability to distinguish presented messages from foils) was excellent, probably in part, because our foils were relatively easy. However, even with a possible ceiling effect on this measure, there was one interesting effect of framing on recognition of message content: Messages conveying undesirable outcomes, relative to desirable outcomes, were better distinguished from foils. This may suggest that the situation model of negative consequences of neglecting health may be encoded more distinctively in memory relative to positive states of health. We also measured recognition of the message surface form, which generally tends to decay quickly (e.g., Kintsch et al., 1990) to determine if there were any residual traces of the frame itself in memory. GF messages were better recognized than LF messages, regardless of age. This is similar to the findings of Notthoff et al. (2016) with a sample of older adults. In fact, the recognition of the surface form patterned with that of the reading times, suggesting some advantage in retaining the surface forms of messages that were also easier to process.

This study has some limitations. The information conveyed in the messages may have already been familiar to participants, because physical exercise is a common health topic in public discourse. Therefore, the cued-recall performance may not have been a pure reflection of what participants learned from reading the messages, and may have been influenced by participants' prior knowledge. Furthermore, the materials contained messages only on exercise-related information, which may have reduced discriminability for the information conveyed. Other than studying messages of prevention behaviors, studies need be conducted to include messages of detection behaviors, such as getting a disease screening test. The effects of message framing are expected to vary between prevention and detection health behaviors (Rothman & Salovey, 1997). Therefore, the function of health behavior being promoted (i.e., prevention vs. detection) might have an effect on how message framing impacts the affective and cognitive-linguistic processing.

Our findings have implications for conveying health information to the public. Simpler framing of messages, such as GF messages

focusing on desirable outcome, should be used, as those messages are easier to understand and evoke more positive affect. Positive affect, in turn, can lead to better memory. Importantly, these principles apply to both younger and older adults.

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