Predictors of listening-related fatigue across the adult lifespan

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Abstract

Listening-related fatigue is a potentially serious negative consequence of an aging auditory and cognitive system. However, the impact of age on listening-related fatigue, and the factors underpinning any such effect, remain unexplored. Using data from a large sample of adults ($N = 281$), we conducted a conditional process analysis to examine potential mediators and moderators of age-related changes in listening-related fatigue. Mediation analyses revealed opposing effects of age on listening-related fatigue; aging was associated with *increased* listening-related fatigue for individuals with higher self-reported hearing impairment, but also *decreased* listening-related fatigue via reductions in mood disturbance and sensory-processing sensitivity. Results also suggested that the effect of auditory attention ability on listening-related fatigue was moderated by sensory-processing sensitivity; for individuals with high sensory-processing sensitivity, better auditory attention ability was associated with increased fatigue. These findings shed light on the perceptual, cognitive, and psychological factors underlying age-related changes in listening-related fatigue.

Keywords: Listening-related fatigue, effortful listening, cognitive aging, speech perception.

Statement of relevance

Listening-related fatigue (i.e., fatigue associated with sustained and effortful listening) may have serious negative psychosocial consequences for the aging population, including withdrawal from social engagement and reduced well-being. However, currently little is known about the factors that govern such connections. Knowledge of how listening-related fatigue changes with age is paramount given the: (a) high prevalence of older adults in today's society, (b) ubiquity of noise and generally suboptimal communication environments, and (c) well-documented cognitive and sensory declines associated with aging. Overall, this study highlights the perceptual, cognitive, and psychological mechanisms that underpin age-related changes in listening-related fatigue. Specifically, the effects of aging on listening-related fatigue appear twofold; susceptibility is *heightened* via increased perceived hearing impairment, but also *mitigated* via reductions in mood disturbance and sensory-processing

sensitivity. Understanding the factors that underlie listening-related fatigue will ultimately help to reduce the burden that older adults experience during everyday communication.

Introduction

Successful and effortless listening relies on both the fidelity of the incoming signal (e.g., speech) and the sensory and cognitive profile of the listener. The near-ubiquitous presence of noise in everyday environments means that speech understanding often comes at the cost of tiring mental effort expenditure (Pichora-Fuller et al., 2016). Listening-related fatigue is a common complaint from individuals with hearing loss and may lead to withdrawal from social activities (Davis et al., 2020). Generally, fatigue has been characterised as a subjective experience associated with feelings of tiredness, weariness, and/or a lack of energy/motivation to complete a task (Hornsby et al., 2016). However, the link between aging and fatigue specifically associated with compromised listening skills remains unclear. In a lab-based pupillometry study, McGarrigle et al. (in press) found no difference in listening-related fatigue between young and older adults. However, generalizations were limited by the relatively small sample size ($N = 63$) and restricted age range (i.e., 18-24 years and 62-82 years only). The current study aimed to explore the perceptual, cognitive, and psychological factors that underlie changes in listening-related fatigue across the adult lifespan.

Normal healthy aging is associated with reduced hearing sensitivity (Stach et al., 2009) as well as changes in cognitive functioning, including shifts in memory capacity and reduced inhibition (Craik & Bialystok, 2006; Kane et al., 1994). Complex listening skills that rely on intact sensory processing and top-down attentional control are therefore particularly susceptible to age-related decline and may mediate (i.e., explain) age-related increases in listening-related fatigue. For example, auditory attention ability – the ability to follow one speaker while simultaneously ignoring another – is particularly disrupted in older adults (Rogers et al., 2018). Age-related reductions in auditory attention ability may compromise the ease with which older adults communicate in everyday environments, thus giving rise to a heightened sense of listening-related fatigue. On the other hand,

listening-related fatigue may correspond more closely with a subjective awareness of one's own hearing or cognitive challenges (Hornsby & Kipp, 2016). In other words, aging might increase susceptibility to listening-related fatigue via increases in one's own perceived functional hearing impairment. Listening in everyday environments (e.g., noisy cafés or restaurants) relies heavily on intact memory processes (Rönnberg et al., 2008). A perceived reduction in memory capacity may also underlie potential age-related increases in listening-related fatigue. Indeed, self-perceived abilities have been shown to influence listening skills in older adults (Carr et al., 2019; Chasteen et al., 2015).

The extent to which individuals experience listening-related fatigue may also depend on factors independent of their sensory and cognitive profile. Hockey's (2013) motivational control theory posits that fatigue has an adaptive role, ensuring that finite cognitive resources are allocated only to tasks deemed sufficiently important. Hockey (2013) therefore treats fatigue as an emotional response that ultimately serves to trigger evaluation of cost/reward trade-offs in ongoing cognitive pursuits. Thus, motivation to engage in effortful cognitive activity can influence the extent to which one experiences subjective fatigue from such exertion. One way to measure motivation to engage in effortful cognitive activity is to assess 'need for cognition' (Cacioppo et al., 1984). Need for cognition is a personality trait that reflects an individual's tendency to enjoy, and thus be motivated to participate in, activities involving effortful cognitive processing (e.g., abstract thinking; Cacioppo et al., 1996). No study to date has examined whether need for cognition moderates age-related changes in listening-related fatigue.

There is also growing recognition that a comprehensive understanding of effortful listening and fatigue must include a role for emotional responses to environmental stressors, like noise (Francis & Love, 2020; Strand et al., 2018). The Profile of Mood States (POMS) questionnaire provides a global marker of mood disturbance, emotional or psychological distress, and subjective well-being ('total mood disturbance'; Heuchert & McNair, 2012) which may be a key factor underlying age-related changes in listening-related fatigue. Relatedly, physiological stress responses associated with hearing difficulties may heighten the experience of listening-related fatigue (Xu & Francis, 2019). The Highly Sensitive Person Scale (HSPS) is one way to measure an individual's sensitivity to

environmental stimuli (e.g., noise) at the trait level (Aron & Aron, 1997). Strand et al. (2018) found that individuals scoring high on sensory-processing sensitivity showed increased effort, measured both subjectively and behaviorally, during performance of a challenging listening task. Individual differences in each of these psychological traits may therefore help to explain some of the variability associated with age-related changes in listening-related fatigue.

For this study, we recruited a large sample of healthy adults ($N = 281$) across the lifespan (18 – 85 years). Participants completed a battery of online tests and questionnaires measuring predictors of listening-related fatigue. Listening-related fatigue was measured using the Vanderbilt Fatigue Scale for adults (VFS-A; Hornsby et al., in press). First, based on expected age-related declines in sensory and cognitive functions, we predicted that listening-related fatigue would increase with age. Second, based on the literature reviewed, we hypothesized that this effect would be mediated by: (1) poorer auditory attention ability, (2) higher perceived hearing impairment (HI), and/or (3) lower perceived memory ability. Finally, we predicted that the direct effect of age and/or its indirect effects (i.e., via our proposed mediator variables) on listening-related fatigue would be moderated by: (1) mood disturbance, (2) need for cognition, and/or (3) sensory-processing sensitivity. Specifically, we hypothesized that individuals with higher mood disturbance (Francis & Love, 2020) and sensory-processing sensitivity (Strand et al., 2018) and lower need for cognition (Pichora-Fuller et al., 2016) would report increased daily life listening-related fatigue. Figure 2 provides a conceptual diagram of these predictions.

Method

All methodological, procedural, and analytic plans for this pre-registered study are accessible on our OSF pages along with the analysis scripts, raw and summary data (<https://osf.io/hc8n4/>).

Participants

Participants were 281 adults aged 18-85 years. To ensure an evenly balanced distribution of age ranges across adulthood, we aimed to recruit at least 40 participants from each of the following age categories: 18-29 years, 30-39 years, 40-49 years, 50-59 years, 60-69 years, and 70+ years. There is currently little consensus in the literature on how to calculate sample size requirements for complex models involving multiple predictors, including moderated mediation analysis (Perugini et al., 2018). However, to ensure that our study would have sufficient power to detect a possible mediation effect, we used the ‘mc_power_med’ app (Schoemann et al., 2017) to calculate sample size requirements for a basic mediation analysis. Assuming the smallest effect size of interest between each of the pathways (a, b, and c’) of $r = .3$, a total sample size of 240 participants would provide power of .95 to detect a significant mediation effect at $\alpha = 0.05$. We aimed to achieve power of .95 (rather than the field standard of .8) to allow for potential increases in residual error arising from online data collection and to increase our power to detect other potential effects (e.g., moderation) in the analyses, if they exist. Based on recommendations for screening online data for low quality responses (Buchanan & Scofield, 2018), we recruited 15% more participants than our target sample size.

The majority of participants (268/281) were recruited via Prolific, an online recruitment platform (prolific.co) and financially compensated for their time. We applied the following eligibility criteria on Prolific: (1) age (adjusted for each of the six age categories listed above), (2) English as a first language, (3) normal or corrected-to-normal visual acuity, (4) no known language-related disorders, (5) no diagnoses of mild cognitive impairment or dementia, and (6) a minimum Prolific approval rating of at least 95%. Approval rating is calculated as the percentage of studies for which a participant has not been rejected by the researcher (e.g., due to unrealistically fast completion times, attention check failures, etc.) and therefore indicates their level of compliance in previous studies. The remaining 13 participants were recruited via an existing database of older adult participants and were compensated with Amazon vouchers. All 13 participants reported fully adhering to the same eligibility criteria as those recruited via Prolific. This study was granted ethical approval by the departmental research ethics committee (ID: 733).

General Procedure

We used Gorilla Experiment Builder (www.gorilla.sc) to design and host both our pre-screening questionnaire and all tasks and questionnaires in the main experiment (Anwyl-Irvine et al., 2020). We initially recruited between 146 and 188 participants from each of the six age categories (1,043 participants in total) to take part in a brief online questionnaire study. The goal of this pre-screening questionnaire was to exclude participants who suffer from a chronic health condition (or take medication) that can cause fatigue and also to rule out participants with a clinically-significant hearing loss. Participants were instructed to only take part in the pre-screening questionnaire if they: (1) had access to a set of headphones or earbuds, (2) could complete the study on a laptop or desktop computer, and (3) did not suffer from a known unilateral hearing loss. Participants were also informed that they may be invited to take part in a follow-up study on listening experiences. For the pre-screening questionnaire, participants provided a simple yes/no response to the following questions: (1) Do you currently suffer from a chronic health condition that can cause fatigue (e.g., chronic fatigue syndrome, cancer, diabetes)? (2) Do you regularly take any medication that can cause fatigue (e.g., antihistamines)? (3) Do you regularly use a hearing device (e.g., hearing aid or cochlear implant)? Only participants who responded ‘no’ to all three questions were sent a follow-up invitation to take part in the main experiment within 24 hours of completing the questionnaire. In total, 287 out of 1043 (27.5%) participants failed one or more of the three screening criteria and were therefore not invited to take part in the main study.

The invited participants then completed a series of audio checks before starting the main experiment. For the first of the audio checks, participants were given the opportunity to play one of the audio stimuli used in the dichotic listening task of the main experiment and adjust the volume to an audible and comfortable level. They then performed a validated headphone check that involved identifying the quietest of three sounds. Importantly, this task could only be performed accurately with the use of stereo headphones (see Woods et al., 2017, for more details). In order to continue with the experiment, participants were required to accurately identify the quietest sound on at least 5 of the 6 trials presented. To allow for potential misunderstanding of the instructions, participants who scored

<5 on the first attempt were given a second opportunity to pass the test. Finally, participants completed a brief ‘autoplay’ check to ensure that their browsers would permit the playback of auditory stimuli during the dichotic listening task. Audio checks lasted approximately 5 minutes in total.

Following successful completion of the audio checks, participants performed a series of tasks and questionnaires (details provided below). In total, the main experiment lasted approximately 50 minutes. Figure 1 shows a schematic illustration of the full sequence of tasks and questionnaires.

Figure 1. Schematic outline of the study procedure with time estimates for each component.

Psychomotor vigilance test data were collected for a separate study and are therefore not reported in the current paper.

Stimuli and individual task procedures

Dichotic listening task. The dichotic listening task was used as a measure of auditory attention ability. We used the dichotic listening task (Koch et al., 2011), adapted for use on the Gorilla online platform. For this task, participants were presented with two digits simultaneously; one in the right ear and one in the left ear, of which one was a male voice and the other a female voice. At the beginning of each trial, a visual text cue displayed the word ‘Male’ or ‘Female’ (presented centrally on the screen) indicating which voice participants should attend to for that particular trial. The visual cue remained on-screen for two seconds. Immediately after the visual cue disappeared, the two speech tokens were presented over the headphones. Following presentation of the speech tokens, participants were asked to indicate whether the number spoken by the attended voice was above or below five. ‘Below 5’ responses were given by pressing ‘f’ with the participant’s left index finger, and ‘above 5’ responses were given by pressing ‘j’ with their right index finger. Participants were given visual prompts with these two response options on the left (press ‘f’) and right (press ‘j’) side of the screen. Presentation of the visual prompts was synchronized with the onset of the audio stimuli. Participants were asked to respond as quickly and accurately as possible, and were given four practice trials to familiarize themselves with the task.

All dichotic speech tokens were edited in Audacity to include matching silent onsets lasting 200 ms. Audio files were also converted from .wav to .ogg, as the .wav file type is not generally supported for online use. Participants performed 40 experimental trials in total; 20 using the ‘female’ prompt, and 20 using the ‘male’ prompt. Audio stimuli were digits 1-9, excluding 5, recorded by a male and female talker. Of the 20 ‘female’ and 20 ‘male’ prompt trials, half (i.e., 10/20) were ‘congruent’ trials, in which both digits were either above or below 5 (however, note that the same digits were never presented together). The other half (i.e., 10/20) were ‘incongruent’, in which one digit was above, and the other below, 5. The number of ‘above 5’ and ‘below 5’ correct response trials were balanced (i.e., 20 each). The lateral position of the female and male voice was also counterbalanced (i.e., the female voice was presented to the left ear on 20 trials, and vice versa). The order of stimuli presentation was fully randomized for each participant.

Vanderbilt Fatigue Scale for Adults (VFS-A). The Vanderbilt Fatigue Scale for Adults (VFS-A) was administered to measure daily life experiences of listening-related fatigue. The VFS-A is designed to measure fatigue that is experienced specifically in the context of listening (Bess et al., 2020; Hornsby et al., in press). The VFS-A has been shown to have high marginal reliability ($r = .98$), adequate test-retest reliability ($r = .60 - .69$), and good construct validity across the adult age-range (Hornsby et al., in press). The VFS-A consists of 40 items, each with 5-point Likert-type responses (1 – 5) with verbal anchors ranging from ‘Never/Almost never’ to ‘Always/Almost always’ or ‘Strongly Disagree’ to ‘Strongly Agree’. Examples of test items include; *‘I feel worn out from everyday listening’* and *‘It takes a lot of energy to listen and understand’*. One item (*‘I need to remove or turn off my hearing device to take a break from listening’*) is relevant only for individuals who wear a hearing device and as such was not included in the current study, leaving a total of 39 questionnaire items. The listening-related fatigue score was a summed score of all 39 items on the scale. Possible scores therefore ranged from 39 to 195, with higher scores indicating more listening-related fatigue.

Multifactorial Memory Questionnaire (MMQ). The Multifactorial Memory Questionnaire (MMQ) is a self-report measure tapping multiple aspects of memory, and has been validated for use across the adult lifespan (Troyer et al., 2019). The MMQ contains three subscales which assess (1) memory satisfaction, (2) memory ability, and (3) memory strategies. For the current study, we administered the memory ability component (MMQ-Ability) only. The MMQ-Ability scale measures self-perception of everyday memory ability. Analyses on English-speaking middle-aged and older adults show that the MMQ-Ability scale has good internal consistency (Cronbach’s $\alpha = .93$) and high reliability ($r = .86$) (Troyer & Rich, 2002). For this scale, respondents were asked to rate how often they experienced each of 20 common memory ‘mistakes’ over the past two weeks. Examples include *‘Forget to pay the bill on time’*, and *‘Not recall the name of someone you just met’*. Responses were provided on 5-point Likert-type scales (1 – 5) with verbal anchors ranging from ‘All the time’ (1) to ‘Never’ (5). Scores ranged from 20 to 100, with higher scores indicating better perceived memory ability.

Perceived Hearing Impairment (HI). To measure perceived hearing impairment (HI), we used the adapted World Health Organisation (WHO) hearing impairment grading system (Humes, 2019). This grading system was developed by a combination of experts and adopted by the WHO to assess functional hearing-related outcomes at the population level (Stevens et al., 2013). Overall, the WHO-proposed HI grade system was shown to have strong consistency across five datasets including individuals with various hearing loss classifications (Humes, 2019). Participants were asked to answer a single question by indicating which of the following statements best described their hearing ability: (1) *I have no or very slight hearing problems*, (2) *I have no problems hearing speech in quiet but may have some difficulty following conversation in noise*, (3) *I have some difficulty hearing a normal voice in quiet and have difficulty following conversation in noise*, (4) *I need speech to be loud to hear in quiet and have great difficulty in noise*, (5) *I can only hear speech in quiet when it is loud and directly in my ear and I have very great difficulty in noise*, (6) *I am unable to hear and understand even a shouted voice whether in quiet or noise*. Higher scores indicate greater perceived HI.

Need for Cognition Scale. We administered the 18-item need for cognition scale to measure motivation to engage in effortful cognitive activities (Cacioppo et al., 1984, 1996). This scale comprises 18 items, each of which provides a statement about one's tendency to engage in effortful thinking (e.g., *I would prefer complex to simple problems*). The 18-item scale has high internal consistency (Cronbach's $\alpha = .90$), is highly correlated with the original 34-item scale ($r = .95$), and is characterized by one dominant factor capturing 37% of the variance (Cacioppo et al., 1984). A more recent examination of need for cognition scores suggests that interpretation of the construct is consistent across the adult lifespan (Soubelet & Salthouse, 2017). Responses indicate the extent to which individuals feel the statements are characteristic of them, and were provided on a 5-point Likert-type scale (1 - 5). Verbal anchors ranged from 'Extremely uncharacteristic of me' (1) to 'Extremely characteristic of me' (5). Half (i.e., 9/18) of the items are negatively worded. These items were therefore reverse-scored before summed scores were calculated for each participant. Overall scores ranged from 18 to 90, with higher scores indicating greater motivation for effortful thinking.

Profile of Mood States (POMS). We measured psychological distress and mood disturbance using the Profile of Mood States 2nd Edition (POMS 2) questionnaire (Heuchert & McNair, 2012). The POMS scale is a 65-item questionnaire designed to measure multiple factors relating to mood state including: (1) anger-hostility, (2) confusion-bewilderment, (3) depression-dejection, (4) fatigue-inertia, (5) tension-anxiety, and (6) vigor-activity. Total mood disturbance represents a composite score encompassing all of the above factors. The total mood disturbance score has been shown to have good psychometric properties, including high internal consistency (Cronbach's $\alpha = .96$), and powerful convergent validity for both positive and negative affect, with r s ranging from .57 to .84 for POMS subscales making up the total mood disturbance score (Heuchert & McNair, 2012). Participants used a 5-point Likert-type response scale to indicate *'how you have been feeling during the past week, including today'*. Verbal anchors ranged from 'Not at all' to 'Extremely' and item responses were scored from 1 to 5. The 'vigor-activity' subscale includes items with positive affect descriptors (e.g., *'alert'*). These scores were therefore subtracted from the combined score on the other five subscales to provide a total mood disturbance score, as is advised in the POMS scoring manual. Six of the total 65 items relate to an additional 'friendliness' subscale and were not included in the total mood disturbance score calculation. Total mood disturbance raw scores were therefore calculated based on 59 items only, with possible values ranging from -36 to 200 and with more positive scores indicating increased mood disturbance and negative affect.

Highly Sensitive Person Scale. Sensory-processing sensitivity was measured using the Highly Sensitive Person Scale (Aron & Aron, 1997). This 27-item scale has been shown to have high internal consistency (Cronbach's $\alpha = .85-.87$) and good construct validity, with all items on the 27-item scale loading onto a unidimensional construct (scree test indicating single factor solution; Aron & Aron, 1997). Participants were asked to respond to questions about how they feel about and respond to sensory stimulation (e.g., *'Are you easily overwhelmed by strong sensory stimuli?'*). Responses were provided on a 7-point Likert-type scale with verbal anchors including 'Not at all' (1), 'Moderately' (4), and 'Extremely' (7). Total scores were calculated as the mean score (1 – 7) on all items. Higher scores indicate increased sensory-processing sensitivity.

300

301 **Analysis**

302 **Data cleaning and exclusion.** First, to mitigate against low quality questionnaire data, we
303 applied a set of screening procedures designed to identify potentially problematic (e.g., low effort)
304 responses from questionnaire data collected online (Buchanan & Scofield, 2018). We excluded
305 participants who failed two (or more) of the criteria described in Buchanan and Scofield (2018) for
306 detecting low quality questionnaire responses. These include anomalies in relation to: (1) overall
307 study completion timing (i.e., implausibly short completion times), (2) number of scale options
308 chosen (i.e., use of more response options can indicate a “bot” or low effort responding), and (3)
309 performance on the manipulation check (i.e., an incorrect response indicating inattention). Data
310 cleaning was implemented as follows. First, for each age category and questionnaire, we calculated
311 the lowest 2.5% (i.e., fastest) percentile completion time. Participants failed check (1) if they appeared
312 in the lowest 2.5% percentile in at least three of five main questionnaires. A total of 9 participants
313 failed this check. Second, participants were flagged if they used all of the available response options
314 on a given scale (e.g., if all 5 response anchors were selected in a Likert scale ranging from 1-5) on at
315 least three of the five questionnaires. A total of 77 participants were flagged based on this check.
316 Third, we included the following item at the end of the HSPS as an attention check; *‘Please mark*
317 *number 7 (‘Extremely’) for this question?’*. Participants were flagged if they did not respond ‘7’. A
318 total of four participants failed this check. Table 1 shows the number of participants in each age group
319 who failed each of the three screening checks. Overall, only one participant (from Group 2) failed two
320 or more of the three screening checks (response options and attention check) and was subsequently
321 removed from the dataset, leaving a total of 280 participants.

322

323 Table 1.

324 *Number of participants in each group who failed each of the three questionnaire screening checks.*

Group	Completion time	Response options	Attention check
1 (18-29 yrs)	1	16	0
2 (30-39 yrs)	1	16	2
3 (40-49 yrs)	2	8	0
4 (50-59 yrs)	2	14	0
5 (60-69 yrs)	1	14	1
6 (70-85 yrs)	2	9	1

Note. The same subject may appear in more than one column.

Auditory attention ability score. Individual trial RTs in the dichotic listening task that exceeded 3 SDs below or above the mean RT for each participant were removed from the dataset. This resulted in the removal of 164 trials (1.5% of the entire dataset). Performance decrements on the dichotic listening task may manifest as an incorrect and/or a slowed response on a given trial. To adequately account for both types of performance disruption, auditory attention ability scores reflect a balanced combination of response accuracy and response time. Scores were calculated using the Balanced Integration Score (BIS) approach (Liesefeld & Janczyk, 2019). Specifically, each participant's BIS was calculated as follows;

$$BIS = Z_{PC} - Z_{\overline{RT}}$$

Where $\overline{RT}$ is the mean correct response RT and PC is the proportion of correct responses. BIS is thus the difference in standardized (i.e., z-scored) mean correct RTs and proportion of correct responses. We opted to use an integrated measure as we had no reason to believe that either accuracy or RT would provide a more important measure of task performance. By applying equal weights to both performance accuracy and RT, BIS therefore helps to control for potential differences in speed/accuracy trade-offs between participants.

Conditional Process Analysis. Conditional process analysis (also known as 'moderated mediation analysis') is a regression-based path analysis approach that tests the conditional nature of

the mechanisms by which one variable transmits its effect on another variable (Hayes, 2017). First, to allow a consistent interpretation of the path coefficients in the model, we computed z-scores for all variables (except auditory attention ability which was already a normalized score; see previous section for details). Mediation and conditional process analyses were conducted using the PROCESS (Hayes, 2017) macro on SPSS v25. For the mediation analysis, we entered age as the predictor variable. Auditory attention ability, perceived HI, and perceived memory ability were entered as the mediator variables. Listening-related fatigue was entered as the dependent variable. For the conditional process analysis, mood disturbance, need for cognition, and sensory-processing sensitivity were entered as moderator variables in three separate models. Figure 2 shows the conceptual model entered into the full conditional process analysis. For all analyses, confidence intervals were derived from 5000 bootstrap samples using a random seed generator of 270488. Following the recommendations of Hayes (2017), direct and indirect effects were deemed statistically significant if both bootstrap confidence intervals were either entirely above or below zero. The index for moderated mediation coefficient (Hayes, 2015) was used as a statistical test of moderated mediation.

Figure 2. Conceptual schematic representing the variables entered into the conditional process analysis (Hayes, 2017). We entered age as the predictor variable. Auditory attention ability, perceived HI, and perceived memory ability were entered as the mediator variables (in light grey shade). Listening-related fatigue was the dependent variable. Mood disturbance, need for cognition, and sensory-processing sensitivity were the moderator variables (in dark grey shade). HI = hearing impairment. NfC = need for cognition. SPS = sensory-processing sensitivity. Note that all three moderator variables are included for illustrative purposes only. Three separate models were tested in the conditional process analyses with either mood, need for cognition, or sensory-processing sensitivity included as a single moderator variable.

Results

Descriptive statistics for all variables in the analyses are presented in Table 2.

Table 2.

Sample characteristics and raw descriptive statistics (M, SD) for variables entered into the analysis.

	Group 1:	Group 2:	Group 3:	Group 4:	Group 5:	Group 6:
Variable	18-29 yrs	30-39 yrs	40-49 yrs	50-59 yrs	60-69 yrs	70-85 yrs
<i>N</i>	47	44	49	46	48	46
Age (in yrs)	22.55 (3.32)	33.77 (3.02)	44.27 (2.81)	53.15 (3.04)	63.29 (2.53)	72.65 (2.86)
VFS_Total	84.79 (26.05)	96.70 (28.98)	83.57 (29.58)	77.78 (23.40)	79.31 (26.57)	75.30 (28.67)
BIS	0.54 (1.22)	0.20 (1.67)	0.26 (1.41)	0.29 (1.61)	-0.37 (1.35)	-0.93 (1.66)

MMQ_ability	74.00 (13.10)	69.59 (11.67)	75.67 (13.99)	74.96 (11.83)	72.08 (13.19)	77.48 (12.60)
Perceived_HI	1.32 (0.56)	1.48 (0.59)	1.39 (0.61)	1.67 (0.63)	1.81 (0.76)	1.67 (0.79)
NfC	51.96 (9.74)	48.05 (11.79)	50.73 (14.45)	50.46 (13.68)	53.69 (11.63)	53.43 (15.17)
POMS_TMD	52.66 (28.00)	52.39 (29.25)	36.45 (29.22)	36.00 (24.96)	31.94 (25.59)	29.63 (25.99)
HSPS	4.49 (0.87)	4.30 (0.95)	4.10 (0.87)	3.99 (0.94)	3.97 (0.68)	4.05 (0.95)

Note. VFS_Total = Vanderbilt Fatigue Scale total fatigue score. BIS = Balanced Integration Score (RT and accuracy combined) on dichotic listening task reflecting auditory attention ability. MMQ_ability = Multifactorial Memory Questionnaire ability subscale score. Perceived_HI = Perceived hearing impairment score. NfC = Need for cognition score. POMS_TMD = Profile of Mood States Total Mood Disturbance score. HSPS = Highly Sensitive Person Scale score measuring sensory-processing sensitivity.

Mediation analysis

First, a mediation model was tested to examine whether there were any indirect effects of age on listening-related fatigue through auditory attention ability, perceived HI, or perceived memory ability. Figure 3 shows all path coefficients in the model. We found an indirect effect of age on listening-related fatigue through perceived HI. Specifically, older participants were more likely to report increased perceived HI ($a_2 = 0.236, p < .001$), and individuals who reported increased perceived HI were more likely to report increased listening-related fatigue ($b_2 = 0.308, p < .001$). A bootstrap confidence interval for the indirect effect ($a_2b_2 = 0.073$) was entirely above zero (0.032 to 0.121). Age was a significant negative predictor of auditory attention ability ($a_1 = -0.462, p < .001$), with older adults showing poorer auditory attention ability. However, auditory attention ability did not

predict listening-related fatigue ($b_1 = 0.023$, $p = .50$). We found no evidence that auditory attention ability mediated the effect of age on listening-related fatigue. Bootstrap confidence intervals for the indirect effect of age on listening-related fatigue via auditory attention ($a_1b_1 = -0.011$) straddled zero (-0.042 to 0.021). Perceived memory ability was a significant negative predictor of listening-related fatigue, with individuals with poorer perceived memory ability also reporting increased listening-related fatigue ($b_3 = -0.402$, $p < .001$). However, age did not predict perceived memory ability ($a_3 = 0.087$, $p = .15$). We also found no evidence that perceived memory ability mediated the effect of age on listening-related fatigue. Bootstrap confidence intervals for the indirect effect of age on listening-related fatigue via perceived memory ability ($a_3b_3 = -0.035$) straddled zero (-0.084 to 0.013). Finally, there was a significant negative direct effect of age on listening-related fatigue ($c' = -0.194$, bootstrap CIs: -0.294 to -0.089). In other words, independent of the effects of all three proposed mediators, older participants were more likely to report *less* listening-related fatigue.

Figure 3. Diagram showing regression coefficients between all variables tested in the 1st mediation model. A solid arrow connecting variables represents a significant regression coefficient ($p < .05$). A dashed arrow represents a non-significant coefficient. HI = Hearing impairment.

409

410 **Conditional process analysis**

411 Next, three independent conditional process models were tested to examine the hypotheses
412 that indirect effects of age on listening-related fatigue through auditory attention ability, perceived HI,
413 or perceived memory ability are moderated by mood disturbance, need for cognition, and/or sensory-
414 processing sensitivity. First, we found no evidence that mood disturbance moderated the direct effect
415 of age on listening-related fatigue (coef = 0.038, bootstrap CIs: -0.062 to 0.138) or the indirect effects
416 of age on listening-related fatigue via auditory attention ability (coef = -0.027, bootstrap CIs: -0.073
417 to 0.013), perceived HI (coef = -0.010, bootstrap CIs: -0.038 to 0.014), or perceived memory ability
418 (coef = -0.006, bootstrap CIs: -0.021 to 0.007). Second, we found no evidence that need for cognition
419 moderated the direct effect of age on listening-related fatigue (coef = -0.008, bootstrap CIs: -0.122 to
420 0.106) or the indirect effects of age on listening-related fatigue via auditory attention ability (coef = -
421 0.013, bootstrap CIs: -0.047 to 0.027), perceived HI (coef = 0.003, bootstrap CIs: -0.027 to 0.035), or
422 perceived memory ability (coef = 0.003, bootstrap CIs: -0.010 to 0.017).

423 In our third model, we found no evidence that sensory-processing sensitivity moderated the
424 direct effect of age on listening-related fatigue (coef = 0.006, bootstrap CIs: -0.090 to 0.101) or the
425 indirect effects of age on listening-related fatigue through perceived HI (coef = -0.007, bootstrap CIs:
426 -0.035 to 0.020), or perceived memory ability (coef = -0.007, bootstrap CIs: -0.024 to 0.004).
427 However, we did find evidence that sensory-processing sensitivity moderated the indirect effect of
428 age on listening-related fatigue through auditory attention ability (coef = -0.042, bootstrap CIs: -0.076
429 to -0.010). In other words, the indirect effect of age on listening-related fatigue via auditory attention
430 ability differed as a function of sensory-processing sensitivity score. See Figure 4 (upper panel) for an
431 illustration of the specific conditional effect under investigation. In generic terms, this conditional
432 indirect effect quantifies the amount by which two cases with the same sensory-processing sensitivity
433 value but differing by one unit of 'age' are estimated to differ in listening-related fatigue indirectly via
434 auditory attention ability.

To probe this conditional indirect effect, PROCESS generated estimates of the conditional effect of age on listening-related fatigue for various values of sensory-processing sensitivity. The sensory-processing sensitivity values were -1.008 (16th percentile; ‘low’), -0.047 (50th percentile; ‘moderate’), and 1.112 (84th percentile; ‘high’). We found a significant negative indirect effect of age on listening-related fatigue through auditory attention ability for individuals high (coef = -0.057, bootstrap CIs: -0.106 to -0.009), but not for individuals moderate (coef = -0.008, bootstrap CIs: -0.039 to 0.023) or low (coef = 0.033, bootstrap CIs: -0.008 to 0.081) in sensory-processing sensitivity. Therefore, although auditory attention ability was poorer in older adults overall ($a_1 = -0.462$), this actually resulted in less listening-related fatigue amongst those high in sensory-processing sensitivity (see Figure 5; left panel). To better understand this conditional effect, we examined how the effect of auditory attention ability on listening-related fatigue was moderated by sensory-processing sensitivity, independent of age (see Figure 4; lower panel, for a conceptual diagram). Irrespective of age, better auditory attention ability resulted in significantly more listening-related fatigue for individuals high in sensory-processing sensitivity only (coef = 0.092, bootstrap CIs: 0.031 to 0.153). This direct conditional effect is illustrated in Figure 5 (right panel).

Figure 4. Conceptual diagrams illustrating (a) the conditional indirect effect of age on listening-related fatigue via auditory attention ability (upper panel) and (b) the conditional effect of auditory attention ability on listening-related fatigue (lower panel).

Figure 5. Left panel; the indirect effect of age on listening-related fatigue through auditory attention ability (y axis) as a function of sensory-processing sensitivity (x axis) using scores that fall in the 16th, 50th, and 84th percentiles of the distribution (see Figure 4, upper panel). More negative y axis values reflect lower listening-related fatigue ratings with increasing age via poorer auditory attention ability. Right panel; the effect of auditory attention ability (x axis) on listening-related fatigue (y axis) as a function of sensory-processing sensitivity using the 16th, 50th, and 84th percentiles of the distribution (low, moderate, and high, respectively). Higher scores reflect increased listening-related fatigue and better auditory attention ability. SPS = Sensory processing sensitivity. See Figure 4 (lower panel) for a conceptual schematic of this effect.

Exploratory mediation analysis

Given the unexpected direct negative effect of age on listening-related fatigue in the mediation analysis, an additional mediation model was tested to explore whether that effect might be explained by age-related differences in mood disturbance, need for cognition, or sensory-processing sensitivity. Figure 6 shows all path coefficients in this model. We found indirect effects of age on listening-related fatigue through both mood disturbance and sensory-processing sensitivity. Specifically, older participants were more likely to report decreased mood disturbance ($a_1 = -0.305$, $p < .001$) and reduced sensory-processing sensitivity ($a_1 = -0.179$, $p = .003$). Reduced mood disturbance and sensory-processing sensitivity resulted in lower listening-related fatigue ratings ($b_1 = 0.323$ and $b_3 = 0.344$, respectively; $ps < .001$). Bootstrap confidence intervals for the indirect effect of age on listening-related fatigue through mood disturbance ($a_1b_1 = -0.098$) and sensory-processing sensitivity ($a_3b_3 = -0.062$) were both entirely below zero (-0.156 to -0.052 and -0.112 to -0.020, respectively). Need for cognition was a significant negative predictor of listening-related fatigue ($b_2 = -0.108$, $p = .03$). However, age did not predict need for cognition ($a_2 = 0.097$, $p = .11$). We found no evidence of an indirect effect of age on listening-related fatigue through need for cognition ($a_2b_2 = -0.011$), with bootstrap confidence intervals straddling zero (-0.032 to 0.003). Finally, when controlling for the effects of all three mediators in the model, there was no longer a direct effect of age on listening-

related fatigue ($c' = -0.004$, bootstrap CIs: -0.094 to 0.102), suggesting that mood disturbance and sensory-processing sensitivity captured much of variance associated with the effect of age on listening-related fatigue.

Figure 6. Diagram showing regression coefficients between all variables tested in the 2nd mediation model. A solid arrow connecting variables represents a significant regression coefficient ($p < .05$). A dashed arrow represents a non-significant coefficient.

Discussion

This study examined the effect of age on listening-related fatigue and explored mediating and moderating variables underlying this effect. First, as predicted, we found an indirect effect of age on listening-related fatigue that was mediated by perceived HI; older adults reported higher perceived HI, and this in turn was associated with increased listening-related fatigue. Contrary to our predictions, we found no indirect effect of age on listening-related fatigue via auditory attention ability or perceived memory ability. Moreover, when controlling for the effects of perceived HI, auditory

attention ability, and perceived memory ability, older adults reported *less* listening-related fatigue. A follow-up exploratory mediation analysis revealed that this negative direct effect might be attributable to age-related reductions in mood disturbance and sensory-processing sensitivity. When we controlled for these factors, there was no longer a direct effect of age on listening-related fatigue. Finally, we found a conditional indirect effect of age on fatigue via auditory attention ability. Specifically, older adults generally had poorer auditory attention ability, which resulted in less listening-related fatigue, but only for those with high sensory-processing sensitivity.

Previous research suggests that perceived HI may be a mechanism by which older adults report increased listening-related fatigue (Hornsby & Kipp, 2016). Consistent with this idea, we found that older adults reported higher perceived HI, and those with higher perceived HI also tended to report increased listening-related fatigue. We also hypothesized that poorer auditory attention ability may represent another pathway to increased listening-related fatigue in older adults. Older listeners showed poorer auditory attention ability, which is consistent with the literature (Rogers et al., 2018). However, auditory attention ability did not predict listening-related fatigue¹. Finally, we also predicted that reductions in perceived memory ability might account for some changes in listening-related fatigue over the lifespan. Although perceived memory ability negatively predicted listening-related fatigue, we found no effect of age on perceived memory ability.

The main results from the mediation analysis suggest that perceived HI represents one mechanism by which healthy older adults report more listening-related fatigue. However, results from a follow-up mediation model exploring the unexpected direct negative effect of age on listening-related fatigue revealed that mood disturbance and sensory-processing sensitivity both decrease with age and positively predict listening-related fatigue. In other words, reduced mood disturbance and sensory-processing sensitivity appear to be mechanisms by which older adults ultimately report *less* listening-related fatigue. This finding highlights the pivotal role of negative affective responses, in particular to unwanted sensory stimuli, in the subjective experience of listening-related fatigue

¹ Subsequent analysis revealed that this indirect effect was in fact moderated by sensory-processing sensitivity (discussed later).

(Francis & Love, 2020; Strand et al., 2018). This is consistent with a recent study showing that negative emotional responses may influence our tolerance of background noise in general (Mackersie et al., 2021). It also sheds light on the ongoing ‘tug-of-war’ in the relationship between age and listening-related fatigue. While aging is associated with higher perceived HI, which may increase susceptibility to listening-related fatigue, it is also associated with more positive mood characteristics which appear to counteract this effect. Age-related improvements in emotion regulation, in particular, have been reported elsewhere in the literature (Charles & Carstensen, 2010). However, given the exploratory nature of the follow-up mediation analysis, confirmatory research is warranted. Need for cognition predicted listening-related fatigue, with higher motivation to engage in effortful thinking predicting less listening-related fatigue. This is consistent with the notion that individuals who derive more pleasure from effortful cognitive activities are less likely to experience listening-related fatigue (Matthen, 2016). However, unlike mood disturbance and sensory-processing sensitivity, need for cognition scores did not show a concomitant change with age.

Finally, it was predicted that mood disturbance, need for cognition, and sensory-processing sensitivity would moderate the effect of age on listening-related fatigue. Only the prediction about sensory-processing sensitivity was supported; however, the direction of the effect was not as hypothesized. Specifically, we predicted an indirect positive effect of age on listening-related fatigue through poorer auditory attention (i.e., older adults would report more listening-related fatigue via poorer auditory attention abilities), an effect that would be strongest in individuals with high sensory-processing sensitivity. We found evidence for this indirect effect, but it was more *negative* for individuals high in sensory-processing sensitivity (see Figure 5; left panel). In other words, higher sensory-processing sensitivity was associated with lower listening-related fatigue for older adults with compromised auditory attention ability. In contrast, irrespective of age, better auditory attention ability was associated with increased listening-related fatigue for those with high sensory-processing sensitivity (see Figure 5; right panel). This conditional effect highlights an important distinction between functional outcomes and subjective experiences. For individuals who are highly sensitive to sensory stimuli, preserved auditory attention ability may exacerbate listening-related fatigue. One

explanation for this finding is that individuals who are highly sensitive and who also have intact top-down attentional control may sustain their attention at the expense of increased stress and effort during challenging listening situations. Consistent with Hockey's (2013) motivational control theory of fatigue, for these individuals, the reward of persevering and expending cognitive effort may not justify the effort, resulting in a heightened experience of listening-related fatigue.

This study highlights potential avenues for future research. For example, more research is required to help disentangle the relationship between effortful listening, mood, and listening-related fatigue. Changes in mood may represent a mechanism by which reward-induced effortful listening may mitigate perceived fatigue (Hockey, 2013). There are, of course, some limitations with the current study. Our findings are mostly limited to self-report data. The predicted age-related increase in effortful listening and fatigue may be detected using objective (e.g., behavioural or physiological) methods (Francis & Love, 2020; McGarrigle et al., 2021).

Conclusions

This study suggests that the relationship between age and listening-related fatigue is underpinned by a complex set of perceptual, cognitive, and psychological phenomena. Normal, healthy aging is associated with changes that simultaneously increase (heightened perceived HI) and protect against (reduced mood disturbance and sensory-processing sensitivity) daily life listening-related fatigue. For individuals with high sensitivity to sensory stimuli, better auditory attention ability may even increase susceptibility to listening-related fatigue. A better understanding of the impact of aging on various functional and subjective outcomes will help healthcare professionals tailor intervention strategies (e.g., hearing aids or counselling) to reduce the burden of communication difficulties in the transition into older adulthood.

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