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Sensory-processing sensitivity predicts fatigue from listening, but not perceived effort, in young and older adults

Ronan McGarrigle[1,2] & Sven Mattys[2]

[1]*Department of Psychology, University of Bradford, UK.*

[2]*Department of Psychology, University of York, UK.*

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Correspondence concerning this article should be addressed to: Ronan McGarrigle, Department of Psychology, University of Bradford, UK, BD7 1DP. Email: r.mcgarrigle@bradford.ac.uk

Abstract

Purpose: Listening-related fatigue is a potential negative consequence of challenges experienced during everyday listening, and may disproportionately affect older adults. Contrary to expectation, we recently found that increased reports of listening-related fatigue were associated with *better* performance on a dichotic listening task (McGarrigle et al., 2021a). However, this link was found only in individuals who reported heightened sensitivity to a variety of physical, social, and emotional stimuli (i.e., increased 'sensory-processing sensitivity'; SPS). The current study examined whether perceived effort may underlie the link between performance and fatigue.

Methods: 206 young adults, aged 18-30 years (Experiment 1) and 122 older adults, aged 60-80 years (Experiment 2) performed a dichotic listening task and were administered a series of questionnaires including: the NASA task load index of perceived effort, the Vanderbilt Fatigue Scale (measuring daily life listening-related fatigue) and the Highly Sensitive Person Scale (measuring SPS). Both experiments were completed online.

Results: SPS predicted listening-related fatigue but perceived effort during the listening task was not associated with SPS or listening-related fatigue in either age group. We were also unable to replicate the interaction between dichotic listening performance and SPS in either group. Exploratory analyses revealed contrasting effects of age; older adults found the dichotic listening task more effortful, but indicated lower overall fatigue.

Conclusions: These findings suggest that SPS is a better predictor of listening-related fatigue than performance or effort ratings on a dichotic listening task. SPS may be an important factor in determining an individual's likelihood of experiencing listening-related fatigue irrespective of hearing or cognitive ability.

Keywords: Listening-related fatigue, effortful listening, sensory-processing sensitivity, auditory attention, dichotic listening, speech perception, cognitive aging

Introduction

Listening in naturalistic settings (e.g., a café or office) may come at a cost for some individuals due to excessive levels of background noise. For example, fatigue associated with effortful listening is a common complaint from individuals with hearing loss (Alhanbali et al., 2017; Davis et al., 2020; Holman et al., 2019). Listening-related fatigue has been defined as a feeling of tiredness, weariness, and/or lack of energy/motivation to complete a listening task (Hornsby et al., 2016). In its mildest form, fatigue may disincentivize engagement in social activities known to promote health and well-being (Umberson & Montez, 2010). In its more severe form, chronic experiences of fatigue may be debilitating and significantly reduce quality of life (Bess & Hornsby, 2014; Evans & Wickstrom, 1999; Robinson-Smith et al., 2000). Recent development of the Vanderbilt Fatigue Scale for Adults (VFS-A), a scale for measuring listening-related fatigue in the adult population, has led to a renewed focus on understanding the factors that contribute to the experience of effortful listening and fatigue in various populations (Hornsby et al., 2021).

The extent to which an individual experiences listening-related fatigue likely depends on a variety of factors. For example, an individual's hearing sensitivity will influence the level of difficulty they encounter understanding speech, and thus also their subjective experiences of effort and fatigue from listening (Alhanbali et al., 2017; Davis et al., 2020; Holman et al., 2019). However, fatigue does not simply increase with severity of hearing loss in a linear fashion. Hornsby and Kipp (2016) found that although individuals with hearing loss were more likely to report 'severe' fatigue (compared with normative data), fatigue severity was not associated with degree of hearing loss. The cognitive profile (e.g., working-memory capacity) of the listener may also influence their experience of listening-related fatigue. Subjective reports of the challenges faced by individuals with a hearing impairment in naturalistic environments are often cognitive in nature (e.g., *'my brain felt like it was out of power';* Davis et al., 2020).

Given the overlapping psychophysiological mechanisms of stress, effort, and fatigue responses, an individual's emotional responses to environmental stimuli (like noise) may also impact the extent to which fatigue becomes an unwelcome by-product of everyday listening (Francis & Love, 2020). Recent evidence suggests that personality traits may influence the extent to which an individual experiences effort or fatigue from listening (Strand et al., 2018; McGarrigle et al., 2021a). For example, sensory-processing sensitivity (SPS) reflects an individual's awareness of, and receptivity to, a variety of physical, social, and emotional stimuli (e.g., noise, pain, caffeine, hunger; Aron & Aron, 1997). It is believed that individuals with high SPS process information at a deeper level, have heightened awareness of subtleties in the environment (e.g., ambient changes in light, noise), and are more likely to become overwhelmed (Greven et al., 2019). High levels of SPS have been linked to perceived stress and symptoms of poor health (Benham, 2006), depression (Liss et al., 2005), and social anxiety (Neal et al., 2002). SPS is therefore a personality trait that may lead to heightened emotional response to stress. In the context of hearing research, Strand et al. (2018) found that young normal-hearing adults with higher SPS scores showed increased listening effort, measured both subjectively and behaviorally, during performance on a challenging listening task.

While many previous listening effort studies have used speech-in-noise tasks to modulate effort (see Strand et al., 2020 for a recent review), others have used alternative approaches to eliciting an effortful listening response, including dichotic listening tasks (Mackersie & Cones, 2011; Seeman & Sims, 2015; Baldock et al., 2019; McGarrigle et al., 2021a). Dichotic listening tasks involve attending to speech presented to a given ear as instructed in a visual prompt (i.e., 'right' or 'left' ear) while ignoring the stimulus presented simultaneously to the other ear (Koch et al., 2018). As such, these tasks recruit attentional resources in a manner analogous to the kinds of everyday listening scenarios often considered most taxing and effortful, particularly for older adults (e.g., switching attention during a fast-paced conversation). Indeed, an item on the VFS-A (Hornsby et al., 2021) refers specifically to this kind of situation (*'Listening to fast-paced conversations wears me out'*).

McGarrigle et al. (2021a) used the dichotic listening task in a study investigating a variety of perceptual, cognitive, and personality factors that underlie changes in listening-related fatigue across the adult lifespan. Participants (age-range: 18 – 85 years) performed the dichotic listening task online along with a series of questionnaires assessing listening-related fatigue, SPS, and perceived hearing-impairment. Mediation analysis revealed an age-related increase in listening-related fatigue via greater perceived hearing-impairment. In other words, older adults tended to report higher perceived hearing-impairment ratings, which were generally associated with increased listening-related fatigue scores. However, controlling for perceived hearing-impairment, mediation analysis also revealed an age-related *decrease* in listening-related fatigue via reduced SPS. In other words, older adults generally reported lower SPS which, in turn, was associated with reduced listening-related fatigue. Lower SPS as a function of age has also been reported elsewhere in the literature (Ueno et al., 2019). However, an unexpected finding was that SPS actually moderated the effect of dichotic listening task performance on listening-related fatigue; for individuals with high SPS scores, better dichotic listening task performance was associated with *increased* listening-related fatigue (McGarrigle et al., 2021a). This suggests the possibility that daily life listening-related fatigue may be increased in individuals for whom auditory attention skills are unimpaired or even improved. One potential explanation for the above finding is that individuals who perform well on the dichotic listening task (and thus demonstrate superior auditory attention ability) may do so at the expense of increased listening effort. In other words, it is likely that individuals with high SPS have heightened awareness and sensitivity to auditory distraction and therefore recruit more cognitive resources during a listening task (cf. Strand et al., 2018). These same individuals are therefore also more likely to experience listening-related fatigue as a longer-term consequence of these repeated exertions. The current study therefore aimed to elucidate the nature of the associations between introspective assessments of daily life experiences (SPS and listening-related fatigue) and listening task-based performance and effort metrics in a group of healthy young adults (Experiment 1) and healthy older adults (Experiment 2). Specifically, we examined the hypothesis that perceived effort may account for the increased reports of listening-related fatigue in individuals with superior dichotic listening performance and high SPS. In other words, we predicted that for individuals high in SPS, performing better on a taxing auditory attention task (i.e., dichotic listening) comes at the cost of increased perceived effort, which in turn results in higher likelihood of reporting increased daily life listening-related fatigue. We were interested to see if that prediction held true for both young and older listeners.

Experiment 1

Young normal-hearing adults completed a dichotic listening task and were asked to provide perceived effort ratings immediately after to assess subjective listening effort. Participants also completed the VFS-A questionnaire as a measure of daily life listening-related fatigue (Hornsby et al., 2021) and the Highly Sensitive Person Scale as a measure of SPS (Aron & Aron, 1997). Based on the studies reviewed above, we made the following specific predictions:

1. SPS will positively predict listening-related fatigue.
2. SPS will moderate the relationship between dichotic listening task performance and listening-related fatigue such that only individuals with high SPS will show a positive relationship between dichotic listening task performance and listening-related fatigue (see Figure 1, panel A).
3. SPS will moderate the conditional positive indirect relationship between dichotic listening task performance and listening-related fatigue via perceived effort. In other words, for individuals high in SPS (and only them), dichotic listening task performance will positively predict listening-related fatigue via increased perceived effort (see Figure 1, panel B).

****Figure 1 here (1a directly above 1b)****

Method

Hypotheses, methodological plans and analytic plans for this study were pre-registered (https://osf.io/treau)[1]. Analysis scripts as well as raw and summary data can be found on our Open Science Framework (OSF) project homepage (https://osf.io/b2q89/). Methods for this study were similar to the methods used for a previous online study conducted by the same lab (McGarrigle et al., 2021a).

Participants

We recruited a total of 231 participants (132 male), aged 18-30 years (*M* = 24.43, *SD* = 3.84[2]). There is currently little consensus in the literature on how to calculate sample size requirements for moderated mediation analysis (Perugini et al., 2018). We therefore used Schoemann et al.'s (2017) 'mc_power_med' app to calculate sample size requirements for a basic mediation analysis. The direct effect of dichotic listening task performance on listening-related fatigue (i.e., pathway c') was .02 in a previous study (McGarrigle et al., 2021a). Assuming a standardised coefficient of $a = .2$ for the effect of dichotic listening task performance on listening-related fatigue and a standardised coefficient of $b = .3$ for the effect of perceived effort on listening-related fatigue, a total sample size of 200 participants would provide power of .80 to detect a significant mediation effect at $\alpha = 0.05$. We recruited more participants than our target sample size (i.e., 231) to allow for potential exclusions for failing to meet the inclusion criteria recorded in a screening questionnaire at the end of the experiment (described below), failing the attention check, or performing the dichotic listening task at below chance level.

All participants were recruited via Prolific, an online recruitment platform (prolific.co), and financially compensated for their time. We applied the following initial eligibility criteria on Prolific, based on self-reports: (1) age (18-30 years), (2) English as a first language, (3) normal or corrected-to-

[1] Any deviations from the preregistered plan are outlined, with justifications provided, in the supplementary materials.

[2] Note that these descriptive values were calculated based on a Prolific export downloaded three months after experiment completion and therefore reflect participants' age (in years) at the time of download, not at the time of experiment completion.

normal visual acuity, (4) no known language-related disorders, (5) no diagnoses of mild cognitive impairment or dementia, (6) a minimum Prolific approval rating of at least 95%, and (7) did not take part in the study reported in McGarrigle et al. (2021a). Participants were also asked to complete the study in the hours between 8am – 6pm. After data collection, participants were excluded if they responded 'yes' to any of the screening questions administered at the end of the experiment (details below in 'general procedure' section). In total, 21 participants were excluded from the analyses due to being flagged on at least one of the screening checks. Specifically, 12 reported currently suffering from a chronic condition that can cause fatigue; 11 reported currently taking medication that can cause fatigue; and 3 reported currently suffering from a hearing loss. A further four participants were excluded due to either failing the attention check (n = 3) or scoring below chance (i.e., < 50%) on the dichotic listening task (n = 1). A total of 206 participants remained and were entered into the analyses. This study was granted ethical approval by the departmental research ethics committee at University of York (ID: 733).

General Procedure

We used Gorilla Experiment Builder (www.gorilla.sc; Anwyl-Irvine et al., 2020) to design and host both our pre-screening questionnaire and all tasks and questionnaires in the main experiment. Participants were instructed to only take part in the experiment 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 hearing loss. Participants completed a series of audio checks before starting the main experiment. First, 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 can 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 accurately identified fewer than 5 trials 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 the dichotic listening task. This task took approximately 10 minutes to complete. Immediately after the dichotic listening task, participants were administered the perceived effort rating scale. Participants then completed the VFS-A questionnaire followed by the Highly Sensitive Person Scale. After these questionnaires, participants were asked the following (verbatim) questions used to identify individuals who do not meet the strict inclusion criteria: (1) do you have a known hearing loss in either or both ears and/or regularly use a hearing device (e.g., hearing aid or cochlear implant)?, (2) do you currently suffer from a chronic health condition that can cause fatigue (e.g., CFS, cancer, diabetes), and (3) do you regularly take any medication that can cause fatigue (e.g., antihistamines)? In total, the experiment lasted approximately 20 minutes.

Stimuli and individual task procedures

Dichotic listening task. We used the dichotic listening task developed by Koch et al. (2011) and adapted for use on the Gorilla online platform. For this task, participants heard 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 prompt displayed the word 'Male' or 'Female' (presented centrally on the screen) indicating which voice participants should attend to for that particular trial. The visual prompt remained on-screen for two seconds. Immediately after the visual prompt disappeared, the two spoken digits were presented over the headphones. Following presentation of the spoken digits, participants were asked to indicate whether the digit spoken by the attended voice was above or below five. 'Below 5' responses were given by pressing 'f' with the left index finger, and 'above 5' responses were given by pressing 'j' with the right index finger.

Participants were given visual prompts for 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 spoken digits. 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 spoken digits were edited in Audacity to include matching silent onsets lasting 200 ms. Audio files were converted from .wav to .ogg, as the .wav file type is not generally supported for online use. Each audio file had a sampling rate of 48 kHz. Participants performed 40 experimental trials in total; 20 with the 'female' prompt, and 20 with the 'male' prompt. Audio stimuli were digits 1-9 (except 5) recorded by a male talker and a female talker. Of the 20 'female' and 20 'male' prompt trials, half (i.e., 10/20) were 'congruent' trials, in which both spoken digits were either above or below 5. The same digits were never presented together. The other half (i.e., 10/20) were 'incongruent', in which one digit was above 5 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.

Perceived effort rating. Perceived effort ratings were an adapted version of the NASA task load index item assessing mental demand (Hart & Staveland, 1988), a commonly used subjective measure of effort (Dimitrijevic et al., 2019; McGarrigle et al., 2017; 2020; Pals et al., 2019; Peng & Wang, 2019; Strand et al., 2018). Specifically, we asked the following question; 'How hard did you have to work to accomplish your level of performance (speed AND accuracy) in the listening task? (EFFORT)' (100-step scale from Very low effort—Very high effort). Participants provided responses using an on-screen slider bar with values ranging from 0 to 100 in increments of 1. A circular icon was positioned on the midpoint of the scale (50) to begin with and participants adjusted the icon using a mouse, with verbal anchors positioned at each endpoint of the slider scale. A "Next" box was positioned at the bottom of the screen which participants clicked on to advance to the next stage of the experiment. We opted to use the NASA tlx as a measure of perceived effort to align with Strand and colleagues (2018) who found a correlation between trait-level SPS and effort ratings during an acute, controlled listening task, using that scale.

Vanderbilt Fatigue Scale for Adults (VFS-A). The 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 (Hornsby et al., 2021). 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., 2021). 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'*. On the VFS-A, participants are given the following (verbatim) instructions: 'For each item, select the SINGLE response which best describes your day-to-day experiences over a typical WEEK.' The listening-related fatigue score was a summed score of all 40 items on the scale. Possible scores therefore ranged from 40 – 200, with higher scores indicating more listening-related fatigue.

Highly Sensitive Person Scale (HSPS). Sensory-processing sensitivity (SPS) was measured using the Highly Sensitive Person Scale (Aron & Aron, 1997). This 27-item scale has been shown to have good content, convergent, and discriminant validity as well as adequate reliability (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)[3]. Total scores were calculated as the mean score (1 – 7) on all items. Higher scores indicate increased SPS.

Analysis

[3] Unlike the VFS-A, participants are not given specific time course instructions before completing this scale.

Attention check. First, to help identify inattentive participants, we included an attention check at the end of the Highly Sensitive Person Scale. As the final item on the scale, participants were asked to *'Please mark number 7 ('Extremely') for this question?'*. Participants were flagged if they responded incorrectly (i.e., did not respond '7'). Of the participants who remained in the analysis following the screening questionnaire responses (i.e., 210/231), two failed this additional attention check, leaving 208 participants.

Dichotic listening task performance 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 147 trials (1.9% of all correct responses in the dataset). Most (138/147) of these trials came from different participants in the dataset, with just 9 participants having two, rather than one, trials removed. Performance decrements may manifest as an incorrect and/or a slowed response on a given trial. To account for both types of performance disruption, dichotic listening task performance 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 PC is the proportion of correct responses and $\overline{RT}$ is the mean correct response RT. BIS is thus the difference in standardised (z) scores between mean correct RTs and proportion of correct responses. As in McGarrigle et al. (2021a), 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 accuracy and RT, BIS therefore provides an integrated measure of overall task performance. Higher BIS scores reflect better combined accuracy and RT.

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 is proposed to transmit its effect on another variable (Hayes, 2017). Conditional Process Analysis can be used to test hypotheses regarding potential mediating effects by harnessing regression-based parameter estimates that are commonly used in the behavioral and social sciences (Hayes & Rockwood, 2020). As one of the primary aims of the current study was to elucidate an effect revealed in a previous study using this statistical approach (McGarrigle et al., 2021a), we chose to use the same analysis for consistency. Multiple linear regression analysis was conducted using SPSS v25. Conditional process analysis was conducted using the PROCESS (Hayes, 2017) macro on SPSS v25. We entered dichotic listening task performance as the predictor variable and perceived effort as the mediator variable. SPS was entered as the moderator variable and listening-related fatigue as the dependent variable. Figure 1b shows the conceptual model entered into the full conditional process analysis. 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 the hypothesized conditional indirect effect of dichotic listening task performance on listening-related fatigue via perceived effort.

Statistical assumptions for Conditional Process Analysis are generally the same as those expected for standard Ordinary Least Squares (OLS) regression. First, relationships between the Y variable (VFS-total) and all three X variables (BIS, HSPS score, effort) were checked for potential non-linearity. Based on visual inspection, none of the relationships appeared to be non-linear. Second, QQ plots suggested that all four variables approximated normality, with the exception of BIS score which showed some minor inflections at both ends of the distribution. As this particular variable had already been transformed (see ‘Analysis’ section) and only extreme breaches of normality typically affect the validity of statistical inferences in OLS regression when sample sizes are sufficiently large (Hayes, 2018; Pek et al., 2018), we did not perform any further transformations. Third, to examine homoscedasticity, we plotted the standardised residuals for each X variable (BIS, HSPS score, effort) regressed on the Y variable (VFS-Total). All three residual plots suggested homoscedasticity (data points clustered consistently around best fit line). Finally, we examined correlations between all three

X variables in the model for signs of multicollinearity. As can be seen in Table 2, all correlation coefficients were very low (rs < .1).

Results

Descriptive statistics and correlations

Table 1 shows the descriptive statistics for all variables based on the 206 participants entered into the analyses. Correlation coefficients between variables can be found in Table 2. These analyses are presented to help disentangle the relationships modelled in the subsequent Conditional Process Analysis. There was a significant positive correlation between SPS and listening-related fatigue, $r(204) = .57$, $p < .001$. Individuals with greater listening-related fatigue were more likely to also have higher SPS. As expected, BIS scores on the dichotic listening task were positively associated with accuracy, $r(204) = .79$, $p < .001$, and negatively associated with correct response RTs, $r(204) = -.79$, $p < .001$. Accuracy was negatively associated with correct response RT on the dichotic listening task also, $r(204) = -.25$, $p < .001$. There were no other significant correlations (all ps > .05).

****Table 1 here****

****Table 2 here****

Regression analysis

We conducted a multiple linear regression analysis to examine whether SPS, perceived effort, and dichotic listening performance[4] were significant predictors of listening-related fatigue and to test

[4] Note that the variable entered in this analysis was the Balanced Integration Score (BIS) on the dichotic listening task, which combines accuracy and correct response RT.

the basic hypothesis (H1) that SPS will positively predict listening-related fatigue. Overall, the model explained 33% of the variance and was a significant predictor of listening-related fatigue, $F(3, 202) = 33.67$, $p < .001$. SPS was a significant predictor of listening-related fatigue, $t(202) = 9.83$, $\beta = .57$, $p < .001$. However, neither perceived effort, $t(202) = 1.56$, $\beta = .09$, $p = .12$, nor dichotic listening performance, $t(202) = -0.29$, $\beta = -.02$, $p = .77$, significantly predicted listening-related fatigue. Figure 2 displays the association between SPS and listening-related fatigue.

****Figure 2 here****

Conditional process analysis

Next, we conducted a conditional process analysis to examine the hypothesis that SPS would moderate the relationship between dichotic listening performance and listening-related fatigue via perceived effort (cf. Figure 1b). We found no evidence that SPS moderated the direct relationship between dichotic listening performance and either perceived effort (Figure 1, path 2; coef = -0.76, 95% CIs: -3.24 to 1.72) or listening-related fatigue (Figure 1, path 1; coef = -1.46, 95% CIs: -3.88 to 0.96). Finally, there was no evidence that SPS moderated the indirect relationship between dichotic listening performance and listening-related fatigue via perceived effort (Figure 1, paths 2 & 3; coef = -0.08, bootstrap CIs: -0.43 to 0.33). Table 3 provides all coefficients in the conditional process model.

****Table 3 here****

Discussion

We conducted a regression analysis to examine predictors of listening-related fatigue in young normal-hearing adults. The findings revealed support for H1; SPS significantly predicted listening-related fatigue. Further, SPS scores did not predict effort ratings. In other words, the extent to which young adults found the dichotic listening task effortful was not associated with either their trait-level sensitivity to sensory stimuli or their daily life listening-related fatigue score. Next, we conducted a conditional process analysis (Hayes, 2017) to test whether SPS moderated the relationship between dichotic listening task performance and listening-related fatigue, and whether perceived effort could explain this moderation. We did not find support for H2 or H3; SPS did not moderate the relationship between dichotic listening task performance and listening-related fatigue, and we found no evidence that perceived effort played a mediating role in this hypothesized conditional process.

The findings from the regression analysis are consistent with McGarrigle et al. (2021a) in demonstrating an association between SPS and listening-related fatigue. There was, however, no association between perceived effort ratings following a dichotic listening task and daily life listening-related fatigue scores. This is despite effort ratings being considerably high (*M* = 69/100) and variable (*SD* = 23/100) in the current study (see Figure 4 for the response distributions). Although links between effortful listening and fatigue are intuitive and replete in the literature (Hornsby et al., 2016; McGarrigle et al., 2014; Pichora-Fuller et al., 2016), SPS appears to be a more salient predictor of listening-related fatigue in young adults. The fact that the Highly Sensitive Person Scale taps qualitative dimensions from multiple modalities and domains (e,g., empathy, pain, visual/olfactory sensations) suggests that the extent to which one is sensitive to a wide range of multi-dimensional sensory and psychological experiences can predict negative outcomes associated with listening-related fatigue.

Strand et al. (2018) showed that SPS was positively related to perceived effort ratings during a challenging listening task. In their study, young normal-hearing adults with higher SPS scores rated the listening task as more effortful. However, in the current study, we found no association between SPS scores and perceived effort ratings. Although both studies examined a similar population (young normal-hearing adults) and administered a NASA task load index of perceived effort (Hart & Staveland, 1988), there were differences in the type of listening task employed to elicit an effortful response which may help to explain the discrepant findings. Strand et al. (2018) administered a word recognition task in speech-shaped noise at two signal-to-noise ratios (+5 dB: 'easy' and -2 dB: 'hard'). Mean performance accuracy in the hard SNR condition during the speech recognition task was between 80-91%, while performance accuracy on the dichotic listening task in the current study was relatively higher (M = 95%). Despite these performance differences, mean effort ratings in both studies were comparable; 66/100[5] for the hard SNR condition in Strand and colleagues (2018) and 69/100 in the current study. It is therefore possible that an association between SPS and perceived effort ratings is contingent on the presence of noise during the listening task. In other words, the extent to which SPS predicts effort ratings might depend not on the cognitive demands of the listening task *per se*, but rather on the level/extent of the disruptive noise present. Recent evidence also suggests that the specific type of demands imposed during a listening task (e.g., processing speech in noise versus non-native accented speech) may differentially impact physiological markers of effort (Francis et al., 2021). The extent to which different forms of acoustic and cognitive demand elicit a variety of perceptual and physiological responses warrants further investigation.

Experiment 2

To examine the possibility that the moderating role of SPS on the effect of dichotic listening task performance on listening-related fatigue pertains only to the older adult population, we recruited a sample of healthy older adults aged 60-80 years. Hypotheses were identical to those outlined in Experiment 1.

Method

[5] As Strand et al. (2018) used a different value range (1-21), we converted the mean score (13.9/21) in the hard SNR condition into a percentage for a comparison.

Hypotheses, methodological plans and analytic plans for this study were pre-registered (https://osf.io/z3mtk). Analysis scripts used and the raw and summary data can be found on our OSF project homepage (https://osf.io/b2q89/).

Participants

We recruited a total of 160 participants (86 male), aged 60-80 years (M = 64.03, SD = 3.68). We used Schoemann et al.'s (2017) 'mc_power_med' app to calculate sample size requirements for a basic mediation analysis. Assuming a standardized coefficient of a = .3[6] for the effect of dichotic listening task performance on perceived effort and a standardized coefficient of b = .3 for the effect of perceived effort on listening-related fatigue, a total sample size of 122 participants would provide power of .80 to detect a significant mediation effect at $\alpha = 0.05$. We initially recruited 150 participants to allow for potential omissions for failing to meet the inclusion criteria. Participants were excluded if they responded 'yes' to any of the screening questions administered at the end of the experiment. Participants could also be excluded for either: (i) failing the attention check, (ii) reporting a score of >3 on the WHO perceived hearing impairment scale (described below), or (iii) performing at below chance level (<50% correct) on the dichotic listening task.

After applying the above criteria, we were slightly below (N = 113) our target sample size. Specifically, thirty-four participants were excluded for responding 'yes' to at least one of the three screening questions: 24 reported currently suffering from a chronic condition that can cause fatigue; 16 reported currently taking medication that can cause fatigue; 9 reported currently suffering from a hearing loss. Of these 34 participants, one also failed the attention check, three scored >3 on the WHO perceived HI scale (indicative of a hearing loss which is greater than 'moderate'), and two scored <50% correct on the dichotic listening task. An additional three participants were excluded for scoring <50% on the dichotic listening task. To meet our target sample size, we therefore recruited an

[6] Note that this is larger than the predicted effect of a = .2 in Experiment 1, as we anticipated that older adults would show more variability in performance and effort scores overall (Morse, 1993).

additional ten participants. All but one of these additional ten participants met the eligibility criteria, with one participant reporting that they suffered from a chronic health condition and took medication that can cause fatigue. As a result, we were left with the target sample size of $N = 122$ for the analyses, with a mean age of 63.55 ($SD = 3.03$). As in Experiment 1, all participants were recruited via Prolific and financially compensated for their time. We applied the same initial eligibility criteria as in Experiment 1 on Prolific, with only the 'age' criterion adjusted to include participants aged 60+ years only. The study was granted ethical approval by the departmental research ethics committee at University of York (ID: 733).

General Procedure, Stimuli, and Analysis

Tasks, questionnaire materials, design, procedure, and analysis were the same as those in Experiment 1, and the experiment was once again hosted using the Gorilla Experiment Builder platform (www.gorilla.sc). In this experiment, an additional questionnaire was administered to measure perceived hearing impairment (HI). This was used to exclude participants who indicated a hearing impairment that fell outside of the age-normal mild-moderate range. We used an adapted version of 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 one 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. This questionnaire was administered after performance of the dichotic listening task and just before participants completed the VFS-A.

Individual trial RTs on 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 75 trials (1.7% of all correct responses in the dataset). Most (70/75) of these trials came from different participants in the dataset, with just 5 participants having two, rather than one, trials removed. To compare data between the two age groups (Experiments 1-2), exploratory by-group analyses were conducted based on combined data sets from both experiments using independent samples t-tests on SPSS v25. In cases of a significant Levene's test for equality of variances ($p < .05$), we reported the statistics with equal variances not assumed and adjusted degrees of freedom rounded to the nearest whole number.

We performed the same assumption checks for Experiment 2 as for Experiment 1. Once again, visual inspection of the data plots suggested no non-linear relationships. Residual plots for all three X variables regressed on Y suggested homoscedasticity (data points clustered consistently around best fit line). QQ plots showed some minor deviations from normality for BIS scores, VFS scores, and effort ratings. Natural log transformation on each variable unfortunately did not correct these deviations. Finally, relationships between the X variables were very low (rs < .1) suggesting no concerns over multicollinearity in the model (see Table 5).

Results

Descriptive statistics and correlations

Table 4 shows the descriptive statistics for all variables. Correlation coefficients between variables can be found in Table 5. There was a significant positive correlation between HSPS and VFS-total scores, $r(120) = .60$, $p < .001$. Individuals with greater overall listening-related fatigue were more likely to also have higher SPS. As expected, BIS scores on the dichotic listening task were positively associated with performance accuracy, $r(120) = .80$, $p < .001$, and negatively associated with correct response RTs, $r(120) = -.80$, $p < .001$. Performance accuracy was negatively associated with correct response RT on the dichotic listening task also, $r(120) = -.29$, $p = .001$. There were no other significant correlations (all *p*s > .05).

****Table 4 here****

****Table 5 here****

Regression analysis

We conducted a multiple linear regression analysis to examine whether SPS, perceived effort, and dichotic listening performance were significant predictors of listening-related fatigue and to test the basic hypothesis (H1) that SPS will positively predict listening-related fatigue. Overall, the model explained 38% of the variance and was a significant predictor of listening-related fatigue, $F(3, 118) = 24.19$, $p < .001$. Amongst the individual predictors, SPS was a significant predictor of listening-related fatigue, $t(118) = 8.38$, $\beta = .61$, $p < .001$. However, neither perceived effort $t(118) = 0.82$, $\beta = .06$, $p = .42$, nor dichotic listening performance, $t(118) = -1.51$, $\beta = -.11$, $p = .13$, significantly predicted listening-related fatigue. Figure 3 displays the association between HSPS (SPS) and VFS-Total (listening-related fatigue) scores.

****Figure 3 here****

Conditional process analysis

Next, we ran a conditional process analysis to examine the hypothesis that SPS would moderate the relationship between dichotic listening performance and listening-related via perceived effort (cf. Figure 1b). We found no evidence that SPS moderated the direct relationship between dichotic listening task performance and either perceived effort (Figure 1, path 2; coef = 1.86, 95% CIs: -0.13 to 3.85) or listening-related fatigue (Figure 1, path 1; coef = -1.40, 95% CIs: -3.27 to 0.47). Finally, there was no evidence that SPS moderated the indirect relationship between dichotic listening task performance and listening-related fatigue via perceived effort (Figure 1, paths 2 & 3; coef = 0.17, bootstrap CIs: -0.48 to 0.62). Table 6 provides all coefficients in the conditional process model.

****Table 6 here****

Discussion

First, we once again found support for H1; SPS significantly predicted listening-related fatigue, but this time in a sample of older adults aged 60 – 80 years. As with the young adult group, older adults' perceived effort ratings following the dichotic listening task did not predict daily life listening-related fatigue. Second, as before, SPS scores did not predict effort ratings. In other words, the extent to which older adults considered a challenging dichotic listening task to be effortful was not associated with either their trait-level sensitivity to sensory stimuli or their daily life listening-related fatigue score. Third, consistent with Experiment 1, we did not find support for either H2 or H3; SPS did not moderate the relationship between dichotic listening task performance and listening-related fatigue, and we found no evidence that perceived effort played a mediating role in this hypothesised conditional process in a group of older adults. In sum, the regression and conditional process analyses results were broadly comparable for the young and older listeners.

Exploratory by-group analyses

Next, we combined data from Experiments 1 and 2 to conduct additional exploratory analyses examining age differences in listening-related fatigue, SPS, dichotic listening performance, and perceived effort.

Figure 4 displays mean scores for each outcome variable (VFS-Total, HSPS, dichotic listening performance, perceived effort) plotted as a function of age group. Independent samples t-tests (or non-parametric equivalents) were conducted on each outcome variable to compare scores as a function of age group. VFS-Total scores were significantly higher in the young (*Mdn* = 89.50) than the older adult (*Mdn* = 62.00) group, U ($N_{\text{young adult}}$=206, $N_{\text{older adult}}$=122) = 6287, z = -7.57, p < .001. Analyses of domain-specific (physical, emotional, social, and cognitive) listening-related fatigue scores revealed significantly higher scores for the young than the older adult group across all four domains (all *ps* < 0.05). SPS scores were significantly higher in the young (M = 4.34) than the older group (M = 3.95), $t(326)$ = 3.58, p < .001, d = 0.41. BIS scores were also significantly higher (i.e., better) in the young (*Mdn* = .59) than the older group (*Mdn* = -.05), U ($N_{\text{young adult}}$=206, $N_{\text{older adult}}$=122) = 8260, z = -5.19, p < .001. However, perceived effort ratings were significantly higher in the older group (*Mdn* = 78) than the young group (*Mdn* = 71), U ($N_{\text{young adult}}$=206, $N_{\text{older adult}}$=122) = 15123, z = 3.08, p = .002.

****Figure 4 here****

General Discussion

Sensory-processing sensitivity (SPS) predicts listening-related fatigue but does not interact with dichotic listening performance

The current study provides robust evidence that SPS is a salient predictor of daily life listening-related fatigue. Specifically, a 1-unit increase in SPS was associated with a 16.73-unit increase in listening-related fatigue in young adults (Experiment 1) and a 13.93-unit increase in listening-related fatigue in older adults (Experiment 2). For both young and older adults, neither performance nor perceived effort on a dichotic listening task significantly predicted listening-related fatigue. This suggests that SPS is a stronger predictor of listening-related fatigue in the healthy adult population than either their ability to perform a demanding auditory attention task or the extent to which an individual perceives that task to be effortful. The finding that SPS significantly predicts listening-related fatigue lends support to a previous study reporting a similar finding (McGarrigle et al., 2021a).

However, the lack of an association between perceived effort on a listening task and daily life listening-related fatigue is somewhat surprising given that many items in the VFS-A are cognitive in nature and allude to listening scenarios similar to that experienced in the dichotic listening task (e.g., '*Listening to fast-paced conversations wears me out*'). However, it is also the case that many of the items on the VFS-A allude to situations involving background noise (e.g., '*I try to avoid social events that involve listening in background noise*'). Future research could explore the effect of masker type (e.g., noise versus competing talker) on the association between perceived effort on a listening task and overall daily life listening-related fatigue. For example, it is possible that the specific characteristics of interfering stimuli (e.g., distractors causing annoyance versus distraction; Kjellberg et al., 1996) may elicit different physiological responses that may or may not ultimately manifest in the experience of effort or fatigue from listening (Francis et al., 2021).

We were unable to replicate the finding in McGarrigle et al. (2021a) that SPS moderates the relationship between dichotic listening task performance and listening-related fatigue in either healthy young adults (Experiment 1) or healthy older adults (Experiment 2). A possible reason for this may be insufficient variance in our dependent variables. For example, variance in listening-related fatigue ratings was lower for the older adult group in this study (SD = 22.96) compared with those in McGarrigle et al. (SD = 27.90). A Levene's test conducted on the combined data sets confirmed that variances for listening-related fatigue scores were not equal between samples ($p < .05$). Reduced variability in listening-related fatigue may have been influenced by the additional screening requirement of the current study which included only older adult participants who reported a perceived HI of no greater than 'moderate'. However, variance in listening-related fatigue scores in the young adults of the current study (*SD* = 27.04) did not differ significantly to the McGarrigle et al.'s sample ($p > .05$). SPS score variances also did not differ significantly when comparing all three samples (*p*s > .05). As dichotic listening task performance represents a standardized score, variability in these composite scores within each study is equivalent. Finally, as both McGarrigle et al. (2021a) and the current study were conducted during the global COVID-19 pandemic (September, 2020 and January-April, 2021, respectively), it is unlikely that this impacted the results discrepancy. Overall, the current study findings suggest that the interaction between dichotic listening task performance and SPS does not replicate.

Age-related differences in listening-related fatigue and sensory-processing sensitivity (SPS)

Although sensory and cognitive declines associated with aging would suggest that older adults may be more susceptible to listening-related fatigue, recent evidence appears to contradict this idea. McGarrigle et al. (2021b) found that a group of young (aged 18 – 24 years) and older (aged 62 – 82 years) adults did not differ significantly in their reports of total daily life listening-related fatigue. Domain-specific analysis, however, revealed that older adults reported significantly higher listening-related fatigue within the 'social' domain than their younger counterparts. Nevertheless, as the primary outcome variable in the McGarrigle et al. (2021b) study was pupillometry-based, the total sample size was relatively small ($N = 65$). In a follow-up study (McGarrigle et al., 2021a), age-related changes in listening-related fatigue were examined in more detail and in a larger sample ($N = 280$). Aging was associated with increased listening-related fatigue *only* in cases where there was a concomitant increase in perceived HI. Otherwise, aging was actually associated with *reduced* listening-related fatigue; an effect that could be largely attributed to age-related declines in SPS and mood disturbance (McGarrigle et al., 2021a).

The current study reports significantly lower listening-related fatigue and SPS scores in the older compared to the young adult group. This finding is consistent with the idea that, in the absence of greater perceived hearing impairment, older adults may actually experience less listening-related fatigue than young adults. The age-related reduction in SPS reported in the current study is broadly consistent with recent studies that have examined the developmental trajectory of SPS (Panagiotidi et al., 2020; Ueno et al., 2019). In some cases, a hearing impairment may result in the experience of 'hyper-stimulation' within the auditory domain caused by hearing-aid amplification. As a result, an older adult may experience reduced sensitivity by leaving their hearing device switched off. However, in the current study, participants were only included in the analyses if they reported: (a) not regularly using a hearing device and (b) having either no known hearing loss or hearing acuity in the 'mild-to-moderate' range only. Additionally, it is important to note that sensitivity to noise is just one dimension of the SPS scale. For example, only two of the 12 HSPS scale items refer specifically to negative responses to auditory stimuli ('*Are you easily overwhelmed by things like bright lights, strong smells, coarse fabrics, or sirens close by?*' and '*Are you bothered by intense stimuli, like loud noises or chaotic scenes?*'). Therefore, given the limited range of perceived HI scores, as well as the domain generality of the SPS scale, we believe that older adults' reduced SPS is unlikely to be solely attributable to age-related hearing problems.

In the original HSPS validation paper, Aron and Aron (1997) proposed that SPS is a unidimensional construct. However, in a subsequent psychometric evaluation of the HSPS using principle component analysis, Smolewska et al. (2006) instead proposed a three-component structure to best describe SPS. These components include: (1) aesthetic sensitivity, which reflects appreciation of arts and music, (2) ease of excitation, which reflects likelihood of being overwhelmed by either internal (e.g., hunger) or external stimuli (e.g., being easily distracted by multiple sensations), and (3) low sensory threshold, which pertains more specifically to unpleasant sensory arousal due to external stimuli (e.g., loud noises, bright lights). In a cross-sectional study of adult aging (age range: 20-69 years), Ueno et al. (2019) found that aging impacted these three components in different ways. While aesthetic sensitivity showed a positive association with age, ease of excitation and low sensory threshold both showed a linear decrease with age. Therefore, exploring the relationship between specific components of SPS, listening-related fatigue, hearing acuity, cognitive control, and emotion regulation represents an interesting avenue for future research.

Age-related differences in dichotic listening performance and perceived effort

In the current study, dichotic listening performance was poorer overall and the task itself was rated as more effortful in older than young adults. Age-related decrements in dichotic listening task performance are reported elsewhere in the literature (Rogers et al., 2018; McGarrigle et al., 2021a). However, age-related increases in perceived effort are less frequently found in the literature, which actually shows mixed results. For example, while some speech perception studies reveal higher perceived effort ratings in older listeners under adverse acoustic conditions (Brown et al., 2021; Meister et al., 2018), other studies report either no difference between age groups or even higher perceived effort ratings in young adults (Ahlstrom et al., 2014; Hällgren et al., 2005; Veneman et al., 2013). The current study findings suggest that rapid auditory attention allocation comes at the cost of relatively increased perceived mental effort in older compared to young adult listeners.

The performance and perceived effort costs for older adults are in stark contrast with the lower listening-related fatigue reported in that group. A possible reason for this disconnect is that, while adverse listening conditions are indeed more effortful and fatiguing for older listeners, these conditions are actually encountered less frequently in their everyday lives. In other words, young adults aged 18 – 30 years may be more often exposed to cognitively-demanding listening scenarios (e.g., socialising in a café, bar, nightclub) and this more frequent exposure is reflected in their relatively high daily life listening-related fatigue scores. However, for young healthy adults, the relative reward of engaging socially in these kinds of scenarios may outweigh the perceived costs of allocating additional cognitive resources to understand speech. Another possibility is that perceived effort allocation during listening does not necessarily result in fatigue from listening, and may instead (at least partly) reflect a more positive form of task engagement (Inzlicht et al., 2018). Future research should examine in more detail the relative trade-off between choosing to engage in rewarding (yet effortful) social activities versus opting to preserve ‘energy’ by withholding from such costly interactions.

Conclusions

The current study suggests that sensory-processing sensitivity (SPS) represents a more salient predictor of daily life listening-related fatigue than either performance or perceived effort on a challenging dichotic listening task. The results also shed light on the multi-faceted effects of aging on communication outcomes; while auditory attention skills are compromised and perceived to be more effortful in older adults, aging appears to have a positive effect on more introspective measures of SPS and listening-related fatigue. Irrespective of age, knowledge of trait-level SPS may help in the identification of those at most risk of developing problematic listening-related fatigue.

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See Supplementary file for a list of any deviations from the preregistration, with justifications included.

Tables

Table 1. Descriptive statistics for all variables of interest.

	Descriptive statistics	
Variable	*M*	*SD*
Highly Sensitive Person Scale (HSPS) score (out of 7)	4.34	0.92
NASA tlx Effort score (out of 100)	68.55	22.70
Vanderbilt Fatigue Scale (VFS) Total score (out of 200)	91.12	27.04
Dichotic listening task accuracy (% correct)	94.76	8.24
Dichotic listening task correct response RT (ms)	1738	497

Table 2. Correlation coefficients between variables of interest.

	HSPS	Effort	VFS-Total	DL_Accuracy	DL_RT	DL_BIS
HSPS	.					
Effort	.02	.				
VFS-Total	.57**	.10	.			
DL_Accuracy	-.10	.04	-.05	.		
DL_RT	.04	.11	.06	-.25**	.	
DL_BIS	-.09	-.04	-.07	.79**	-.79**	.

** $p < .001$. HSPS = Highly Sensitive Person Scale score, Effort = NASA tlx Effort subscale score, VFS-Total = Vanderbilt Fatigue Scale score, DL_Accuracy = Accuracy on dichotic listening task, DL_RT = Mean correct response RT on dichotic listening task, DL_BIS = Balanced Integration Score on dichotic listening task (accuracy and RT combined).

Table 3. Model coefficients for the conditional process analysis in the young adult group. DL_BIS = Balanced Integration Score on the dichotic listening task. Effort = perceived effort. SPS = Sensory-processing sensitivity. Fatigue = Listening-related fatigue.

	Dependent variable					
	Effort			Fatigue		
Predictor	Coeff.	*SE*	*p*	Coeff.	*SE*	*p*
DL_BIS	2.70	5.58	.48	6.07	5.44	.27
Effort	-	-	-	0.10	0.07	.13
SPS	0.42	1.76	.81	16.94	1.71	< .001
DL_BIS x SPS	-0.76	1.26	.55	-1.46	1.23	.24
Constant	66.64	7.80	< .001	10.29	8.86	.25
	$R^2 = .004$			$R^2 = .34$		
	$F(3, 202) = 0.26$, $p = .85$			$F(4, 201) = 25.65$, $p < .001$		

Table 4. Descriptive statistics for all variables of interest.

Variable	Descriptive statistics *M*	*SD*
Highly Sensitive Person Scale (HSPS) score (out of 7)	3.95	1.00
NASA tlx Effort score (out of 100)	75.84	19.81
Vanderbilt Fatigue Scale (VFS) Total score (out of 200)	68.13	22.96
Dichotic listening task accuracy (% correct)	90.21	11.73
Dichotic listening task correct response RT (in ms)	1945	506

Table 5. Correlation coefficients between variables of interest.

	HSPS	Effort	VFS-Total	DL_Accuracy	DL_RT	DL_BIS
HSPS	.					
Effort	-.09	.				
VFS-Total	.60**	.00	.			
DL_Accuracy	-.05	.10	-.09	.		
DL_RT	-.05	.13	.09	-.29**	.	
DL_BIS	-.00	-.02	-.11	.80**	-.80**	.

** $p \leq .001$. HSPS = Highly Sensitive Person Scale score, Effort = NASA tlx Effort subscale score, VFS-Total = Vanderbilt Fatigue Scale score, DL_Accuracy = accuracy on dichotic listening task, DL_RT = Mean correct response RT on dichotic listening task, DL_BIS = Balanced Integration Score on dichotic listening task (accuracy and RT combined).

Table 6. Model coefficients for the conditional process analysis in the older adult group. DL_BIS = Balanced Integration Score on dichotic listening task (accuracy and RT combined). Effort = perceived effort. SPS = Sensory-processing sensitivity. Fatigue = Listening-related fatigue.

	Dependent variable					
	Effort			Fatigue		
Predictor	Coeff.	*SE*	*p*	Coeff.	*SE*	*p*
DL_BIS	-7.60	4.13	.07	3.97	3.88	.31
Effort	-	-	-	0.09	0.09	.29
SPS	-1.42	1.79	.43	13.68	1.66	< .001
DL_BIS x SPS	1.86	1.01	.07	-1.40	0.94	.14
Constant	81.46	7.31	< .001	7.24	9.68	.46
	$R^2 = .037$			$R^2 = .39$		
	$F(3, 118) = 1.50$, $p = .22$			$F(4, 117) = 18.88$, $p < .001$		

Figure Captions

Figure 1. Conceptual schematic representing the variables entered into the conditional process analysis (Hayes, 2017). Panel (a) illustrates the conditional relationship between dichotic listening task performance (i.e., index of auditory attention capacity) and daily life listening-related fatigue. Panel (b) illustrates the conditional indirect relationship between dichotic listening task performance and listening-related fatigue via perceived effort on the dichotic listening task. To test the hypothesis that this conditional process is moderated by one's trait-level sensory-processing sensitivity (i.e., 'sensitivity'), we entered dichotic listening task performance as the predictor variable, perceived effort as the mediator variable, sensory-processing sensitivity as the moderator variable, and listening-related fatigue as the dependent variable. Note that these models are shown separately for illustrative purposes only. The full conditional process model in the analysis incorporated both the direct (panel a) and indirect (panel b) conditional effects.

Figure 2. Scatterplot displaying raw listening-related fatigue (VFS-Total) scores (y axis) and raw SPS (HSPS) scores (x axis) in the young adult group. The solid black line displays the linear regression line with shaded 95% CIs.

Figure 3. Scatterplot displaying raw VFS_Total (listening-related fatigue) scores (y axis) and raw HSPS (sensory-processing sensitivity) scores (x axis) in the older adult group. The solid black line displays the linear regression line with shaded 95% CIs.

Figure 4. Violin plots displaying mean scores as a function of age group (young vs older adult) for listening-related fatigue (top left), sensory-processing sensitivity (top right), dichotic listening task performance (bottom left) and perceived effort (bottom right). Error bars indicate 95% CIs around the mean. Possible mean values range from 40 to 200 for listening-related fatigue, from 1 to 7 for

sensory-processing sensitivity, and from 0 to 100 for perceived effort ratings. Dichotic listening task performance (BIS) scores are calculated as the difference in standardised (i.e., z-scored) mean correct RTs and proportion of correct responses, and thus reflect a balanced combination of response accuracy and response time. VFS = Vanderbilt Fatigue Scale, HSPS = Highly Sensitive Person Scale, BIS = Balanced Integration Score. *** $p < .001$, ** $p < .01$.