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## Mood shapes the impact of reward on perceived fatigue from listening

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1 **Mood shapes the impact of reward on perceived fatigue from listening.**

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### Abstract

Knowledge of the underlying mechanisms of effortful listening could help to reduce cases of social withdrawal and mitigate fatigue, especially in older adults. However, the relationship between transient effort and longer-term fatigue is likely to be more complex than originally thought. Here, we manipulated the presence/absence of monetary reward to examine the role of motivation and mood state in governing changes in perceived effort and fatigue from listening. In an online study, 185 participants were randomly assigned to either a ‘reward’ ( $n = 91$ ) or ‘no-reward’ ( $n = 94$ ) group and completed a dichotic listening task along with a series of questionnaires assessing changes over time in perceived effort, mood, and fatigue. Effort ratings were higher overall in the reward group, yet fatigue ratings in that group showed a shallower linear increase over time. Mediation analysis revealed an indirect effect of reward on fatigue ratings via perceived mood state; reward induced a more positive mood state which was associated with reduced fatigue. These results suggest that: (a) listening conditions rated as more ‘effortful’ may be *less* fatiguing if the effort is deemed worthwhile, and (b) alterations to one’s mood state represents a potential mechanism by which fatigue may be elicited during unrewarding listening situations.

*Keywords:* Listening-related fatigue, effortful listening, motivation, reward, auditory attention, dichotic listening, speech perception

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## Introduction

47           Fatigue from mental exertion is a familiar subjective experience for most individuals. In most  
48 cases, this experience is transient and does not have lasting negative consequences. However, for  
49 some individuals (e.g., those with chronic conditions like cancer and diabetes), the effects of mental  
50 fatigue may be more pronounced and potentially debilitating (Bryant et al., 2004; Hockey, 2013). As  
51 well as compromising wellbeing, mental fatigue has been shown to disrupt an individual's ability to  
52 perform a wide range of tasks (Herlambang et al., 2021; Marcora et al., 2009), and may result in  
53 safety issues like increased likelihood of traffic accidents (Ting et al., 2008). Theoretical approaches  
54 highlight the roles of cognitive resource depletion (Craig & Klein, 2019; Gergelyfi et al., 2015) and  
55 motivation (Herlambang et al., 2019) in determining the experience of mental fatigue. Hockey's  
56 (2013) Motivational Control Theory (MCT) proposes that fatigue is an adaptive emotional response to  
57 conflict that arises in everyday life due to competing demands and priorities. In other words, we  
58 experience fatigue as an evolutionarily adaptive response to signal that a particular task or goal is no  
59 longer worth the investment of cognitive effort.

60           Interest in the mental fatigue that arises from effortful speech understanding has increased  
61 rapidly in recent years, with recent evidence revealing associations between hearing loss and fatigue  
62 (Alhanbali et al., 2017; Davis et al., 2020; Holman et al., 2019; Hornsby & Kipp, 2016).  
63 Understanding speech, even for normal-hearing listeners, can tax cognitive resources due to the  
64 presence of background noise and other forms of distraction during everyday communication (Mattys  
65 et al., 2012). While the link between repeated episodes of effortful listening and longer-term fatigue  
66 makes intuitive sense (McGarrigle et al., 2014), the relationship between perceived effort and fatigue  
67 appears more complex than originally conceived (Herrmann & Johnsrude, 2020; McGarrigle &  
68 Mattys, 2023; Pichora-Fuller et al., 2016). In particular, fatigue may accumulate independently of  
69 perceived effort (McGarrigle, Rakusen, et al., 2021), or vice versa (Alhanbali et al., 2023). While  
70 perceived effort is often seen as a proxy for performance estimation (Moore & Picou, 2018), fatigue is  
71 determined at least partly by one's affective state (van der Linden et al., 2003). Indeed, in the context

72 of speech perception, heightened daily life experiences of listening-related fatigue have been shown to  
73 be associated with an individual's level of mood disturbance (McGarrigle, Knight, et al., 2021).

74         The Framework for Understanding Effortful Listening (FUEL) proposes that listening-related  
75 effort and fatigue may be influenced by one's state of motivational arousal (Pichora-Fuller et al.,  
76 2016). Studies to date have generally focused on the effects of reward-based motivation on perceived  
77 (i.e., self-reported), behavioural, and/or physiological measures of effort allocated (Carolan et al.,  
78 2021; Koelewijn et al., 2018; Richter, 2016). These studies have revealed mixed findings. Koelewijn  
79 et al. (2018) examined the effect of monetary reward (high/low) on the task-evoked pupil response (a  
80 physiological marker of cognitive effort) and self-reported indices of effortful listening in normal-  
81 hearing young adults. As predicted, the task-evoked pupil response was larger (indicating increased  
82 resource allocation) in the high than low reward condition. However, there was no effect of reward on  
83 perceived effort. Carolan et al. (2021) also manipulated reward amount in a sample of young normal-  
84 hearing adults. In their study, however, effort ratings were higher when the monetary reward was  
85 higher, suggesting that the additional monetary incentive translated into an increase in perceived  
86 effort.

87         Current evidence suggests that mental fatigue may be sensitive to motivational factors  
88 (Herlambang et al., 2019; Hopstaken et al., 2015). Hopstaken et al. (2015) provided a monetary bonus  
89 for accurate working-memory task performance in the final block of their experiment to measure the  
90 extent to which a reward incentive could curb the accumulation of mental fatigue. They found that  
91 mean fatigue ratings did indeed decrease in the final block, reflecting some recovery from mental  
92 fatigue. However, as the monetary incentive was provided in the final experimental block only, the  
93 time course of reward effects on perceived fatigue remains unclear. To our knowledge, no studies  
94 have monitored the effect of reward on perceived effort and fatigue over the course of a listening task  
95 to examine whether reward-based motivation leads to a transient or sustained change in the subjective  
96 experiences of effort and fatigue. Figure 1 illustrates two potential hypothetical scenarios in relation to  
97 fatigue.

98 Finally, the studies described above also failed to include an independent measure of current  
99 mood state to explore the potential role of emotional processes in modulating perceived effort and  
100 fatigue as a function of reward-based motivation. As well as the aforementioned link between mental  
101 fatigue and mood (van der Linden et al., 2003), the extent to which an individual experiences a task as  
102 subjectively pleasurable has been invoked in FUEL as a factor that may also moderate effortful  
103 listening and fatigue (Matthen, 2016; Pichora-Fuller et al., 2016). In other words, listening activities  
104 perceived as more rewarding might elicit a more positive mood state (e.g., a sense of contentment  
105 from an engaging dialogue) which could in-turn diminish the onset of fatigue. In the current study, we  
106 aimed to examine associations between perceived effort, mood, and fatigue over time during an  
107 effortful listening task in the presence (versus absence) of a monetary reward incentive. We  
108 administered a dichotic listening task to simulate a listening scenario with significant cognitive  
109 demands, but one in which listening performance would depend critically on the allocation of  
110 processing resources (Knight et al., 2023). We hypothesised that:

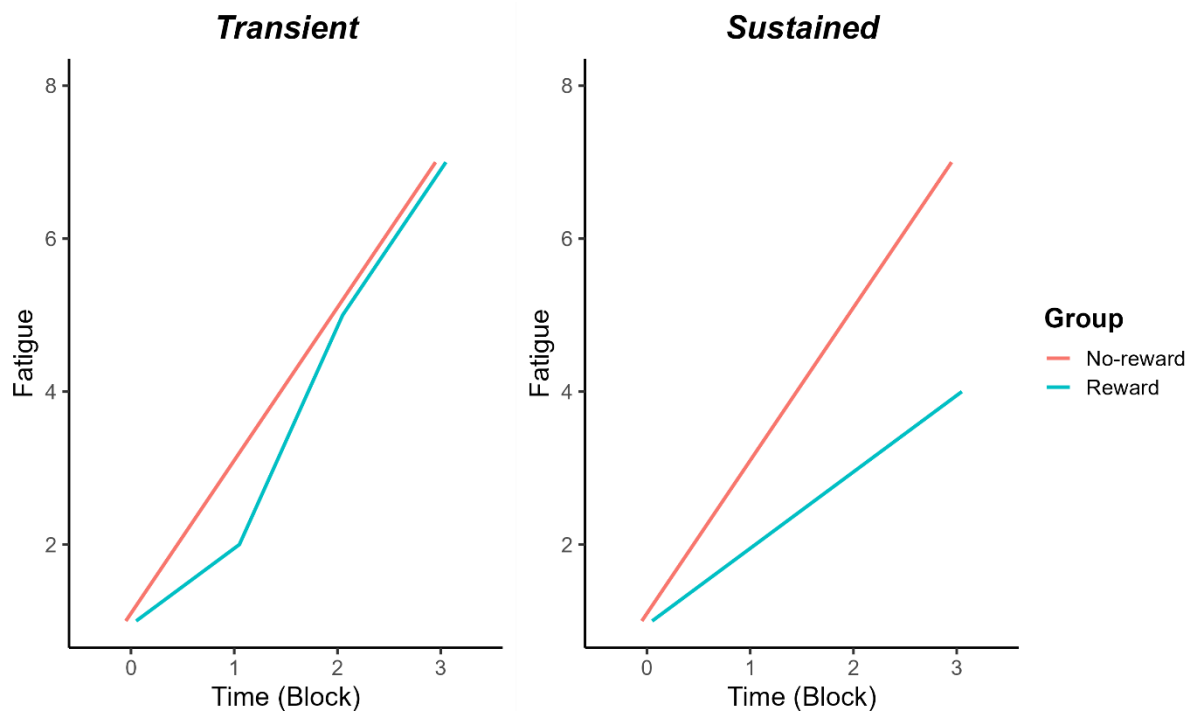
111 H1: Fatigue ratings in the reward group will be lower overall than fatigue ratings in the no-reward  
112 group (Hockey, 2013), with no difference in effort ratings between groups (Koelewijn et al., 2018).

113 H2: Fatigue ratings will show a steeper linear increase in the no-reward group than the reward group,  
114 reflecting a sustained (rather than transient) inhibition of fatigue over time owing to continuous  
115 reward-based motivation (see Figure 1).

116 H3. Effort ratings will show either a transient effect of reward (i.e., reduced effort after block 1 only)  
117 or no effect of reward on change over time (Koelewijn et al., 2018).

118 H4. The effect of reward on perceived fatigue will be mediated by mood ratings; mood ratings will be  
119 overall more positive in the reward than the no-reward group, which will be associated with lower  
120 fatigue ratings (Matthen, 2016; van der Linden et al., 2003).

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123 Figure 1. Hypothetical data supporting either a transient (left panel) or sustained (right panel) effect of  
 124 Group (i.e., reward) on perceived fatigue from listening. Note, Block ‘0’ represents baseline fatigue  
 125 rating. The divergent fatigue scores at time-point 1 in the ‘Transient’ panel reflect the hypothesised  
 126 time frame in which fatigue might show a relative (transient) reduction in the ‘Reward’ group before  
 127 re-converging with the ‘No-reward’ group at time-point 2.

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### Method

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131 Hypotheses, methodological plans, and analytic plans for this study were pre-registered

132 (<https://osf.io/cvehd/registrations>). Experiment stimuli, analysis scripts, raw data, and summary data

133 can be found on our Open Science Framework (OSF) project homepage (<https://osf.io/cvehd/>). The

134 experiment procedure and materials can also be previewed on Gorilla Open Materials

135

136 **Participants**

137 We recruited a total of 200 participants (60 male), aged 18-30 years ( $M = 23.39$ ,  $SD = 3.76$ ).  
138 Schoemann et al.'s (2017) 'mc\_power\_med' app was used to calculate sample size requirements for a  
139 basic mediation analysis of the hypothesised indirect effect of group (i.e., reward) on fatigue via  
140 perceived mood. Figure 2 illustrates the conceptual model tested in the analysis. To calculate sample  
141 size requirements, we hypothesised a standardised coefficient of .25 (small-medium effect size) for  
142 both the effect of Group on mood rating (pathway  $a$ ) and the effect of mood rating on fatigue rating  
143 (pathway  $b$ ), and a standardised coefficient of .1 (small effect size) for the direct effect of Group on  
144 fatigue rating (pathway  $c'$ )<sup>1</sup>. Using a random seed of 270488, 1000 power analysis replications, and  
145 20000 Monte Carlo draws per replication, and confidence level of 95%, we calculated that a total  
146 sample size of 162 (81 per group) would provide the desired statistical power of .80 at  $\alpha = 0.05$  to  
147 detect the indirect effect of interest (pathway  $ab$ ). To allow for attrition (given the large number of  
148 screening criteria), we recruited 200 participants in total (100 per group).

149 All participants were recruited via the online recruitment platform Prolific (prolific.co) and  
150 financially compensated for their time at a standard rate of £6.50 p/h. We applied the following initial  
151 eligibility criteria on Prolific, based on self-reports: (1) Based in UK and Ireland, (2) age between 18  
152 and 31 years, (2) English as a first language, (3) normal or corrected-to-normal visual acuity, (4) no  
153 known language-related disorders, (5) no diagnoses of mild cognitive impairment or dementia, (6) a  
154 minimum Prolific approval rating of at least 95%. A total of 200 participants met the initial screening  
155 criteria on Prolific (100 in each condition). After data collection, participants were excluded if they  
156 responded 'yes' to any of the screening questions administered at the end of the experiment (details  
157 below in 'general procedure' section). In total, 15 participants were excluded from the analyses due to  
158 being flagged on at least one of the screening checks. In the reward group ( $n = 9$ ), two reported  
159 currently suffering from a chronic condition that can cause fatigue; six reported currently taking  
160 medication that can cause fatigue; and one reported a hearing loss. In the no-reward group ( $n = 6$ ), one

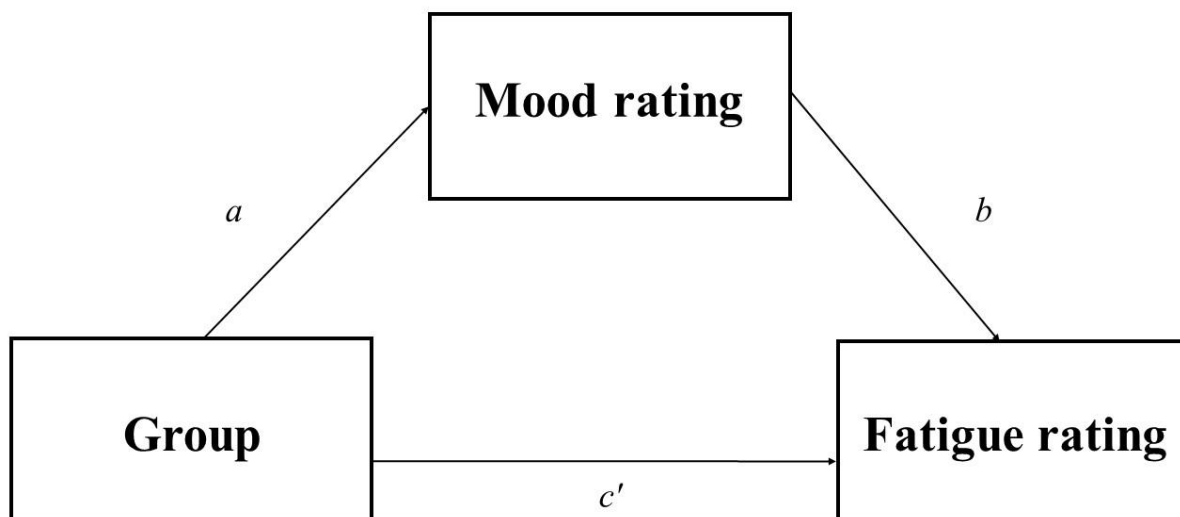
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<sup>1</sup> Note that the apostrophe ( $c'$ ) denotes the fact that this path represents the effect of X (Group) on Y (Fatigue) whilst controlling for M (Mood), as opposed to the total effect which is commonly represented without an apostrophe and includes the indirect effect.

161 reported currently suffering from a chronic condition that can cause fatigue, and all six reported  
 162 currently taking medication that can cause fatigue.

163 All remaining participants scored above chance (i.e., > 50%) on the dichotic listening task and  
 164 were therefore retained in the analyses. A total of 185 participants were entered into the analyses: 94  
 165 in the no-reward group, and 91 in the reward group. Table 1 shows the demographic breakdown of  
 166 each group. This study was granted ethical approval by the departmental research ethics committee at  
 167 the University of York (ID: 733, year: 2020).

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170 Figure 2. Schematic representing the variables entered into the mediation analysis. Group (no-reward,  
 171 reward) was entered as the categorical predictor variable, mood rating (BMIS score) as the mediator  
 172 variable, and fatigue rating (BFI score) as the dependent variable.

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174 Table 1. Demographic information for participants included in the analyses.

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Group

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	<i>No-Reward</i>	<i>Reward</i>
<i>N</i>	94	91
Age in years ( <i>M, SD</i> )	23.61 (3.67)	23.08 (3.75)
Sex (Male/Female)	33/61	23/68
Study completion time in minutes ( <i>M, SD</i> )	24.45 (10.62)	24.73 (7.90)

175 Note: Study completion time reflects the time taken from when participants began the study to when  
 176 they returned their completion on Prolific.

177

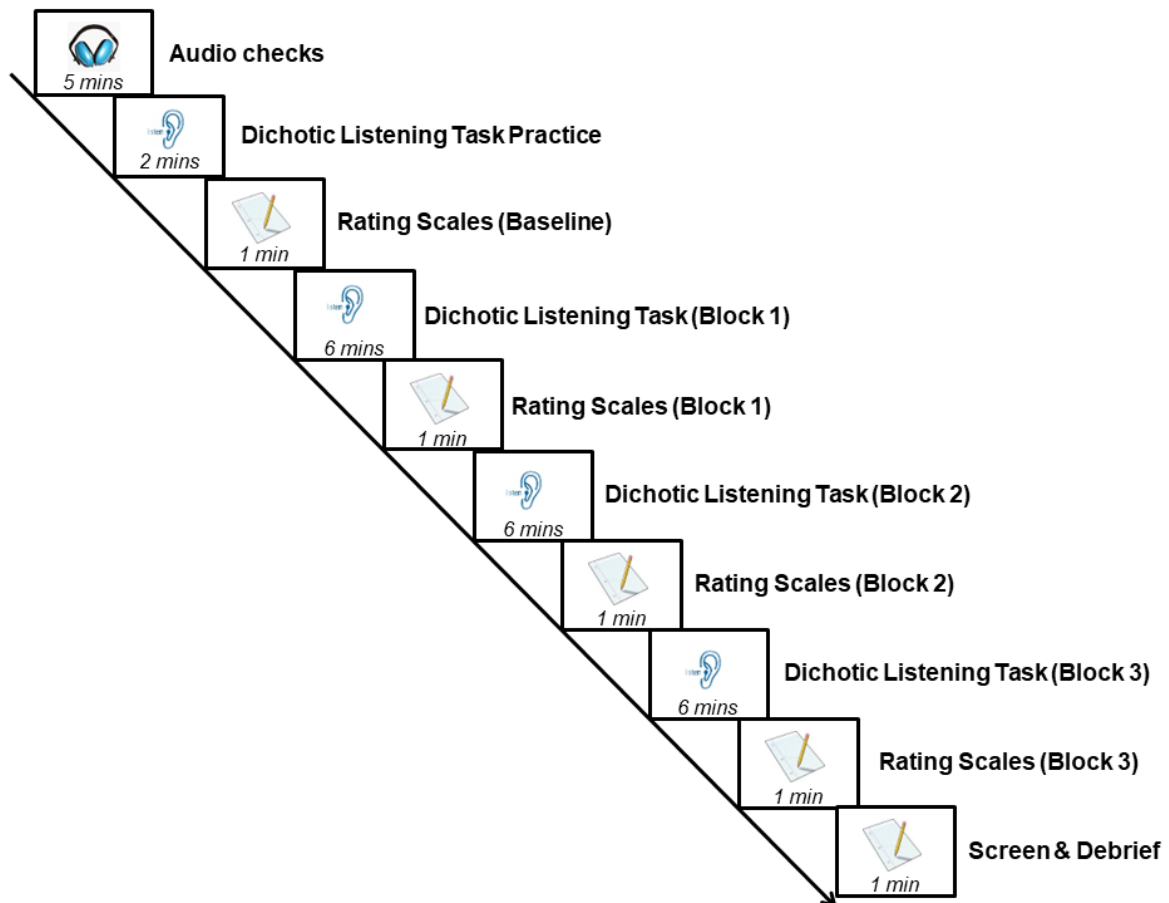
## 178 **General Procedure**

179 We used Gorilla Experiment Builder ([www.gorilla.sc](http://www.gorilla.sc); Anwyl-Irvine et al., 2020) to design  
 180 and host all tasks and rating scales in the main experiment. Participants were recruited on Prolific and  
 181 directed to Gorilla using the experiment link. On Prolific, participants were instructed to only take  
 182 part in the experiment if they: (1) had access to a set of headphones or earbuds, (2) could complete the  
 183 study on a laptop or desktop computer, and (3) did not suffer from a known hearing loss in either ear,  
 184 (4) did not suffer from a chronic condition known to cause fatigue (e.g., CFS), (5) were not currently  
 185 taking medication known to cause fatigue, (6) had not consumed abnormal amounts of a highly-  
 186 caffeinated substance (e.g., coffee) in the last four hours, and (7) had a normal night's sleep (e.g., > 6  
 187 hours) in the previous night. Participants in both groups completed a series of audio checks before  
 188 starting the main experiment. First, participants were given the opportunity to play one of the audio  
 189 stimuli used in the dichotic listening task of the main experiment and adjust the volume to an audible  
 190 and comfortable level. They then performed a validated headphone check that involved identifying  
 191 the quietest of three sounds. Importantly, this task can only be performed accurately with the use of  
 192 stereo headphones (see Woods et al., 2017, for more details). To progress to the experiment,  
 193 participants were required to accurately identify the quietest sound on at least 5 of the 6 trials  
 194 presented. To allow for potential misunderstanding of the instructions, participants who accurately  
 195 identified fewer than 5 trials on the first attempt were given a second opportunity to pass the test.  
 196 Finally, participants completed a brief 'autoplay' check to ensure that their browsers would permit the

197 playback of auditory stimuli during the dichotic listening task. Audio checks lasted approximately 5  
198 minutes in total.

199           Following successful completion of the audio checks, participants were given instructions and  
200 practiced the dichotic listening task. The dichotic listening task practice session consisted of four  
201 trials. They then completed each of the three rating scales: perceived effort, mood, and fatigue (details  
202 about each scale provided below) in that order. After completing the rating scales, participants  
203 performed block 1 of the dichotic listening task, consisting of 60 trials and lasting approximately 6  
204 minutes. After completing block 1, participants once again filled out the three rating scales. This  
205 sequence was then repeated for blocks 2 and 3 of the dichotic listening task. As an additional  
206 screening check after completing block 3 of the dichotic listening task, participants were asked the  
207 following five (verbatim) questions, each of which involved a binary (yes/no) response option: (1) do  
208 you currently suffer from a chronic health condition that can cause fatigue (e.g., CFS, cancer,  
209 diabetes), (2) do you regularly take any medication that can cause fatigue (e.g., antihistamines)? (3)  
210 Do you have a known hearing loss in either or both ears and/or regularly use a hearing device (e.g.,  
211 hearing aid or cochlear implant)? (4) Have you consumed a highly-caffeinated substance (e.g., coffee)  
212 in the last four hours? and (5) Did you have a good night's sleep (e.g., > 6 hours) last night?  
213 Participants who responded yes to any of questions 1-3 were removed from the analyses (details  
214 below in 'analyses'). As potential confounds, responses to questions 4 & 5 were included as  
215 covariates in the analyses. Finally, participants were debriefed about the study. The experimental  
216 sequence is illustrated in Figure 3.

217



218

219 Figure 3. Schematic outline of the study procedure with time estimates for each component. Rating  
 220 scales included questionnaires measuring perceived effort, mood, and fatigue. Each dichotic listening  
 221 task block comprised 60 trials.

222

223 Participants in both the no-reward and the reward groups completed the same experimental  
 224 sequence as outlined in Figure 3, with the following exceptions. Participants in the reward group were  
 225 given the following instructions before performing the dichotic listening task practice: *‘Before we find  
 226 out about the listening task, please note that you have an opportunity to gain an additional monetary  
 227 reward based on your performance accuracy and speed on the listening task. Specifically, for every  
 228 trial that you perform correctly and in < 2 seconds during the main experiment (i.e., after the  
 229 practice), you will receive an additional £0.02 on top of your participation payment. As there are 180  
 230 trials in total, this means you can earn an additional reward of up to £3.60!’* Participants in the no-  
 231 reward group simply received the message *‘1<sup>st</sup>/2<sup>nd</sup>/3<sup>rd</sup> Listening Task complete!’* upon completion of

232 each listening block. Participants in the reward group were provided with the following additional  
233 information after completing each dichotic listening task block: ‘*Well done! So far, you have earned*  
234 *an additional £\*\**’ with the cumulative amount calculated and revealed based on the number of trials  
235 responded to correctly in < 2 seconds thus far. Total additional performance-based earnings were  
236 given to participants as a bonus payment by the researcher after study completion. The average bonus  
237 payment awarded to the participants in the analyses was £3.05 ( $SD = £0.42$ ).

238 Participants in both conditions took part in the study between the hours of 08:53am –  
239 12:07pm within a three-day testing window. Participants could only take part in the no-reward  
240 experiment if they hadn’t already taken part in the reward experiment, and vice versa. In total, the  
241 experiment lasted approximately 30 minutes.

242

#### 243 **Stimuli and individual task procedures**

244 **Dichotic listening task.** We used the dichotic listening task developed by Koch et al. (2011)  
245 and adapted for use on the Gorilla online platform. For this task, participants heard two digits  
246 simultaneously; one in the right ear and one in the left ear. One of the voices was a male voice and the  
247 other was a female voice. At the beginning of each trial, a visual text prompt displayed the word  
248 ‘Male’ or ‘Female’ (presented centrally on the screen) indicating which voice participants should  
249 attend to for that particular trial. The visual prompt remained on-screen for two seconds. Immediately  
250 after the visual prompt disappeared, the two spoken digits were presented over the headphones.  
251 Following presentation of the spoken digits, participants were asked to indicate whether the digit  
252 spoken by the attended voice was above or below five. ‘Below 5’ responses were given by pressing  
253 ‘f’ with the left index finger and ‘above 5’ responses were given by pressing ‘j’ with the right index  
254 finger. Participants were given visual prompts for these two response options on the left (press ‘f’)  
255 and right (press ‘j’) side of the screen. Presentation of the visual prompts was synchronized with the  
256 onset of the spoken digits. Participants were asked to respond as quickly and accurately as possible,  
257 and were given four practice trials to familiarize themselves with the task.

258 All dichotic spoken digits were edited in Audacity to include matching silent onsets lasting  
259 200 ms. Audio files for digits 1-9 (excluding 5) were created using a free online text-to-speech mp3  
260 creator ([www.ttsmp3.com](http://www.ttsmp3.com)). Mp3 files were created in both a male and a female voice. Of the default  
261 options on the website, we used the British male voice 'Brian' and British female voice 'Emma'. Each  
262 audio file had a sampling rate of 48 kHz. These files were then combined in Audacity to create stereo  
263 dichotic stimuli. Participants performed 180 experimental trials in total; 60 trials in each of three  
264 listening blocks. Within each block, an equal number (30) of 'female' and 'male' prompts were  
265 administered. Of the 30 'female' and 30 'male' prompt trials in each block, half (i.e., 15/30) were  
266 'congruent' trials, in which both spoken digits were either above or below 5. The other half were  
267 'incongruent', in which one digit was above 5 and the other below 5. The same digits were never  
268 presented together in a given trial. The number of 'above 5' and 'below 5' correct response trials were  
269 balanced (i.e., 30 each) within each block. The lateral position of the female and male voice was also  
270 counterbalanced within each block (i.e., the female voice was presented to the left ear on 30 trials, and  
271 vice versa). The order of stimuli presentation was fully randomized within each block.

272 **Perceived effort rating.** Perceived effort ratings were collected based on an adapted version  
273 of the NASA task load index item assessing mental demand (Hart & Staveland, 1988), a commonly  
274 used subjective measure of effort (Dimitrijevic et al., 2019; McGarrigle & Mattys, 2023; Pals et al.,  
275 2019; Peng & Wang, 2019; Strand et al., 2018). Specifically, we asked '*How hard did you have to*  
276 *work to accomplish your level of performance (speed AND accuracy) in the listening task?*  
277 (*EFFORT*)' (100-step scale from Very low effort—Very high effort). Participants provided responses  
278 using an on-screen slider bar with values ranging from 0 to 100 in increments of 1. A circular icon  
279 was positioned on the midpoint of the scale (50) to begin with and participants adjusted the icon using  
280 a mouse, with verbal anchors positioned at each endpoint of the slider scale. A "Next" box was  
281 positioned at the bottom of the screen which participants clicked on to advance to the next stage of the  
282 experiment.

283 **Perceived mood rating.** The Brief Mood Introspection Scale (BMIS) was used to collect  
284 perceived mood ratings (Mayer & Gaschke, 1988). In the BMIS, participants are provided with a list

285 of 16 adjectives (e.g., *lively*, *sad*, *gloomy*) and asked to circle one of 4 categorical response  
286 options ranging from *definitely do not feel* (coded as '1') to *definitely feel* (coded as '4') to indicate  
287 how well each adjective describes their present mood. A "Next" box was positioned at the bottom of  
288 the screen which participants clicked on to advance to the next stage of the experiment.

289 **Perceived fatigue rating.** Perceived fatigue ratings were collected using an item from the  
290 Brief Fatigue Inventory scale (Mendoza et al., 1999), an instrument used to quickly assess fatigue  
291 severity. Specifically, participants were asked to *Please rate your fatigue (weariness, tiredness) by*  
292 *selecting the one number that best describes your fatigue right NOW*. This question was chosen  
293 because it assessed fatigue 'right now', whereas the other items on the scale assessed fatigue over a  
294 24-hour period and would therefore not be suitable for measuring acute changes over time during a  
295 listening task. Participants provided responses using an on-screen slider bar with values ranging from  
296 0 to 10 in increments of 1. A circular icon was positioned on the midpoint of the scale (5) to begin  
297 with and participants adjusted the icon using a mouse, with verbal anchors (*No Fatigue – As bad as*  
298 *you can imagine*) positioned at each endpoint of the slider scale.

299

## 300 **Analysis**

301 **Dichotic listening task data pre-processing.** Individual trial response times (RTs) in the  
302 dichotic listening task that exceeded 3 SDs below or above the mean RT for each participant were  
303 removed from the dataset. This resulted in the removal of 284 trials in the no-reward group (1.7% of  
304 responses) and 262 trials in the reward group (1.6% of responses). The highest number of trials  
305 removed for a single participant was 7/180 (3.9%). To limit the influence of trials for which there may  
306 have been lapses in concentration or misperceptions, RTs were analysed for correct responses only.  
307 Given the generally high level of performance across both groups (> 90%), only 7% of the remaining  
308 trials were removed from the RT analysis due to incorrect responses.

309 **Ratings scales.** Scores on the NASA perceived effort scale ranged from 0-100, with higher  
310 scores reflecting increased perceived effort. Total scores on the BMIS perceived mood scale ranged

311 from 16-64, with higher scores reflecting more pleasant perceived mood ratings. Of the 16 items on  
312 the BMIS scale, 8 were negative/unpleasant items (e.g., ‘gloomy’, ‘grouchy’) and were therefore  
313 recoded to ensure that higher total scores reflected more pleasant mood ratings. Scores on the BFI  
314 perceived fatigue scale ranged from 0-10, with higher scores reflecting increased perceived fatigue.  
315 For all three rating scales, mean scores were calculated as a function of Group (no-reward, reward)  
316 and Block (0, 1, 2, 3) with block level ‘0’ reflecting the baseline rating collected immediately after the  
317 practice trials.

318 **Mixed effects models.** we used the ‘lme4’ package (Bates et al., 2015) in R Studio (R version  
319 4.2.3; R Development Core Team, 2023) to examine the effects of Group (no-reward, reward) and  
320 Block (0, 1, 2, 3) on each outcome variable: (1) Dichotic listening performance accuracy, (2) Dichotic  
321 listening RT, (3) Effort rating, (4) Mood rating, and (5) Fatigue rating. Plots were created using the  
322 ‘ggplot2’ package (Wickham, 2016). Performance accuracy on the dichotic listening task was coded  
323 as a binary outcome variable (1 = correct, 0 = incorrect). A Generalised Linear Mixed-effects Model  
324 (GLMM) was therefore used for analysis of the accuracy data. A binomial response distribution was  
325 specified in the GLMM with a ‘logit’ link function. RTs and responses to each of the three rating  
326 scales (effort, mood, and fatigue) were analysed using four separate Linear Mixed-effects models  
327 (LMMs). For all of the above analyses, the between-subjects categorical variable Group (reward, no-  
328 reward) was modelled as a fixed effect. Binary responses (0 = no, 1 = yes) to the ‘caffeine’ screening  
329 question (*‘Have you consumed a highly caffeinated substance (e.g., coffee) in the last four hours?’*)  
330 and ‘sleep’ screening question (*‘Did you have a good night’s sleep (e.g., > 6 hours) last night?’*) were  
331 included as covariates in each model.

332 The within-subjects continuous variable Block was also included in each model as a fixed  
333 effect. While the models for dichotic listening data (accuracy and RT) included Block with three  
334 levels (1, 2, 3), the models for analysis of the rating scales data (effort, mood, and fatigue) included an  
335 additional level to account for the baseline rating score. Thus, in the rating models, Block was coded  
336 with four levels (1, 2, 3, 4) with ‘1’ representing the baseline score. By-subject intercepts and Block  
337 slopes were included as random effects in each model to account for inter-individual variance in both

338 the overall score (intercept) and change over time (Block slope) for each outcome variable. To  
339 account for by-item variance in the dichotic listening (accuracy, RT) models, we included an intercept  
340 term for the individual items (i.e., auditory stimuli)<sup>2</sup>.

341 Likelihood ratio tests (LRTs) were conducted to determine whether the fixed effects and  
342 interactions contributed significantly to the model. To conduct these tests, we used the ‘mixed’  
343 function from the ‘afex’ package (Singmann et al., 2023), which converts variables in the model from  
344 default dummy coding (0, 1) to sum-coding (-1, 1). Fixed effects in the model can therefore be  
345 interpreted as main effects (i.e., the effect of one variable holding other variables constant), rather  
346 than simple effects (i.e., the effect of one variable but only on a specific level of another variable). R  
347 syntax for each final model can be found on our OSF project page (<https://osf.io/cvehd/>).

348 **Mediation Analysis.** Mediation analysis was conducted to test our hypothesis regarding the  
349 indirect effect of Group on Fatigue via Mood. This analysis was conducted using the PROCESS  
350 (Hayes, 2017) macro on SPSS v25. We entered Group as the categorical predictor variable, mood  
351 rating as the mediator variable, and fatigue rating as the outcome variable. Figure 2 illustrates the  
352 conceptual model tested in the analysis. As with the mixed effects model analyses, binary responses to  
353 the ‘caffeine’ and ‘sleep’ screening questions were included as covariates. Baseline mood and fatigue  
354 ratings were also entered into the model as covariates to control for the effect of baseline differences  
355 in mood and fatigue ratings. Confidence intervals were derived from 5000 bootstrap samples using a  
356 random seed generator of 270488. Following the recommendations of Hayes (2017), direct and  
357 indirect effects were deemed statistically significant if both bootstrap confidence intervals were either  
358 entirely above or below zero.

359

360

## Results

361 **Dichotic listening task performance accuracy and response time**

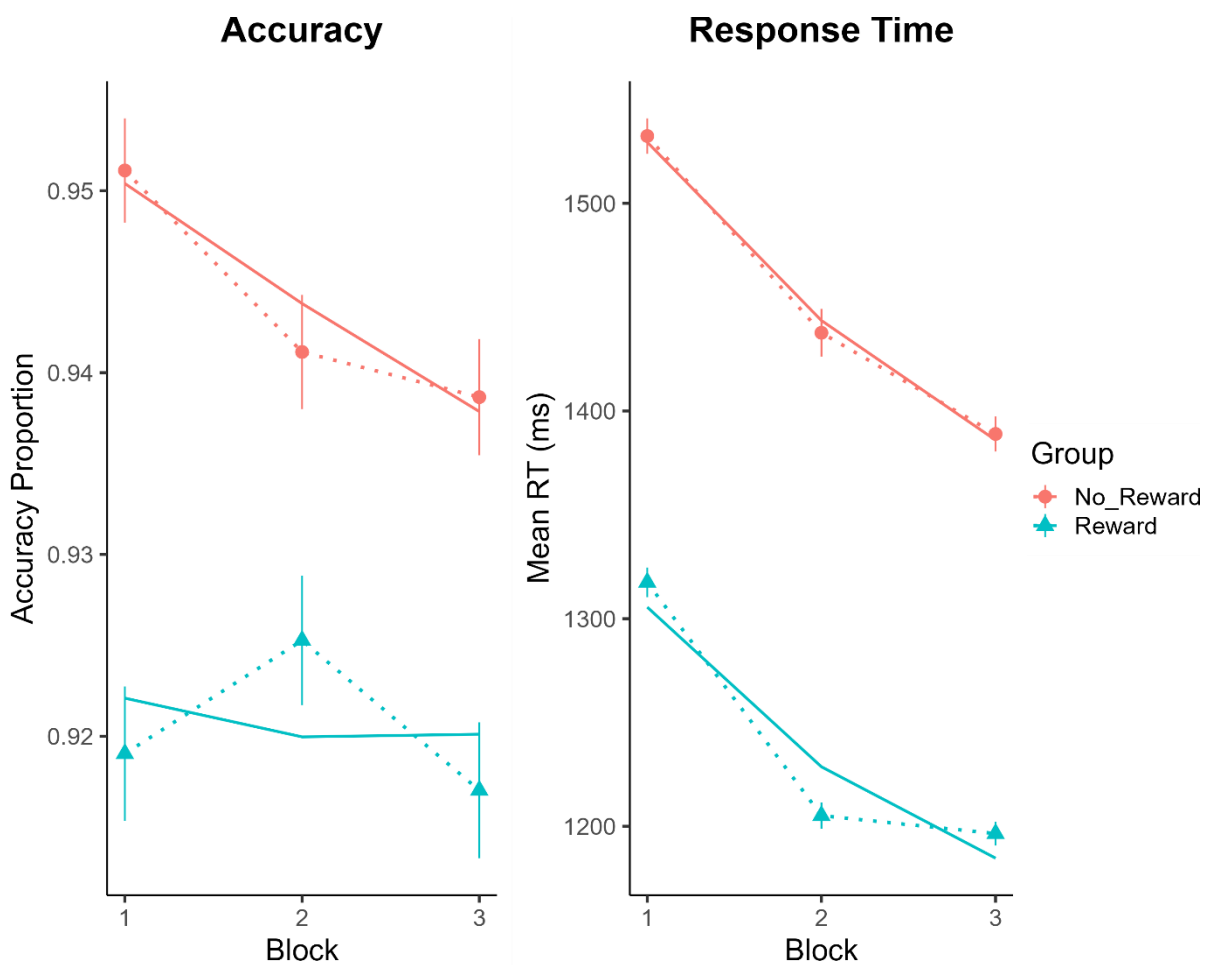
---

<sup>2</sup> As rating scale responses were not made to specific items/stimuli, by-item random effects were not included in the rating scale LMMs.

362 Figure 4 displays the mean dichotic listening task performance accuracy and RT as a function  
 363 of Group and Block. GLMM analyses revealed that there was a significant effect of Group on  
 364 accuracy ( $\chi^2(1, N = 185) = 8.04, p = .005$ ), with better performance in the no-reward than the reward  
 365 group. There was no effect of Block ( $\chi^2(1, N = 185) = 0.87, p = .35$ ) nor any interaction between  
 366 Group and Block ( $\chi^2(1, N = 185) = 1.07, p = .30$ ) on accuracy.

367 LMM analyses revealed a significant main effect of Group on RTs ( $\chi^2(1, N = 185) = 19.24, p$   
 368  $< .001$ ), with slower RTs in the no-reward than reward group. There was also a significant effect of  
 369 Block ( $\chi^2(1, N = 185) = 45.00, p < .001$ ) with RTs becoming faster as the experiment progressed.  
 370 There was no significant interaction between Group and Block ( $\chi^2(1, N = 185) = 0.71, p = .40$ ).

371



372

373 Figure 4. Mean proportion correct (left panel) and RT (right panel) with  $\pm$  SE bars on the dichotic  
374 listening task as a function of Block (1-3) and Group (no-reward, reward). Overlaid solid lines  
375 illustrate the GLM (accuracy) and LMM (RT) model fits to the data.

376

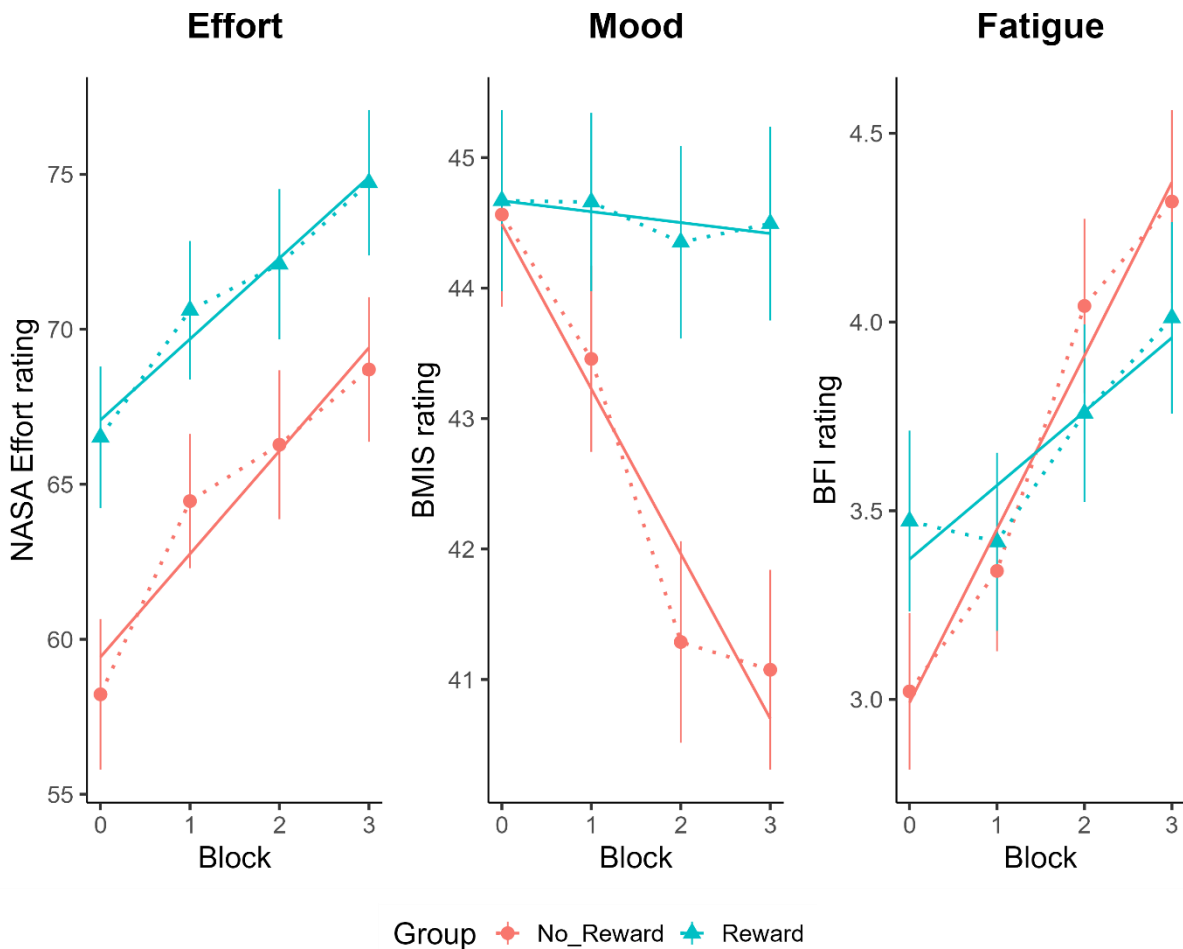
### 377 **Perceived effort, mood, and fatigue ratings**

378 Figure 5 displays the mean perceived effort, mood, and fatigue ratings as a function of Group  
379 and Block. We found a significant effect of Group on perceived effort ( $\chi^2(1, N = 185) = 5.35, p =$   
380  $.02$ ), with higher perceived effort in the reward compared to the no-reward group. There was also a  
381 significant effect of Block on perceived effort ( $\chi^2(1, N = 185) = 35.59, p < .001$ ) with effort ratings  
382 generally increasing as a function of time-on-task. There was no significant interaction between  
383 Group and Block ( $\chi^2(1, N = 185) = 0.57, p = .45$ ).

384 We found no significant effect of Group on mood ratings ( $\chi^2(1, N = 185) = 1.42, p = .23$ ).  
385 There was, however, a significant main effect of Block ( $\chi^2(1, N = 185) = 27.11, p < .001$ ) and a  
386 significant interaction between Group and Block ( $\chi^2(1, N = 185) = 21.15, p < .001$ ). While mood  
387 ratings generally plateaued for participants in the reward group, there was a more pronounced linear  
388 decrease in mood ratings as a function of time-on-task for participants in the no reward group.

389 We found significant effects of Group and Block on fatigue ratings ( $\chi^2(1, N = 185) = 4.56, p$   
390  $= .03$ ;  $\chi^2(1, N = 185) = 44.32, p < .001$ , respectively). There was also a significant interaction  
391 between Group and Block ( $\chi^2(1, N = 185) = 7.96, p = .005$ ). While participants in both the reward  
392 and no reward groups showed a general increase in fatigue as a function of time-on-task, this increase  
393 was relatively steeper in the no reward versus the reward group.

394



395

396 Figure 5. Mean ratings for perceived effort (left panel), mood (middle panel) and fatigue (right panel)  
 397 with  $\pm$  SE bars as a function of Block and Group. Block '0' represents the mean baseline rating score  
 398 provided immediately after the practice trials. Overlaid solid lines illustrate the LMM model fits to the  
 399 data. BMIS = Brief Mood Introspection Scale. BFI = Brief Fatigue Inventory. NASA Effort ratings  
 400 range from 0 to 100, with higher scores reflecting increased perceived effort. BMIS ratings range  
 401 from 16 to 64, with higher scores reflecting a more pleasant perceived mood state. Finally, BFI ratings  
 402 range from 0 to 10, with higher scores reflecting increased perceived fatigue.

403

#### 404 Mediation analysis

405 Table 2 shows the correlations between all five variables when scores are collapsed across the  
 406 three experimental blocks. We conducted a mediation analysis to examine the hypothesis that  
 407 perceived mood would mediate the effect of Group on perceived fatigue ratings (cf. Figure 2). We

408 found an indirect effect of group on perceived fatigue via perceived mood. Specifically, participants  
 409 in the no-reward group were significantly more likely to report lower (i.e., more unpleasant) mood  
 410 ratings overall ( $a = -2.49, p < .001$ ), and individuals who provided lower mood ratings were more  
 411 likely to also provide higher perceived fatigue ratings ( $b = -0.12, p < .001$ ). Bootstrap confidence  
 412 intervals for the indirect effect ( $ab = 0.30$ ) were entirely above zero (0.16 to 0.47). There was no  
 413 significant direct effect of Group on perceived fatigue rating as the bootstrap confidence intervals  
 414 straddled zero ( $c' = 0.19$ , bootstrap CIs: -0.14 to 0.53).

415

416 Table 2. Correlation coefficients between all variables.

	Effort	Mood	Fatigue	DL_Accuracy	DL_RT
Effort	.				
Mood	-.17*	.			
Fatigue	.16*	-.52**	.		
DL_Accuracy	.13	-.008	-.005	.	
DL_RT	.09	-.15*	.02	-.18*	.

417 \*  $p < .05$ . \*\*  $p < .01$ . DL\_Accuracy = % correct on dichotic listening task. DL\_RT = Mean correct  
 418 response RT on dichotic listening task.

419

#### 420 **Exploratory mediation analysis**

421 We conducted an additional mediation analysis to examine the alternative hypothesis that  
 422 reward impacted perceived fatigue which in turn altered mood ratings. Fatigue ratings were this time  
 423 entered as the ‘mediator’ variable and mood ratings as the ‘outcome’ variable. All other aspects of the  
 424 analysis were identical to the original mediation model. This analysis revealed an indirect effect of  
 425 reward group on mood ratings via perceived fatigue ( $ab = -0.59$ , bootstrap CIs: -1.00 to -0.21).  
 426 Participants in the no-reward group were significantly more likely to report higher fatigue ratings  
 427 overall ( $a = 0.50, p = .005$ ), and individuals who provided higher fatigue ratings were more likely to

428 provide lower (more unpleasant) mood ratings ( $b = -1.18, p < .001$ ). However, there was also a  
429 significant direct effect of group on mood rating ( $c' = -1.90$ , bootstrap CIs: -2.92 to -0.89).

430

431

### Discussion

432 The present study examined the effect of reward-based motivation on changes over time in  
433 perceived effort, mood, and fatigue. First, we hypothesised that fatigue ratings would be lower in the  
434 reward than the no-reward group reflecting reward-based inhibition of mental fatigue, but that there  
435 would be no overall differences between groups in perceived effort (H1). H1 was partially supported;  
436 overall perceived fatigue ratings were lower in the group who received a monetary incentive, but  
437 perceived effort was also higher in this group than in the no-reward group. Second, we predicted that  
438 fatigue ratings would show a sustained linear increase over time which would be more pronounced in  
439 the no-reward group (H2). We found support for this hypothesis, with results showing greater  
440 accumulation of mental fatigue in the unrewarded listening condition. On the other hand, we  
441 hypothesised that changes over time in effort would show either a transient effect of reward or no  
442 effect at all (H3). And indeed, while effort ratings did show an increase over time, this change did not  
443 interact with the absence/presence of monetary reward, supporting H3. Finally, we predicted that  
444 mood ratings would mediate the effect of reward on perceived fatigue (H4). Mediation analysis  
445 supported this hypothesis, demonstrating: (a) evidence for an indirect effect of reward on perceived  
446 fatigue via mood ratings, and (b) no evidence for a direct effect of reward on perceived fatigue when  
447 mood ratings were statistically controlled.

448 The current study provides novel evidence for a differential impact of reward-based  
449 motivation on perceived effort versus fatigue. Specifically, results highlight a scenario in which  
450 listening is perceived to be more effortful yet shielded from the onset of mental fatigue over time. The  
451 effect of reward on perceived fatigue became more pronounced as the task progressed, suggesting a  
452 gradual but more pronounced accumulation of fatigue during unrewarding listening challenges.  
453 Feedback at the end of each block on how much monetary reward had been accumulated may have

454 contributed to this sustained inhibition of perceived fatigue in the reward group. Previous research  
455 suggests that performance feedback may help to increase task engagement and motivation (Salmoni et  
456 al., 1984) and thus help to reduce mental fatigue (Herlambang et al., 2019). Higher overall perceived  
457 effort ratings in the ‘reward’ group supports previous literature showing that young adults are  
458 generally more willing to engage cognitive resources during listening if doing so can result in a  
459 monetary gain (McLaughlin, et al., 2021). The differential effects of reward-based motivation on  
460 perceived effort and fatigue are consistent with both FUEL (Pichora-Fuller et al., 2016) and MCT  
461 (Hockey, 2013) by illustrating that the experience of effort may not result in mental fatigue if the  
462 effort investment is deemed sufficiently valuable. Nonetheless, while both theoretical accounts  
463 highlight the role of motivation during effortful listening (FUEL) and mental fatigue (MCT),  
464 subjective perceptions of effort and fatigue are often described synonymously. The current study  
465 shows that perceived effort and fatigue are underpinned by different mechanisms.

466         Links between an individual’s current mood state and their propensity to experience mental  
467 fatigue have been demonstrated in previous research (Leavitt & DeLuca, 2010; McGarrigle, Knight,  
468 et al., 2021; van der Linden et al., 2003). However, the extent to which mood state may govern the  
469 effect of reward-based motivation on perceived fatigue from listening has not yet been the focus of  
470 systematic examination. The current study revealed an indirect effect of reward on perceived fatigue  
471 via mood ratings; individuals who completed the listening task with a monetary incentive indicated  
472 more pleasant mood ratings overall which, in turn, was associated with reductions in the experience of  
473 fatigue. Importantly, there was no direct effect of reward on perceived fatigue independent of mood  
474 ratings. This suggests that a mechanism by which reward-based motivation inhibits the onset of  
475 listening-related fatigue is by improving one’s mood state during task completion. Interestingly, while  
476 baseline mood ratings were similar in both the no-reward and the reward groups, perceived mood  
477 showed a clear progressive decline over time in the no-reward group, whereas monetary reward  
478 resulted in more stable (and pleasant) mood ratings over time in the reward group. These findings  
479 support the MCT (Hockey, 2013) characterization of mental fatigue as a fundamentally emotional  
480 response that instigates a cost-benefit analysis of goal pursuit. These findings also support Matthen’s

481 (2016) assertion that outcomes relating to effortful listening may vary according to how much  
482 pleasure or value is derived from the process of listening.

483         Although the listening task performance and RTs were not primary outcomes of interest in the  
484 current study, some discussion of these findings is warranted. Despite being instructed to prioritise  
485 both accuracy and speed (i.e., they could only earn bonus money for trials performed correctly AND  
486 in less than two seconds), the monetary incentive seems to have induced a speed-accuracy trade-off in  
487 the reward group; performance accuracy was significantly worse in this group but responses were  
488 significantly faster. One possibility is that, because performance accuracy was generally very high (>  
489 90%) in both groups, participants in the reward group felt that prioritising response speed over  
490 accuracy would be a more productive response strategy. Indeed, the literature suggests that  
491 individuals will often trade off in this manner if it serves to maximise reward benefit (Bogacz et al.,  
492 2010).

493         As mediation analysis is a correlational approach, determining the precise sequence of effects  
494 in the path model is not straightforward. In other words, while our analysis supports the interpretation  
495 that reward impacted mood ratings, which in turn impacted perceived fatigue, another interpretation is  
496 possible; that reward impacted perceived fatigue which in turn altered mood ratings. To statistically  
497 test for this alternative hypothesis, we conducted an additional exploratory mediation analysis, this  
498 time with fatigue ratings entered as the ‘mediator’ variable and mood ratings as the ‘outcome’  
499 variable. This analysis revealed an indirect effect of reward group on mood ratings via perceived  
500 fatigue. However, importantly, this time there was also a significant direct effect of group on mood  
501 rating. Therefore, participants in the reward group were significantly more likely to provide more  
502 pleasant mood ratings, irrespective of perceived fatigue. The strong evidence for a direct effect of  
503 reward on mood ratings, and the lack of a direct effect of reward on perceived fatigue independently  
504 of mood ratings, supports the hypothesised model in Figure 2 as the most plausible path sequence.

505         Mean fatigue scores did not exceed 5 (out of 10) in either group, even at the end of the final  
506 block of trials, suggesting that most participants did not reach their mental fatigue threshold by the  
507 end of the experiment. However, it is clear that mental fatigue was elicited to an extent that was

508 sufficient to reveal both differences as a function of monetary reward and meaningful changes over  
509 time. Examining the relationship between perceived effort, mood, and fatigue in situations where  
510 mental fatigue is more exacerbated may provide insight into the mechanisms that underlie more  
511 severe cases of fatigue (e.g., in individuals with a chronic illness). To simulate a challenging and  
512 effortful listening experience, we used a dichotic listening task in the current study. However, one  
513 limitation of this approach is that it involves responding to a closed-set sequence of digits only, thus  
514 limiting the extent to which the stimuli can resemble everyday listening experiences which typically  
515 involve more complex language operations. Use of more naturalistic stimuli in future research may  
516 help to shed light on the cognitive processes that underlie more routine experiences of effortful  
517 listening. Furthermore, rather than using monetary reward to increase motivation, varying the intrinsic  
518 value of cognitive engagement (e.g., by tailoring speech materials to match the interests of individual  
519 participants) might help to reveal the dynamic interplay between effort, mood, and fatigue during  
520 listening.

521

## 522 **Conclusions**

523 The current findings shed light on the complex relationships between motivation, effort,  
524 mood, and mental fatigue during listening. We report evidence for differential effects of reward-based  
525 motivation on perceived effort and fatigue ratings which highlight their distinct nature. We also  
526 provide novel evidence that changes to one's mood state represent a mechanism by which perceived  
527 fatigue may be inhibited (or elicited) during effortful listening which may be used to inform  
528 interventions for individuals who suffer from listening-related fatigue.

529

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533

534

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