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Research Article

Autonomic Nervous System Responses to Hearing-Related Demand and Evaluative Threat

Carol L. Mackersie[a] and Lucia Kearney[a]

Purpose: This paper consists of 2 parts. The purpose of Part 1 was to review the potential influence of internal (person-related) factors on listening effort. The purpose of Part 2 was to present, in support of Part 1, preliminary data illustrating the interactive effects of an external factor (task demand) and an internal factor (evaluative threat) on autonomic nervous system measures.
Method: For Part 1, we provided a brief narrative review of motivation and stress as modulators of listening effort. For Part 2, we described preliminary data from a study using a repeated-measures (2 × 2) design involving manipulations of task demand (high, low) and evaluative threat (high, low). The low-demand task consisted of repetition of sentences from a narrative. The high-demand task consisted of answering questions about the narrative, requiring both comprehension and recall. During the high evaluative threat condition, participants were filmed and told that their video recordings would be evaluated by a panel of experts. During the low evaluative threat condition, no filming occurred; participants were instructed to "do your best." Skin conductance (sympathetic nervous system activity) and heart rate variability (HRV, parasympathetic activity) were measured during the listening tasks. The HRV measure was the root mean square of successive differences of adjacent interbeat intervals. Twelve adults with hearing loss participated.
Results: Skin conductance increased and HRV decreased relative to baseline (no task) for all listening conditions. Skin conductance increased significantly with an increase in evaluative threat, but only for the more demanding task. There was no significant change in HRV in response to increasing evaluative threat or task demand.
Conclusions: Listening effort may be influenced by factors other than task difficulty, as reviewed in Part 1. This idea is supported by the preliminary data indicating that the sympathetic nervous system response to task demand is modulated by social evaluative threat. More work is needed to determine the relative contributions of motivation and emotional stress on physiological responses during listening tasks.

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Person-Related Factors Influencing Listening Effort

Over the past 10 years, there has been acceleration in research in the area of listening effort. Most studies have focused on how hearing demand, controlled by manipulating *external* factors such as adverse listening conditions and amplification, affect behavioral and physiological measures thought to be sensitive to effort (for reviews, see McGarrigle et al., 2014; Pichora-Fuller et al., 2016). There is also increasing recognition that *internal person-related factors,* such as emotional reactions and appraisal of success importance, may have an impact on effort.

Consider the following scenario. Tom is having a beer in a noisy pub with his boss and her husband. Tom has a hearing loss and is struggling to participate in the conversation. Several communication breakdowns occur. The importance of successful communication with his boss is very high, so Tom exerts a tremendous amount of effort to listen and respond appropriately. This experience may also be emotionally stressful for Tom if he fears that his boss will form a negative opinion of him. As the stress mounts, communication breakdowns increase, possibly because the emotional coping diverts attentional resources that would otherwise be available for communication. At some point, Tom senses irritation from his communication partners and gives up trying to stay in the conversation; he decides that the interaction, though important to him, is just not worth the emotional and mental costs needed to stay engaged.

[a]San Diego State University, CA
Correspondence to Carol L. Mackersie: cmackers@mail.sdsu.edu
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Though fictional, the general cascade of events beginning with the exertion of effort and communication breakdown leading to eventual emotional stress and disengagement are not unlikely events encountered by people with hearing loss. Although exertion of listening effort is certainly an ingredient in this scenario, the scenario depicts interactions among cognitive, emotional, and motivational factors. In other words, effort may be modulated by both motivation and emotional responses to a situation.

Motivation and Emotional Stress as Contributors to Effort

Motivation has been recognized as a modulator of the amount of effort applied to task completion (for reviews, see Brehm & Self, 1989; Richter, Gendolla, & Wright, 2016). For example, Richter (2016) demonstrated that greater success importance, manipulated using monetary rewards, resulted in a greater increase in effort when the listening demand was high than when the listening demand was low. If success is impossible, however, the level of effort drops (Richter et al., 2016).

In a systematic review of endocrine stress biomarkers, Dickerson and Kemeny (2004) identified social evaluative threat as one of the most potent stressors. Social evaluative threat refers to the fear of negative evaluation by others. Greater social evaluative threat has been linked to an increase in mental distress of people with hearing loss (Williams, Falkum, & Martinsen, 2015).

Emotional stress may influence the availability of cognitive resources needed for communication. Given the evidence that emotional stress leads to a deterioration of performance on memory tasks (Lupien, Maheu, Tu, Fiocco, & Schramek, 2007; Schoofs, Wolf, & Smeets, 2009), it is plausible that the increased cognitive demands of emotion regulation that occur with hearing loss–related stress may have an impact on the availability of working memory resources needed for spoken language communication. This, in turn, would be expected to further limit the availability of resources needed for communication.

Autonomic Nervous System Measures of Stress/Effort

The autonomic nervous system is highly responsive to physical, emotional, and cognitive stressors. Autonomic nervous system changes in response to stress may include an increase in sympathetic nervous system arousal (i.e., fight-or-flight response) and/or a decrease in parasympathetic activity (i.e., rest and recovery). It is possible to capture these changes using a variety of psychophysiological measures, including cardiac measures, skin conductance, pupillometry, and temperature. Within the context of auditory tasks, increased auditory task difficulty can result in increased sympathetic nervous system arousal as evidenced by increased pupil dilation (Koelewijn, Zekveld, Festen, & Kramer, 2014; Kuchinsky et al., 2014; Zekveld, Kramer, & Festen, 2011), increased skin conductance (Mackersie, MacPhee, & Heldt, 2015), and a decrease in cardiac pre-ejection period (Richter, 2016). An increase in auditory task difficulty may also result in a reduction of parasympathetic nervous system activity as evidenced by a reduction in high-frequency heart rate variability (HRV; Mackersie & Calderon-Moultrie, 2016). Emotional stress may affect these psychophysiology measures in similar ways; however, the interactions between auditory task demand and emotional stress have not yet been described. In Part 2, we present preliminary data from a study designed to evaluate interactions between auditory task demand and emotional stress using two physiological measures. Sympathetic nervous system activity was indexed using skin conductance level (Boucein, 2012) and parasympathetic activity was indexed using a time-domain HRV measure: root mean square of successive intervals between heartbeats (RMSSD; Friedman, Allen, Christie, & Santucci, 2002). For simplicity, we refer to RMSSD as "HRV" throughout the paper.

Task Demand and Evaluative Threat: Preliminary Data

Purpose

The purpose was to evaluate the interaction between social evaluative threat and auditory task demand in a group of participants with hearing loss.

Method

Participants

Our sample consisted of 12 adults with hearing loss. The mean age was 76 years (range: 64–88 years), and the mean pure-tone average hearing loss was 46 dB HL.

Tasks and Evaluative Conditions

A 2 × 2 repeated-measures design was used to evaluate the level of evaluative observation (high, low) and the effects of task demand (high, low).

Speech understanding tasks. A two-part speech understanding test was administered to participants while monitoring skin conductance and electrocardiographic activity. During the low-demand task, participants were asked to repeat segments of a narrative about a service dog (for details regarding these materials, see Mackersie & Calderon-Moultrie, 2016). Materials for the repetition task were presented in quiet and in noise at a + 6 dB signal-to-noise ratio (SNR). During the high-demand task, we required listeners to answer questions about the narrative; this required comprehension and recall. A practice test was administered under both conditions before beginning data collection.

Evaluative observation conditions. Both the low- and high-demand tasks were presented under two evaluative observation conditions to elicit higher and lower levels of evaluative threat. For the high evaluative threat condition, participants were video recorded and were told that the recordings would be evaluated by a panel of communication experts who would rate their communication competency and their desirability as a communication partner. For the

low evaluative threat condition, there was no video camera present; participants were instructed to "do your best." The tester, who was visible to the participant, scored responses from the control side of a sound booth during the low and high evaluative threat conditions. Listeners were tested in a sound field while wearing their hearing aids.

Physiological Measures

The BioPac 150C Nomadix system was used to simultaneously record skin conductance (sampled at 32 Hz) and electrocardiographic activity (sampled at 1000 Hz). Skin conductance was measured using silver/silver chloride surface electrodes attached to the palmar surface of one hand. Electrocardiographic measures were obtained using three surface electrodes attached to the chest.

Monitoring began with a 5-min baseline (no task) recording. Physiological activity was monitored during each task and during 3-min recovery periods. Premature beats and other physiological artifacts were removed before data analysis. Kubios software (v2.2) was used to calculate the HRV measure (Tarvainen et al., 2014). Mean HRV and skin conductance data were extracted for each condition, and HRV data were log transformed before data analysis.

Results and Discussion

Relative to baseline (no task), skin conductance increased and HRV decreased during all speech understanding tasks consistent with sympathetic nervous system arousal and parasympathetic nervous system withdrawal with the introduction of the listening tasks.

Data from the repetition task were analyzed to determine the effects of noise. There was no effect of noise for either physiological measure. Therefore, the noise and quiet data were collapsed for the subsequent analyses.

Skin Conductance

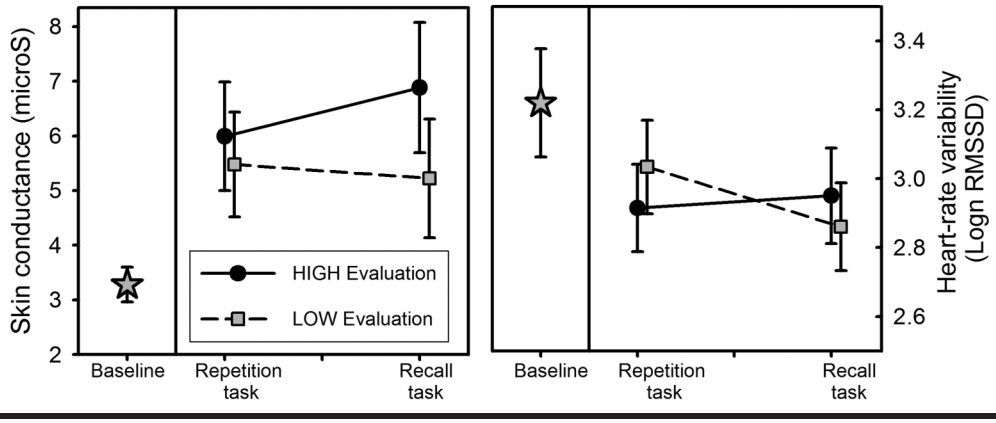
As shown in Figure 1 (left), mean skin conductance level increased with task demand when the level of evaluative observation was high. A repeated-measures analysis of variance using evaluative observation level and task demand as within-subjects factors revealed a significant interaction, $F(1, 11) = 7.10$, $p = .02$, $\eta_p^2 = .39$. Newman–Keuls post hoc tests (Keuls, 1952; Newman, 1939) confirmed that skin conductance level increased significantly with greater evaluative threat, but only for the more demanding comprehension/recall task. The increase in skin conductance level with the addition of evaluative stress is compatible with other works showing a similar increase during the Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993), a public speaking task designed to elicit evaluative threat (Marko, 2016; Montero-López et al., 2016).

HRV

As shown in Figure 1, HRV was not sensitive to increased evaluative threat or task demand as evidenced by an absence of a significant interaction between evaluative threat and task, $F(1, 11) = 0.78$, $p = .39$, $\eta_p^2 = .07$. Given the substantial age range among the participants, data were also analyzed using age as a covariate. Age was not a moderating influence of either evaluative threat or task demand (evaluative threat, $F(1, 10) = 1.67$, $p = .23$, $\eta_p^2 = .14$; task demand, $F(1, 10) = 0.02$, $p = .88$, $\eta_p^2 < .01$).

Contrary to expectation, HRV did not decrease more under the evaluative threat conditions when the task demand was high. Although we expected reciprocal activation of the sympathetic and parasympathetic nervous systems during the listening tasks based on previous work with other auditory tasks (Mackersie & Calderon-Moultrie, 2016; Mackersie et al., 2015), there is ample evidence that sympathetic and parasympathetic nervous systems can operate independently (Berntson, Cacioppo, & Quigley, 1993). In addition, the inclusion of evaluative observation may have led to increased self-consciousness and self-regulatory behavior. An increase in self-regulatory effort can result in an *increase* in parasympathetically mediated HRV

Figure 1. Mean skin conductance level in microsiemens (left) and log-transformed heart-rate variability as the root-mean-square of successive differences (RMSSD; right) for the four conditions. Error bars indicate ± 1 standard error.



(Segerstrom & Nes, 2007), which may counteract the effects of listening demand on HRV.

Summary and Conclusions

As reviewed in Part 1, factors affecting listening effort are complex and most likely include a combination of factors in addition to task difficulty. This idea is supported by preliminary data presented in Part 2 showing a greater effect of task demand on sympathetic nervous system activity when high evaluative threat was present. The modulation of the effects of task demand by evaluative threat may reflect increased effort resulting in increased cognitive load from the combined cognitive and emotional demands. Another explanation is that evaluative threat increased the motivation to succeed, as has been suggested by investigators reporting similar interactions between social observation and *nonauditory* task difficulty (Gendolla & Richter, 2006; Wright, Dill, Geen, & Anderson, 1998; Wright, Tunstall, Williams, Goodwin, & Harmon-Jones, 1995). Further work is needed to evaluate the independent contributions of motivation and emotional stress to listening effort.

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