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Measuring listening-related effort and fatigue in school-aged children using pupillometry

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ABSTRACT

Stress and fatigue from effortful listening may compromise well-being, learning, and academic achievement in school-aged children. The aim of this study was to investigate the effect of a signal-to-noise ratio (SNR) typical of those in school classrooms on listening effort (behavioral and pupillometric) and listening-related fatigue (self-report and pupillometric) in a group of school-aged children. A sample of 41 normal-hearing children aged 8–11 years performed a narrative speech–picture verification task in a condition with recommended levels of background noise ("ideal": +15 dB SNR) and a condition with typical classroom background noise levels ("typical": −2 dB SNR). Participants showed increased task-evoked pupil dilation in the typical listening condition compared with the ideal listening condition, consistent with an increase in listening effort. No differences were found between listening conditions in terms of performance accuracy and response time on the behavioral task. Similarly, no differences were found between listening conditions in self-report and pupillometric markers of listening-related fatigue. This is the first study to (a) examine listening-related fatigue in children using pupillometry and (b) demonstrate physiological evidence consistent with

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increased listening effort while listening to spoken narratives despite ceiling-level task performance accuracy. Understanding the physiological mechanisms that underpin listening-related effort and fatigue could inform intervention strategies and ultimately mitigate listening difficulties in children.

Introduction

Successful spoken language understanding requires a combination of sensory acuity and the mobilization of cognitive resources such as selective attention and working memory (e.g., Pichora-Fuller, Schneider, & Daneman, 1995). The need for support from the cognitive system is increased in adverse listening conditions (e.g., the classroom), resulting in the experience of "effortful listening." Importantly, it is thought that repeated and/or sustained instances of effortful listening may give rise to fatigue (Pichora-Fuller et al., 2016). "Mental effort" refers to "the deliberate allocation of mental resources to overcome obstacles in goal pursuit when carrying out a task," and "listening effort" refers to "a specific form of mental effort that occurs when a task involves listening" (Pichora-Fuller et al., 2016). Listening-related "fatigue" is commonly measured as a decrement in physical or cognitive performance and may relate to the tiredness that results from sustained effortful listening (Hornsby, Naylor, & Bess, 2016; McGarrigle et al., 2014). Although there is reason to believe that stress and fatigue may affect children's social and academic development (Bess, Dodd-Murphy, & Parker, 1998), a better understanding of the mechanisms that underlie listening-related effort and fatigue in school-aged children is needed.

Listening effort has been measured experimentally in children using a variety of approaches. Decrements in listening task performance have been examined as a potential behavioral marker of listening effort (Gustafson, McCreery, Hoover, Kopun, & Stelmachowicz, 2014; Hicks & Tharpe, 2002; Howard, Munro, & Plack, 2010; McCreery & Stelmachowicz, 2013). In Gustafson et al. (2014), a group of normal-hearing (NH) children (aged 7–12 years) were presented with consonant–vowel–consonant nonwords in broadband background noise. To examine the impact of digital noise reduction (DNR) on listening effort, test stimuli were presented via two hearing aids: one with DNR on and one with DNR off. Verbal response time (i.e., the duration from the onset of the stimulus to the onset of the response) was analyzed to assess listening effort. Slower response times (RTs) are thought to reflect an increase in listening effort (Gatehouse & Gordon, 1990; Houben, van Doorn-Bierman, & Dreschler, 2013). DNR resulted in faster verbal RTs, which is consistent with a reduction in listening effort (Gustafson et al., 2014).

Listening-related fatigue in children has been assessed using salivary cortisol levels (Bess et al., 2016). Both chronic fatigue and acute fatigue have previously been associated with decreased levels of adrenocortical activity (reflected in cortisol levels) (DeLuca, 2005; Poteliakhoff, 1981). In Bess et al. (2016), salivary cortisol levels were measured in a group of NH and hearing-impaired (HI) children aged 6–12 years. Six samples were collected each day across 2 school days. The HI group showed elevated cortisol levels on wakening and a reduced growth in cortisol secretion during the subsequent 30-min period compared with their NH counterparts. Dysregulation of the hypothalamic–pituitary–adrenal axis in the form of an elevated cortisol awakening response has also been reported in the adult literature in individuals experiencing fatigue and burnout. The authors suggested that these findings may indicate an increased need for HI children to mobilize energy in order to combat stress and fatigue (Bess et al., 2016).

Self-report measures have also been used to assess listening-related fatigue in children. In Hornsby, Werfel, Camarata, and Bess (2014), a group of HI children (aged 6–12 years) and a group of age-matched NH controls were administered the Pediatric Quality of Life Inventory (PedsQL) Multidimensional Fatigue Scale (Varni, Burwinkle, Katz, Meeske, & Dickinson, 2002). Children with hearing loss