Letter to the Editor

Listening effort: *WHAT* is it, *HOW* is it measured and *WHY* is it important?

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To start with a question, how do you connect the following group of measurements: EEG spikes, Cortisol levels, Chromogranin A, Reaction times, Infra-red spectroscopy, Driving simulators, Questionnaires, Pupil diameter, Response times, Fatigue scales, Functional MRIs and Skin conductance? Although seemingly unrelated, these tools have all been proposed as a proxy measure for listening effort (LE). The variety and abundance in research approaches emphasises the lack of a clear consensus in the literature regarding the best way to measure LE. Even defining the topic of LE has its challenges, perhaps the most structured definition stems from the work of Pichora-Fuller and colleagues via the Framework for Understanding Effortful Listening (FUEL):

> The deliberate allocation of mental resources to overcome obstacles in goal pursuit when carrying out a task, with listening effort applying more specifically when tasks involve listening. (Pichora-Fuller *et al.*, 2016)

This definition highlights some of the key influencing factors which contribute to the level of LE experienced by individuals, namely task difficulty; listening ability; and motivation to succeed (Ayasse and Wingfield, 2018; Bess and Hornsby, 2014; Brookhart *et al.*, 2006). It seems prudent within this paper to further explore each of these components to construct a broader picture of LE.

First, task difficulty is enshrined within Pichora-Fuller's definition through the phrase 'overcome obstacles', which creates an image of the participant needing to actively strive to match the demands of the task. At face value, this seems straightforward: the more difficult the task, the more effort required. Indeed, this notion is reflected if the effort necessary to understand a conversation in a busy restaurant is compared with the effort necessitated by a peaceful environment such as a library. Furthermore, this underlying principle is mirrored by many LE studies (Bernarding *et al.*, 2010; McGarrigle *et al.*, 2019). However, an interesting caveat to this need to strive is the existence of a 'tipping point', whereby above a certain level of difficulty, the individual may disengage from the task, giving up due to a belief that the task is impossible thus leading to a diminution of effort (Ayasse and Wingfield, 2018).

Closely aligned with task difficulty is motivation to succeed, or 'goal pursuit' as delineated in the FUEL definition. It is not unreasonable to surmise that the more desire an individual has 'to overcome the obstacle', the more resources they would be willing to allocate to achieve this goal. Educational models use this premise to accentuate the importance of bolstering students' motivation to improve their performance in the classroom (Kusurkar *et al.*, 2013). This represents a deficiency within current lab-based studies as it may be difficult to foster motivation for an arbitrary task, therefore creating the potential for skewed reports of effort. This is evidenced by the work of Zekveld *et al.* who examined the effect of participant feedback on listening task performance: they found that individuals who received feedback on their performance were more likely to improve in subsequent tasks (Zekveld *et al.*, 2019). A well-established rationale for this observed effect is the understanding that feedback can be an important driver for motivation (Egeth and Kahneman, 1975). This supports shifting the paradigm of research towards the 'real-world' setting within LE studies, although a novel approach (such as those adopted by Zekveld) may help remedy this potential bias.

The final and most overt factor affecting LE relates to the participants' listening ability. This is the most

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widely reported facet of LE within the literature. Many studies have shown that people with hearing impairment appear to experience increased LE compared to normal hearing counterparts, regardless of the outcome measure used (Bess and Hornsby, 2014). This finding resonates well with our current understanding of hearing impairment. Furthermore, measurements from before and after interventional studies have demonstrated that certain therapies such as hearing aids, cochlear implants, and other devices can reduce LE scores amongst hearing impaired individuals (Holman *et al.*, 2020). Since, at present, those with a more severe hearing impairment are more likely to qualify for the aforementioned interventions, a paradoxical situation is created whereby those with mild to moderate impairment may in fact experience more LE than those with severe impairment. This incongruency emanates from persevering with long-established traditional criteria in terms of what we choose to consider in decisions regarding eligibility for implants and other devices. For instance, speech and language development remains the paramount criterion when determining the need for and benefit of hearing interventions. This is evidenced by the plethora of papers which use speech and language as the primary, or even sole, outcome of interest when investigating implantable devices (Geers, 2004; Iwasaki *et al.*, 2012; May-Mederake, 2012; Nikolopoulos *et al.*, 2004). This paper does not wish to discredit the importance of speech and language development as there are pertinent connotations involved from both personal and educational perspectives. However, there is the concern that an over-dependence on speech and language outcomes may inadvertently create a false dichotomy where other important factors, such as LE, are overshadowed. For instance, when examining the evidence of benefit arising from bilateral cochlear implantation, it appears limited to a modest improvement in language development and sound localisation (Balkany *et al.*, 2008; Lammers *et al.*, 2014). This seemingly modest benefit may not be due to an implicit inadequacy of the underlying research strategy but rather from discounting other valid markers of success. This scenario reinforces the potentially critical role that a validated measure of LE may have in the audiological test battery, thereby addressing this hidden burden.

Notwithstanding the challenges involved in researching the abstract concept of LE, several issues result from the way we measure this construct. As aforementioned in the list outlined in the first paragraph, there is an array of potential methods available to capture the mental load of effortful listening. To simplify and compartmentalise this wealth of tools, researchers often index these measures into three broad categories: physiological; behavioural; and self-reported measures. These groupings are shown in Table 1 below.

To further confound LE measurement, studies have demonstrated inconsistent correlations between each overarching category of LE measure. Whilst several papers have shown significant correlations between physiological and self-reported measures (Bernarding *et al.*, 2014, 2017; Dimitrijevic *et al.*, 2019), other studies demonstrate much weaker correlations, highlighting the poor reproducibility of these findings (Holube *et al.*, 2016; Zekveld *et al.*, 2011). This issue of inconsistency is echoed across the literature with a similar data trend arising no matter which methods are compared. Not only this, the test-retest validity of specific measures tends to be poorly reported as well, leaving little guidance for future studies as to the consistency of each measure. Instead of emphasising the weaknesses of each tool, Alhanbali and colleagues offer an alternative hypothesis whereby each measure may encompass a different dimension of LE. This thus suggests that LE is too complex to be

Table 1 Showing the different measures of LE and their associated category.

Physiological	Behavioural	Self-reported
EEG spikes	Reaction times	Effort based questionnaires
Pupil size	Response times	Fatigue based questionnaires
Hormonal measures	Correct v incorrect response	
Infra-red Spectroscopy	Driving simulators	
Functional MRI imaging		

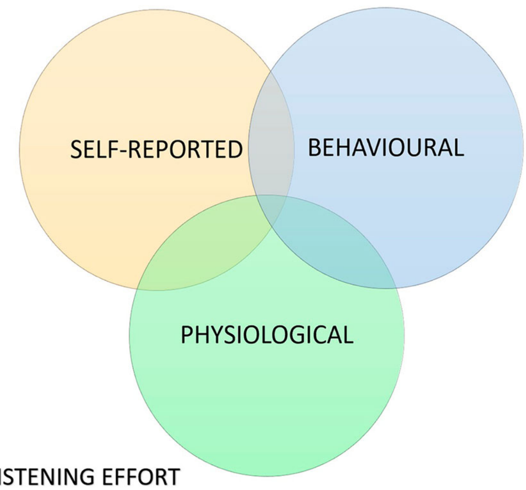

Figure 1 Visual representation of multidimensional theory of LE. Demonstrating the overlap between self-reported/ questionnaires, behavioural and physiological measures in how they capture LE.

addressed with a single tool approach (Alhanbali *et al.*, 2019). A simplified depiction of this multidimensional theory of LE is illustrated in Fig. 1.

Building upon this multidimensional model, the next step would be to quantify the degree of statistical correlation between themes more accurately. Indeed, it may not be possible to identify exactly which LE dimension is measured by each specific tool, but it would still be invaluable knowledge to clarify whether the various LE measures reflect similar or completely different determinants of effort. This is an important step in the move towards a validated clinical tool for LE as it combines a high degree of test sensitivity with clinical acceptability, by minimising the number of tests which need to be performed.

Another issue to address is the alignment between population group and proposed tool. The vast majority of the literature currently focuses on the adult demographic which inherently benefits from a higher willingness to cooperate during testing procedures. Indeed, it may not be practical to attempt to coax a young child into sitting long enough to gain an accurate pupil diameter recording. However, children with hearing impairment may actually benefit the most from strategies to overcome LE. There is mounting evidence to suggest that children with mild to moderate or unilateral hearing loss may display poorer educational outcomes compared with normal hearing students (Bess *et al.*, 1998; Niedzielski *et al.*, 2006; Purcell *et al.*, 2016). As such, the traditional belief that the impact of mild hearing loss on childhood development is negligible or insignificant is no longer generalisable, thus necessitating an individualised approach founded upon a clear understanding of potential hindrances such as LE. There is also growing concern about LE being a stressor in its own right, thus increasing the risk of inducing chronic stress and the associated deleterious consequences on physical and mental health (Kramer *et al.*, 2006; Mattys *et al.*, 2012; Pichora-Fuller, 2016; Pichora-Fuller *et al.*, 2016; Sandi and Haller, 2015; Schneiderman *et al.*, 2005). Indeed, neuroendocrine research conducted in deaf children has revealed elevations in the cortisol awakening response at the beginning of the school day (Bess *et al.*, 2016). These increases in cortisol have been previously associated with unusual stress and even burnout (Bess and Hornsby, 2014; Kumari *et al.*, 2009; Schlotz *et al.*, 2004). The link between LE and fatigue/stress may become more important following the shift in research to focus more on patient-centred outcomes rather than purely clinical metrics. It is thought that research, which recognises patient outcomes may help to bolster engagement in clinical decision making, thereby leading to an overall more positive experience for the patient (Hill-Feltham *et al.*, 2021; Kirwan *et al.*, 2007; Oliver and Greenberg, 2009). Therefore, it is crucial that any measure of LE shown to be applicable in adults is not only appropriately adapted and trialled in the paediatric population but that it also captures the downstream effects of LE such as burnout, fatigue and stress.

Considering the methodological challenges involved in quantifying LE, some may believe that future research is too problematic to even attempt. However, it is important to be cognisant of the potential positive outcomes which may arise from deepening our understanding of the topic. Ultimately, this may lead to a tangible way of identifying an unmet burden of hearing impairment and allow us to act readily and holistically to improve the quality of life of affected individuals. Likewise, it may also enable the ‘real-life’ benefit of hearing devices and implants to be measured in a truly meaningful manner. Failure to explore the impact of devices upon LE risks missing (or even under-estimating) benefit and result in restriction in access to hearing interventions.

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