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Research Note

Empatica E4 Assessment of Child Physiological Measures of Listening Effort During Remote and In-Person Communication

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ABSTRACT

Purpose: Telepractice is a growing service model that delivers aural rehabilitation to deaf and hard-of hearing children via telecommunications technology. Despite known benefits of telepractice, this delivery approach may increase patients' listening effort (LE) characterized as an allocation of cognitive resources toward an auditory task. The study tested techniques for collecting physiological measures of LE in normal-hearing (NH) children during remote (referred to as tele-) and in-person communication using the wearable Empatica E4 wristband.
Method: Participants were 10 children (age range: 9–12 years old) who came to two tele- and two in-person weekly sessions, order counterbalanced. During each session, the children heard a short passage read by the clinical provider, completed an auditory passage comprehension task, and self-rated their effort as a part of the larger study. Measures of electrodermal activity and blood volume pulse amplitude were collected from the child E4 wristband.
Results: No differences in child subjective, physiological measures of LE or passage comprehension scores were found between in-person sessions and telesessions. However, an effect of treatment duration on subjective and physiological measures of LE was identified. Children self-reported a significant increase in LE over time. However, their physiological measures demonstrated a trend indicating a decrease in LE. A significant association between subjective measures and the passage comprehension task was found suggesting that those children who reported more effort demonstrated a higher proportion of correct responses.
Conclusions: The study demonstrated the feasibility of collection of physiological measures of LE in NH children during remote and in-person communication using the E4 wristband. The results suggest that measures of LE are multidimensional and may reflect different sources of, or cognitive responses to, increased listening demand.
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Telerehabilitation is defined as the provision of medical or rehabilitative services to individuals requiring rehabilitation through telecommunication or internet platforms (Alexander, 2022). Telerehabilitation encompasses a specialized area known as telepractice that utilizes telecommunication technology to provide remote speech and hearing services for assessment, intervention, and consultation purposes (American Speech-Language-Hearing Association, 2020). Health professionals, including audiologists and speech-language pathologists (SLPs), have increasingly adopted synchronous telepractice. This method, which involves real-time interaction between providers and patients via live video, is now commonly used in

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services for deaf and hard-of-hearing (DHH) children (Weidner & Lowman, 2020). Synchronous tele-intervention in aural rehabilitation offers several benefits, including feasibility, effectiveness, cost reduction, and increased patient access to services (Hall et al., 2019).

Research on environmental/transmission degradation of signal due to a physical barrier in communication (e.g., noise, distance, face masks) has shown an increase in listening effort (LE) and fatigue in children with and without hearing loss (HL), leading to a decrease in their linguistic performance (Brännström et al., 2020; McGarrigle et al., 2019; Rudner et al., 2018; von Lochow et al., 2018). Recent studies have demonstrated that telepractice introduces new challenges to the provider–pediatric patient interaction by altering the availability and the quality of auditory, visual, and tactile information (Anderson et al., 2014; Bailenson, 2021; Charney et al., 2021; Grogan-Johnson et al., 2013; Keck & Doarn, 2014; Tucker, 2012). Although evidence suggests that children increase their vocal effort during telepractice (Kondaurova, Zheng, Donaldson, Betts, et al., 2023; Kondaurova, Zheng, Donaldson, & Smith, 2023) and adults with HL report an increase in subjective measures of LE during video calls (Naylor et al., 2020; Perea Pérez et al., 2022), there is a gap in our knowledge on the effect of remote communication on child LE.

LE is defined as an allocation of cognitive resources such as working memory capacity, attention, and executive control to overcome obstacles (e.g., source degradation, environmental/transmission degradation, and receiver limitations) to achieving listening-oriented goals (Francis & Love, 2020; Mattys et al., 2012; Pichora-Fuller et al., 2016). Contemporary models of resource allocation in speech perception propose that LE involves the use of limited cognitive resources, such as, for example, attention, at either or both externally directed (perceptual) and internally directed (cognitive) levels of information processing, each representing different components of effort (see Active models, Heald & Nusbaum, 2014; the Ease of Language Understanding model, Rönnberg et al., 2013).

While the use of behavioral (subjective and cognitive) measures of children's LE has been well documented in previous research (Brännström et al., 2020; McGarrigle et al., 2019; Rudner et al., 2018), fewer studies examined physiological measures of pediatric LE (McGarrigle et al., 2017). Physiological responses to increased cognitive effort focus on characteristics of two conceptually distinct system, the central and autonomic nervous systems (ANS; Francis & Love, 2020). The responses associated with the ANS can be assessed using electrodermal activity (Dawson et al., 2007), pupillometry (McGarrigle et al., 2017), and a number of cardiovascular measures such as, for example, heart rate/heart rate variability and peripheral vasoconstriction (i.e., blood volume pulse [BVP] amplitude; Francis & Love, 2020). The current study focuses on two physiological measures associated with increased LE, electrodermal activity, and BVP amplitude. Electrodermal activity refers to changes in electrical conductance through the skin as a result of sympathetically governed eccrine sweat gland activity (Dawson et al., 2007). BVP amplitude measures the volume of blood flow in the peripheral capillaries at systole that is governed by the sympathetic branch of the ANS with increasing arousal leading to peripheral vasoconstriction and therefore decreased amplitude of the BVP signal (Francis & Love, 2020). Research suggests an increase in electrodermal activity due to the arousal of the sympathetic nervous system as a result of increased cognitive effort due to task difficulty, increased demand on working memory capacity, and/or selective attention in auditory tasks (Francis et al., 2016; Mackersie & Calderon-Moultrie, 2016; Seeman & Sims, 2015). A decrease in BVP amplitude and heart rate/heart rate variability is observed with an increase in listening/cognitive effort due to an increase in task difficulty or demand (Iani et al., 2004; Mackersie & Calderon-Moultrie, 2016; Mackersie et al., 2015).

Physiological response measures can be obtained with wearables in a relatively unintrusive manner, making them excellent candidates for studies on naturalistic communication (Caduff et al., 2020). Empatica E4 (Empatica Srl) is a compact, lightweight, and wireless wearable multisensor wristband that is used to collect physiological signals in real-time (Menghini et al., 2019). The E4 wristband has been used in previous research with adults examining physiological responses associated with listening/cognitive effort during different language tasks (e.g., an interactive conversation and/or passage comprehension task; Aliakbaryhosseinabadi et al., 2023; Milstein & Gordon, 2020; Richardson et al., 2020) as well as when examining different stressors (Menghini et al., 2019; Ollander et al., 2016; Vos et al., 2023). The findings suggest increased electrodermal activity and reduced heart rate variability values under more challenging listening conditions (Aliakbaryhosseinabadi et al., 2023), increased cognitive load (i.e., Stroop task) or emotional stress (Menghini et al., 2019; Ollander et al., 2016). Although research with the pediatric population using wireless wearable devices is still limited, recent studies have suggested the feasibility of using the E4 wristband in children to examine physiological measures indicative of child emotional and/or stress levels (Toprak et al., 2023; Uluer et al., 2023).

Recent studies have also suggested an increase in self-reported measures of LE during remote compared to in-person communication in adults with HL (Naylor et al., 2020; Perea Pérez et al., 2022). Research on telepractice has shown a number of prosodic, segmental, and pragmatic modifications in a clinical provider and DHH children speech (Kondaurova et al., 2021; Kondaurova, Zheng, Donaldson, Betts, et al., 2023; Kondaurova, Zheng, Donaldson, & Smith, 2023) usually associated with an increase in cognitive load (MacPherson et al., 2017; Mattys et al., 2012). The goal of the current study was to test the application of the E4 wrist sensor to collect physiological measures of LE during remote and in-person communication between normal-hearing (NH) children and a clinical provider in order to obtain baseline data for future research during real life telepractice service. The results of the study will inform clinicians and caregivers on the potential application of the E4 wrist sensor during aural telerehabilitation to enhance the effectiveness of therapy.

Materials and Method

Participants

Ten children (five females and five males, M_{age} = 10.4 years, SD = 1.7 years) participated in the study. The children were included in the study if their caregiver reported no history of speech, language, and/or hearing disorders. Children were excluded from the study if their caregiver reported intellectual/cognitive disabilities and/or developmental disorders. All children and their caregivers were monolingual native English speakers (mid-Western dialect). Five caregivers and their eight children identified as White/Caucasian; two caregivers and two children identified and as Black/African American. None were Hispanic/Latino. All caregivers provided informed consent and all children provided informed child assent to participate. The protocol was approved by an institutional review board (IRB#22.0568) at the University of Louisville.

Materials

Testing Materials

We used short passages (familiarization: one passage, four testing sessions: four passages) with follow-up questions from the Oral Passage Understanding Scale (Carrow-Woolfolk & Klein, 2019). The choice of passages depended on each child's age (7–8 years old, 9–10 years old, 11–13 years old). After each familiarization and testing session the experimenter used a 5-grade scale (from 1 = *very much* to 5 = *not at all*) with emoticons (see Supplemental Material S1) to collect each child's subjective measures of effort.

Procedures

One licensed SLP and one graduate speech-language pathology student, both referred to as "the experimenter" below, conducted the testing that included 50 visits (10 pretest, 20 in-person sessions, and 20 telesessions). Each caregiver–child dyad came once per week over the period of 5 weeks to participate in testing. The order of in-person sessions and telesessions was counterbalanced. Seven dyads started the experiment with an in-person session, and three dyads started the experiment with a telesession.

During pretest that lasted 60 min, we collected child and caregiver demographic characteristics and evaluated each child's language skills using the Clinical Evaluation of Language Fundamentals–Fifth Edition (Semel et al., 2013). Standard scores and percentile ranks for each child are presented in Supplemental Material S2. At each in-person session, the experimenter and the child sat opposite each other at the table in the soundproof booth and the caregiver sat at the corner of the booth. At each telesession, the experimenter sat at a table with a desktop computer outside the booth. The child sat at a table with a laptop inside the booth and the caregiver sat in the corner of the booth. Prior to testing, the Microsoft Teams application and its videoconferencing function (Microsoft Corporation, 2024) was started on both the child's and the experimenter's computers so that both participants could see and hear one another.

At the start of each (in-person or tele-) session, the experimenter instructed the child to sit quietly for about 1–2 min (baseline condition). Afterward, the child was asked to produce three types of stimuli: automatic speech (to count from 1 to 25), read speech (to read a list of words and sentences), and structured spontaneous speech (a Diapix picture task; Baker & Hazan, 2011) as a part of the larger study. Finally, the child listened to a passage read by the experimenter and answered questions on the passage content asked by the experimenter. After each task, the child rated his/her perceived effort by answering the question "How difficult was it to count/read words and sentences/to describe the picture?" (automatic speech, read speech, structured spontaneous speech) and "How difficult was the test?" (a passage comprehension task) using a scale with emoticons. For in-person sessions, the scale was printed on paper, and for telesessions, the scale was shown on the computer screen. Before the actual testing, the child completed a familiarization session to practice example tasks and to provide responses. The study used stimuli, methodology, and procedures discussed in previous studies examining child vocal (Baker & Hazan, 2011; Eisenberg et al., 2002; Hunter et al., 2021) and LE (Brännström et al., 2020; Rudner et al., 2018; von Lochow et al., 2018).

On average, the length of each visit was 30 min. Equipment setup and instructions took up about 15 min. The testing itself lasted, on average, 14.6 min (*SD* = 4.4 min) for in-person sessions and 14.9 min (*SD* = 3.7 min) for telesessions. The average duration of passages read by the experimenter was 49.9 s (*SD* = 13.7 s) during in-person sessions and 37.8 s (*SD* = 15.5 s) during telesessions. In addition, it took children several minutes to answer the questions on the passage. However, neither the duration of their responses nor their physiological data during these responses were analyzed in the current study.

In-Person Sessions and Telesessions Equipment Setup

Two Sennheiser EW100 G3 wireless lavalier microphone systems were used, one for the child and one for the experimenter. Microphones were taped to the child's and the experimenter's heads at the distance of 9.5 cm from each participant's mouth. The signals were transmitted to two receivers connected via a line to a TASCAM DR-40X 4-channel recorder. During the telesession only, both receivers were connected via a line to two computers. The experimenter used a Dell XPS 8700 desktop with a Dell U2415 24-in. monitor and a Logitech C270 HD webcam. The child used a Dell Latitide 5590 laptop with built-in 15.6-in. HD monitor and a webcam. At each telesession, the experimenter wore Sennheiser HD201 headphones.

At the start of each session, the experimenter turned on the TASCAM recorder. The Time.is application on a Galaxy A52 5G (model SM-A526U) cell phone was started to record the Coordinated Universal Time (UTC). The experimenter took a picture of the TASCAM screen and the Time.is application to record UTCs before pressing the "Record" button. Prior to testing, the child was fitted with an E4 wristband on the nondominant hand. A trigger sent from the E4 to the recording software was activated and deactivated at the start and end, respectively, of each session.

The noise level in the soundbooth was 18 dBA, while in the laboratory, it was 25 dBA. These measurements were taken using NTi Audio's Acoustilyzer AL1 with a Class 2 omnidirectional microphone, calibrated with a GRAS 2AA Pistonphone. The output sound level in the telecondition was set at a comfortable listening level by the experimenter for each child participant, prior to testing (70–75 dBA) as measured at the child face/ear level positioned at approximately 76 cm from the laptop screen. In addition, during in-person sessions, the experimenters were instructed to use a normal conversational intensity level (70 dB SPL), so that the speaker was always sufficiently audible. The experimenters were able to monitor their intensity level (dB SPL) in real time on the TASCAM DR-40X 4-channel recorder that features on-screen level meters showing the input levels for each channel.

Processing of Physiological Measures

Only physiological data collected by the E4 during the baseline condition (when the child was sitting quietly) and when the child was listening to the passage (being read by the experimenter) were analyzed. The physiological data were aligned and trimmed exactly to the start and the end time of each baseline and passage duration using the UTCs. The start/end of baseline duration was defined as the silent interval that lasted 1–2 min after the experimenter asked the child to sit quietly and before the testing started. The start/end of the passage duration was defined as the start/end of the first and the last sound in the first and the last sentence of the passage produced by the experimenter. The baseline and passage durations were determined via visual inspection of spectrogram and waveform information using Praat (version 6.4.12; Boersma & Weenink, 2018). Physiological data collected during other tasks and activities (e.g., child speech tasks, when the experimenter asked questions on passage comprehension, child answers, and self-ratings) were excluded from the analysis.

The tonic conductance measures (skin conductance level, SCL) of the electrodermal activity signal in microsiemens (μS) were collected via electrodermal activity sensor. The SCL curve was smoothed using an infinite impulse response filter with a high pass setting. A sample recording of the raw and detrended electrodermal activity signal is shown in Supplemental Material S3, Figure S1a.

The BVP signal was obtained from the photoplethysmography sensor by the E4 proprietary algorithm that computes interbeat intervals (and average heart rate values). The BVP signal was further used to compute BVP amplitude values defined as the trough-to-peak distance measured in nanowatts using a MATLAB's peak2peak function (https://www.mathworks.com/help/signal/ref/peak2peak.html). A sample recording of the raw BVP signal is shown in Supplemental Material S3, Figure S1b.

The electrodermal activity and BVP amplitude values were normalized for each participant by taking the natural log of the passage to baseline raw scores ratio applied after the amplitudes have been determined (Boucsein et al., 2012). Data from three sessions were excluded from the analysis due to noise.

Statistical Analysis

In all models, the effect of Time (Time 1: First Session and Second Session, Time 2: Third Session and Fourth Session), and Session Type (InPerson, Tele) on measures (subjective, physiological) of child LE and child comprehension scores (the proportion of correct responses) was examined. Time 1 and InPerson were set as reference level for all models. We introduced a random intercept to account for the correlation between observations from the same subject.

A cumulative logit link mixed model was employed to estimate the effect of Time and Session Type, on child self-reports. Wald z test (Wald, 1943) was used to examine the significance of fixed effects. Next, three linear mixed-effects regression models were used to estimate the effect of Time and Session Type on child passage comprehension scores, electrodermal activity and BVP amplitude measures, respectively. Wald t test with the Satterthwaite approximation for degrees of freedom was used to obtain the significance of fixed effects.

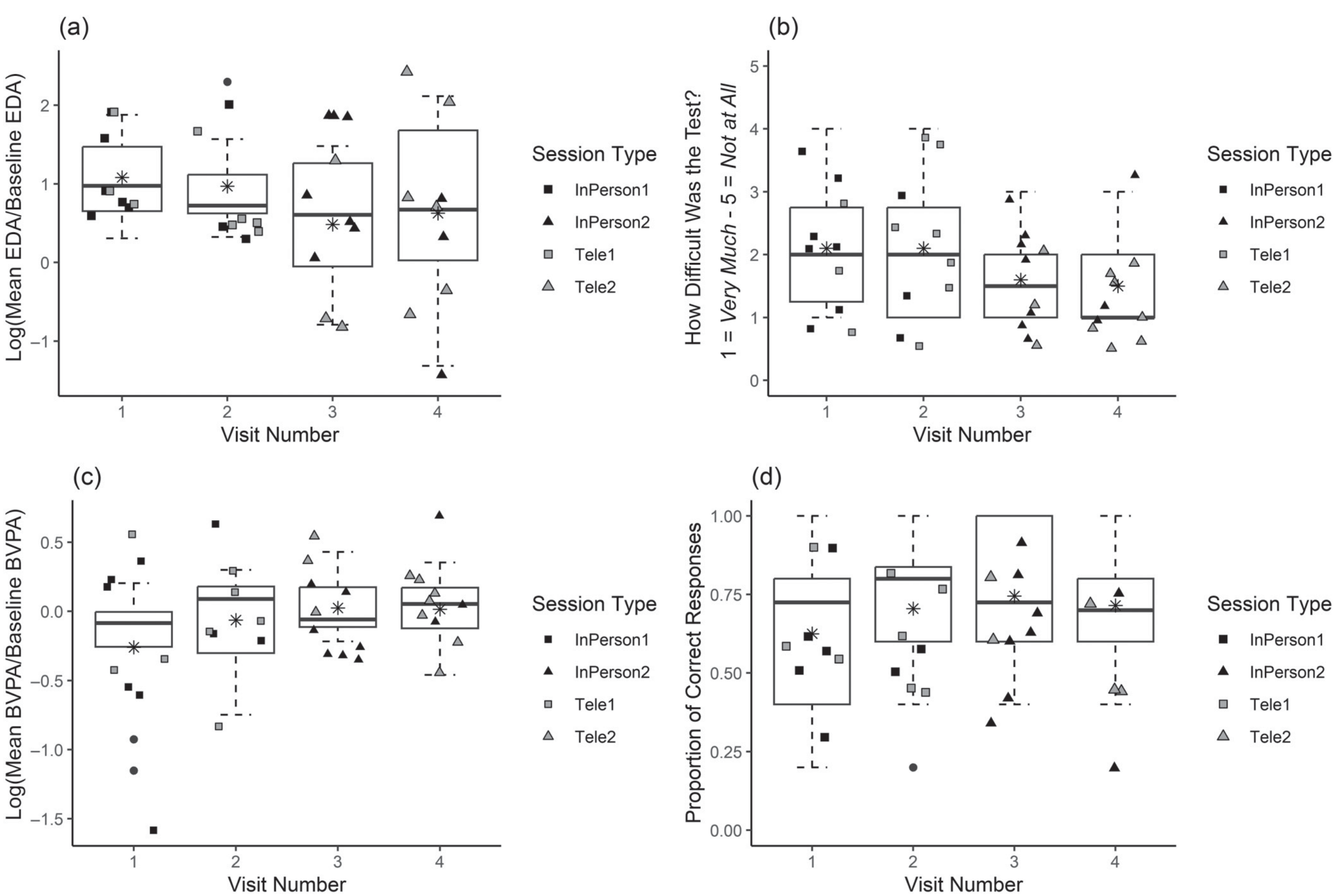
All models were tested with and without interaction between main effects using likelihood ratio tests to obtain the most parsimonious model. There was no difference between models with and without interaction terms (comprehension scores: χ^2 = .73, p = .39, electrodermal activity: χ^2 = .25, p = .62, BVP amplitude: χ^2 = .21, p = .65). Consequently, only main effects are reported.

To identify relationships between self-reported and physiological (electrodermal activity, BVP amplitude) measures of LE and between self-reported measures and the proportion of correct responses, the same cumulative logit link mixed model was employed. The significance of the estimated coefficients (associations) was tested using Wald z tests. To identify relationships between physiological (electrodermal activity, BVP amplitude) measures and the proportion of correct responses, we considered comprehension scores as an outcome variable and employed a linear mixed-effects model. The fitted model was tested using Wald t tests. For both cumulative logit link mixed model and the linear mixed-effects model, the data were aggregated over in-person sessions and telesessions since our previous analysis (reported above) has not identified an effect of session type on any measures of child LE or comprehension scores. All statistical analysis was conducted using R (version 4.3.0; R Core Team, 2023).

Results

Figure 1 presents boxplots of (a) normalized electrodermal activity, (b) self-reported measures of effort, (c)

Figure 1. Boxplots of (a) normalized electrodermal activity, (b) self-reported measures of effort, (c) normalized blood volume pulse amplitude, and (d) the proportion correct of responses in normal-hearing children across in-person and teletesting sessions. EDA = electrodermal activity; BVPA = blood volume pulse amplitude.



normalized BVP amplitude, and (d) the proportion correct of responses in NH children across in-person sessions and telesessions.

For electrodermal activity (Figure 1a and Supplemental Material S4), the effect of Time (Time 1: First Session and Second Session, Time 2: Third Session and Fourth Session) was nonsignificant and negative, β = −0.46, 95% confidence interval (CI) [−0.98, 0.06], p = .08. A marginally higher electrodermal activity during the first two (M = 1.02, SD = 0.57) compared to the last two (M = 0.55, SD = 1) testing sessions indicate a decrease in LE over time. The effect of Session Type (InPerson, Tele) was nonsignificant and positive, β = 0.0007, 95% CI [−0.51, 0.52], p = .99, suggesting no difference in electrodermal activity between in-person session (M = 0.77, SD = 0.8) and telesession (M = 0.77, SD = 0.93).

For child self-reported measures of effort (see Figure 1b and Supplemental Material S5), the effect of Time (Time 1: First Session and Second Session, Time 2: Third Session and Fourth Session) was significant and negative, β = −1.54, 95% CI [−0.29, −0.13], p = .03. The odds ratio (0.51) suggests that the self-reported LE was likely to increase during the last two testing sessions (M = 1.07, SD = 0.68) compared to the first two testing sessions (M = 2.1, SD = 1.55). The effect of Session Type was nonsignificant, β = −0.22, 95% CI [−1.5, 1.1], p = .74, suggesting no difference in self-reported LE between in-person session (M = 1.85, SD = 0.93) and telesession (M = 1.8, SD = 0.95).

For BVP amplitude (Figure 1c and Supplemental Material S6), the effect of Time (Time 1: First Session and Second Session, Time 2: Third Session and Fourth Session) was nonsignificant and positive, β = 0.18, 95% CI [−0.01, 0.37], p = .06. A marginally lower BVP amplitude during the first two (M = −0.16, SD = 0.41) compared to the last two (M = 0.02, SD = 0.21) testing sessions suggest a decrease in LE over time. The effect of Session Type (InPerson, Tele) was nonsignificant and positive, β = 0.10, 95% CI [−0.09, 0.29], p = .28, suggesting no difference in BVP amplitude between in-person session (M = −0.11, SD = 0.35) and telesession (M = −0.009, SD = 0.3).

For the proportion of correct responses (Figure 1d and Supplemental Material S7), the effects of Time (Time 1: First Session and Second Session, Time 2: Third Session and Fourth Session) and Session Type (InPerson, Tele) were nonsignificant and positive (Time: β = 0.09, 95% CI [−0.04, 0.23], p = .17; Session Type: β = 0.06, 95% CI [−0.07, 0.20], p = .34). There was no difference in the proportion of correct responses between the last two testing sessions (M = 0.73, SD = 0.22) and the first two testing sessions (M = 0.66, SD = 0.27). There was also no difference in the proportion of correct responses between in-person session (M = 0.65, SD = 0.27) and telesession (M = 0.74, SD = 0.22). The only significant association (Supplemental Material S8) was found between self-reported measures of LE and the proportion of correct responses, β = − 5.73, p = .002, suggesting that those children who reported higher effort demonstrated a higher proportion of correct responses across in-person sessions and telesessions.

Discussion

The current study tested techniques for collection of physiological measures of LE in NH children using the E4 wrist sensor during remote and in-person communication with a clinical provider. No differences in physiological, self-reported measures of LE and comprehensions scores between in-person sessions and telesessions were found. An effect of intervention duration on child self-reported (significant) and physiological (marginally significant) measures of LE was identified. The results suggest that those children who reported more effort demonstrated a higher proportion of correct responses.

Telecommunication Versus In-Person Communication

The lack of the effect of telepractice on children's physiological (electrodermal activity, BVP amplitude) and subjective measures of LE as well as their comprehension scores contradicts recent findings suggesting an increase in subjective measures of LE in adults during remote communication (Naylor et al., 2020; Perea Pérez et al., 2022). It is likely that several factors, such as participant characteristics (e.g., participant age and hearing status) and/or the study methodology (e.g., laboratory vs. natural environment settings) can account for the difference between the current and the previous studies results (Naylor et al., 2020; Perea Pérez et al., 2022). However, the current study provides a baseline for future research on telerehabilitation in children with and without HL. Thus, we examined multiple measures of LE in NH children while controlling for both the environment and technological aspects of the experiment.

It is also possible that the lack of the effect of telepractice on child physiological and behavioral measures of LE reflects the sensitivity of the various LE paradigms. While a passage comprehension task has been commonly used to measures LE in children with and without HL (Brännström et al., 2020; Rudner et al., 2018; von Lochow et al., 2018), the results indicate that this task might not be sufficiently challenging to detect changes in pediatric LE during telecommunication compared to in-person communication. Other cognitive-based measures of LE (e.g., single- or dual-task paradigms) may be used to tease apart the effect of remote and in-person communication on child LE (McGarrigle et al., 2014).

Effect of Intervention Duration

A significant increase in subjective measures of LE and a marginal decrease in physiological (electrodermal activity and BVP amplitude) measures of LE over time suggest an effect of the total intervention duration on these measures (Warren et al., 2007). The total duration is defined as the time period over which a specified intervention is presented and is one of several constituents (e.g., a dose, dose form, and frequency) that make up intervention intensity (Warren et al., 2007). An increase in subjective ratings of effort reported by children can, possibly, be accounted by a decrease in child interest and/or motivation to complete the experimental tasks due to the lack of the variability in the procedure (Francis & Oliver, 2018). The marginally significant changes in electrodermal activity and BVP amplitude may suggest, instead, a decrease in child LE and/or test anxiety due to familiarization with the procedure (Francis & Love, 2020; Francis & Oliver, 2018). The results of the current study, thus, align well with previous research suggesting that subjective and physiological measures might reflect different components of effort, such as assessed effort (i.e., how effortful listeners feel the task or context to be) and the effort that is actually exerted by a listener attempting to accomplish the task (Francis & Love, 2020; Strauss & Francis, 2017). The preliminary findings of the current study contribute to previous research on multidimensionality of LE (Alhanbali et al., 2019) and inform future studies on optimal intervention dosage parameters during aural telerehabilitation in children with and without HL (Allen, 2013).

Relationships Between Measures of LE and Performance

The results of the current study have demonstrated a positive association between subjective measures of LE and child comprehension scores. It is possible that children increased their use of cognitive resources and, therefore, performed better. According to the Ease of Language Understanding Model an increased use of cognitive resources improves performance and manifests itself as an increased subjective effort (Rönnberg, 2003; Rönnberg et al., 2013). Consequently, a positive association between subjective measures of LE and the proportion of correct responses is to be expected. It is also possible that the children improved their performance over time as a result of learning or the familiarization with the procedure as indicated by marginal changes in their physiological responses associated with both LE and/or affect (Francis & Love, 2020). The learning and/or the familiarization with the procedure may have allowed the children to allocate cognitive resources (e.g., attention) more efficiently improving their performance (Pichora-Fuller et al., 2016). However, this explanation is less likely since no significant association between physiological measures of LE and child proportion of correct responses was identified. The findings that subjective and objective measures of LE demonstrate different relationship with performance measures suggest that measures of LE may reflect different sources of, or cognitive responses to, increased listening demand (Francis et al., 2016; Francis & Oliver, 2018). For example, for subjective measures of LE the child may have reported the difficulty of the overall task, such as listening to a passage and experimenter's questions as well as answering the questions. Although, objective measures of LE (electrodermal activity, BVP amplitude) may have demonstrated child responses during active listening only.

Limitations of the Study

The first limitation of the study is the small sample size that makes the effect of intervention duration on electrodermal activity and BVP amplitude measures underpowered. A further power analysis using the mixedpower package in R (Version 4.3.0; R Core Team, 2023) has demonstrated that a minimum sample size of 22 and 25 subjects, respectively, is needed to achieve 80% of power and alpha level = .05. Consequently, the study's capacity to detect a true effect was limited, increasing the likelihood of Type II errors. The observed mean difference in electrodermal activity and BVP amplitude measures between the first two and the last two sessions, while not statistically significant, still aligns well with prior research suggesting a potential effect of the intervention duration on child LE/stress level (Francis & Oliver, 2018). However, due to the underpowered nature of this study, these results should be interpreted cautiously. Future studies with a larger sample size are necessary to confirm these findings and provide a more definitive assessment of the intervention's duration on child physiological measures.

Another limitation of the study is the study methodology. Future research needs to determine whether other tasks that include cognitive-based measures of LE (Lyberg-Åhlander et al., 2015; McGarrigle et al., 2014) may be more sensitive than the passage comprehension task (Brännström et al., 2020; Rudner et al., 2018; von Lochow et al., 2018) to detect the effect of remote communication on child LE. Previous studies have also demonstrated that participants may substitute the target question on mental effort with an easier question "How did I perform"? (Moore & Picou, 2018). Future studies need to examine whether children reflect on their performance rather than the amount of effort they exerted to explain the dissociation between subjective and behavioral and/or physiological measures of LE during remote and/or in-person communication (Moore & Picou, 2018).

At last, since we included physiological measures during the listening task only, it is unlikely that these measures reflect effort related to other aspects of communication, such as, for example, vocal effort (Hunter et al., 2020) or cognitive effort (Francis & Love, 2020). However, since the physiological system responsible for affect/stress overlaps with neural networks already associated with LE (Francis & Love, 2020), it is not possible to separate them using the present methodology. Nevertheless, from a clinical perspective, whether LE or the affective response was measured may not matter because intervention duration (Warren et al., 2007) can affect both constructs during aural telerehabilitation.

Conclusions

The findings of the study suggest the feasibility of the collection of physiological (electrodermal activity, BVP amplitude) measures of LE using the portable E4 wristband in school-aged NH children during remote and in-person communication with a clinical provider. The E4 wrist sensor is commonly used to monitor physiological responses associated with stress and anxiety levels (Vos et al., 2023; Zhou et al., 2020), cognitive effort (Aliakbaryhosseinabadi et al., 2023; Romine et al., 2022) and task engagement (Richardson et al., 2020). By monitoring child physiological measures, clinicians can, potentially, modify intervention parameters and adjust them to child individual needs improving the effectiveness of therapy. Although the study suggested no effect of telepractice on pediatric LE, the results demonstrated an effect of the total intervention duration on these characteristics. Despite some limitations, such as the small sample size and the type of task used, the study sets the groundwork for research that will help us to fully understand how telepractice affects effortful listening in children with HL using objective psychophysiological data during naturalistic interactive states. The clearer understanding of these factors will guide the implementation of aural rehabilitation strategies to achieve optimal learning outcomes during remote speech-language intervention services.

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Data Availability Statement

The data supporting the findings of this study are available upon request. Please contact the first author, Maria V. Kondaurova at maria.kondaurova@louisville.edu, for access to the data. The authors are committed to transparency and reproducibility in their research and will provide the data promptly to interested parties to facilitate further analysis and validation of the results.

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