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Research Article

ASAD: A Novel Audification Console for Assessment and Communication of Pain and Discomfort

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Pain and discomfort are subjective perceptions that are difficult to quantify. Various methods and scales have been developed to find an optimal manner to describe them; however, these are difficult to use with some categories of patients. Audification of pain has been utilized as feedback in rehabilitation settings to enhance motor perception and motor control, but not in assessment and communication settings. We present a novel tool, the Audification-console for Self-Assessment of Discomfort (ASAD), for assessing and communicating pain and discomfort through sound. The console is a sequence of increasing pitch and frequencies triggered at the press of buttons and displayed as a matrix that can be associated with the subjective perception of pain and discomfort. The ASAD has been evaluated in its ability to capture and communicate discomfort, following a fatigue test in the lower limbs with thirty healthy volunteers, and compared to the most common self-reported methods used in the NHS. (The National Health Service (NHS) is the publicly funded healthcare system in England and one of the four National Health Service systems in the United Kingdom.) This was a qualitative, within subjects and across groups experiment study. The console provides a more accurate assessment than other scales and clearly recognizable patterns of sounds, indicating increased discomfort, significantly localized in specific frequency ranges, thus easily recognizable across subjects and in different instances of the same subject. The results suggest a possible use of the ASAD for a more precise and automatic assessment of pain and discomfort in health settings. Future studies might assess if this is easier to use for patients with communication or interpretation difficulties with the traditional tools.

1. Introduction

Obtaining accurate measurements of pain is difficult even for professionals, especially if the patients have special needs, such as children [1, 2], and others with communication or neurological disabilities [3–5]. An inaccurate diagnosis can result in adverse side effects, including over- or undermedication, or misdiagnosis and over-/undertreatment [6]. Studies have shown that inadequate pain treatment is associated with an increase in avoidance behaviors and social hypervigilance and can have long time consequences, which is observable, for example, in pediatric pain [7] and preterm pain [8, 9].

Other problems of communication have been observed in patients under mechanical ventilation, where vocal cords are blocked due to the endotracheal tube in intensive care; here, patients struggle to make themselves understood by the health care personnel, exposing the necessity for implementing other methods for assessing pain as communication aids [10]. In this sense, difficulties in chronic pain management or the importance of continued pain assessment is critical in assisting pain communication with patients [10, 11], particularly when assessing pain remotely [12]; a study has shown that half of the patients with chronic pain under aggravated circumstances, such as COVID-19 lockdown, altered their pain management style, by increasing their medication intake, due to the disruption of pain management facilities during the pandemic [13, 14].

1.1. Pain Measurements. Commonly in clinical settings, pain assessment is done through self-reporting [3, 15–17]. The

Numeric Rating Scale (NRS) [18, 19] and Visual Analog Scale (VAS) [20] are the most common tools utilized for the assessment of pain [21–23]. However, some studies have reported that elderly with dementia have complications in interpreting traditional self-report scales [24]. Also, when patients have additional needs, such as cognitive impairment or reduced ability to communicate, they might experience difficulties in self-reporting pain or discomfort [15, 25]. Due to grimacing, a facial expression in which the mouth and face are twisted to show disgust, disapproval, or pain, the results from the self-report scales, such as the Pain Assessment Checklist for Senior with Limited Ability to Communicate (PACSLAC) [26] or the Abbey Pain Scale (APS) [27], maybe misinterpreted to another emotion such as sadness. Some studies have tried to overcome these barriers by incorporating an automated facial analysis tool, i.e., ePAT [28], showing promising results in elderly with advanced dementia. Also, in the clinical setting, self-assessment methods are subject to presentation bias [29], and there are a series of other limitations such as the nature of the scales [30], the need to provide continuous monitoring, especially in intensive care; or idiosyncratic factors of the observer [31, 32]; cultural background [31, 33, 34]; and gender [35]. These limitations have led to researching new methodologies to evaluate pain based on nonverbal indicators [36], which is also the effort of this paper.

Various modalities have been developed to overcome these difficulties in self-assessment, for example, using nonverbal expressions such as facial expressions [1, 36–41], facial electromyography (EMG) [42], bodily movements [43–45], or exploring sound analysis for the automatic recognition and monitoring, which for example has been utilized with COVID-19 patients and its symptoms such as breathing, coughing, or sneezing sounds [46].

1.2. Auditory Feedback. Auditory feedback systems address the physiological barriers in order to improve self-efficacy in chronic pain rehabilitation [47–50], sports [51, 52], motor learning [53, 54], or stroke rehabilitation [55], by adding acoustics to enhance motor perception and motor control in arm movement trajectories, or by optimizing and correcting movement in challenging exercises [56, 57]. The utilization of sound enables listeners to recognize small and even invisible variations, as manifested indistinguishable changes in level, frequency, or rhythm; the result is a series of sound "fingerprints" associations [58]. Sound as feedback is particularly beneficial as it increases the bandwidth of communication; widening the sensory channel is utilized [59]. Also, the data conveyed by sound is a complement of the information provided visually; therefore, sound provides data that might be difficult to be visualized otherwise [59].

However, the assessment of the auditory feedback in movement control is a complex task. Discomfort is a sophisticated multidimensional, subjective experience, and the report of discomfort is related to numerous variables [60].

Commonly, data values are used to change the parameters of sound. This method is referred to as *audification* [61]. Flowers [62] has summarized the principles of auditory graphs for the development of an auditory display aiming to facilitate motor learning. In his work, the perception of changes in data profiles is simplified by mapping changes in numeric values to pitch height. Mapping pitch heights to numeric magnitudes afford the perception of function shape or data profile changes. Timbre differences can be useful to minimize perceptual grouping rather than different rhythms [63]. Pitch height can be used to display vertically aligned data, such as vertical movement [61]. For example, Van Hedel et al. [64] explored obstacle avoidance during walking at different pitch heights.

In the above literature review, we have identified the limitations of self-report scales for pain and discomfort and the difficulties connected with their use in some patients' cohorts. Also, we have reviewed the common use and approach to auditory feedback and automated pain recognition. Pain communication is critical, and especially in intensive care, highlighting the need to research other methods for assessing and communicating pain and discomfort that are easy to use and communicate. Thus, in the next session, we present and evaluate a novel console for assessing and communicating discomfort.

2. The ASAD Console

The Audification-console for Self-Assessment of Discomfort (ASAD) is composed of $8 \times 6 + 2$ sets of sounds (pitch and frequency) laid out in a continuous sequence, with a notation similar to standard piano key frequency scales, that can be activated at the press of a button (or square or the screen). The pitches follow a musical notes scale that goes from (A0) 27.5 Hz to (B8) 7,902.133 Hz in pitch (see Figure 1). Pitch is what allows us to perceive a sound as higher or lower.

To make the console usable for elderly people, as well as younger ones, in the development of the ASAD console, we have used sounds in the perceivable hearing range of old persons (~20 to ~8,000 Hz) [65], as younger people are able to hear more. Also, considering the sound reflection conditions of an indoor space, each sound was incremented by 27.5 Hz in order to have a distinctive perceptible difference between the different buttons. This resulted in the use of the human auditory system's most sensitive frequencies (between 2,000 and 5,000 Hz) [66, 67], using a frequency for equal-tempered scale ($A = 440$ Hz) with the following formula:

$$p = 69 + 12 \times \log_2 \left(\frac{f}{440Hz} \right). \tag{1}$$

To assess and communicate, pain suffers are asked to press the buttons on the console at their leisure in order to find the pitch (or button on the console) that can be best associated with their pain and discomfort sensations, where the two buttons placed on the left top of the matrix are used to indicate where the start of the pitch sequence is located.

3. Materials and Methods

3.1. Study Design. This was a qualitative, within subjects, and across group experiment study.

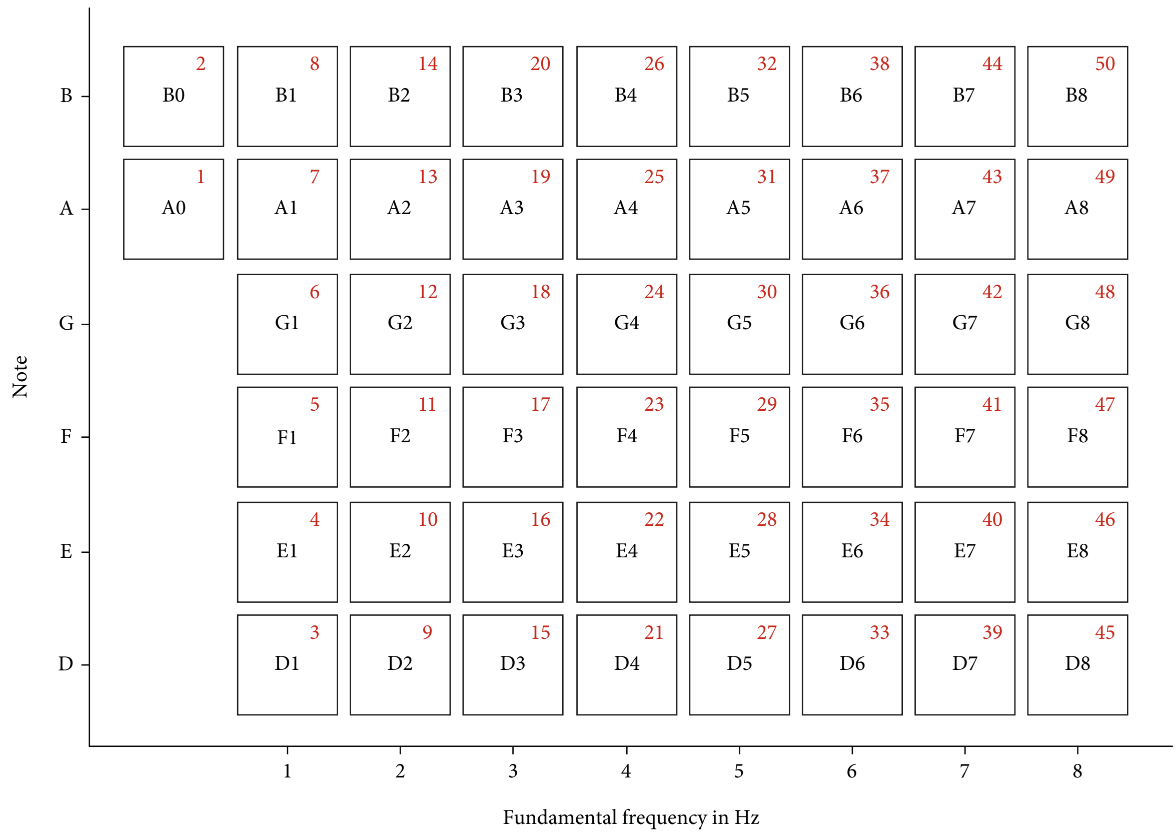

Figure 1: Notes ordered by pitch (frequency) on the ASAD console.

Literature has highlighted the need to research novel methods for the communication and assessment of pain which can be more accessible to all categories of sufferers. We have developed a novel console, named ASAD, which is hypothesized, can support the mapping between the note pitch and timbre (or frequency) and the sensations felt.

In order to establish if the ASAD console is able to capture subjective assessment of discomfort in an objective manner (within subjects and across groups), we have developed an experiment to compare the discomfort before and after a lower limb fatigue test [68], on the strength of the results of Gefen et al. [69] that highlights the comparative differences and bodily adaptations between regular wearers and nonwearers of heels on muscle fatigue and discomfort.

We have considered three distinctive cohorts of participants: (i) regular wearers of high heels (WE-HH), (ii) nonwearers of high heels in heels (NW-HH), and (iii) nonwearers of high heels with no heel shoes (NW-NH).

We did not consider the group wearer with no heels (WE-NH), as due to the COVID-19 pandemic we had to stop the collection of data. We asked all cohorts to report their discomfort or pain, before and after laboratory-induced lower limb fatigue test [68], and considered the patterns in both the standard NHS questionnaires for the assessment of pain and the ASAD console.

Thus, we formulated the following questions and hypothesis:

RQ1. Do the NHS self-reported questionnaires and the ASAD capture the same construct?

H1. We hypothesized significant differences in questionnaires' responses before and after the fatigue test to translate into differences on the ASAD console (within subjects and across groups)

RQ2. Is the ASAD able to identify differences between the three groups of participants as in literature?

H2. The ASAD is able to reproduce the literature findings

RQ3. Do pain and discomfort translate into patterns?

H3. We hypnotized that significant discomfort after the fatigue test would translate into recognizable patterns

The study variables are reported in Table 1.

3.2. Participant Selection. Thirty-one healthy participants were recruited for the study through social media advertising, university mailing lists, and word of mouth. All participants provided informed consent and were compensated with a voucher.

The inclusion criteria for the study were to present no condition that would limit the ability to conduct a physical stress test (assessed with the risk identification questionnaire [70]). Among the risk factors were the inability to perform movements, contraindications, physical condition, and other possible limitations such as people with physical impairments, surgeries, or any other injuries that limit their ability to produce movements [70]. We excluded people presenting any heart problems and people with focalized pain areas, motor control problems, and balance issues. The criteria for the development of this self-assessment tool were

Table 1: Variables in the study. IV = independent variables; CV = covariable; DV = dependent variable.

IV	CV	DV
WE-HH NW-HH NW-NH	Gender, age, weight, height, BMI, footwear size, dominant foot, the amount spent exercising weekly, time spent walking, and time spent sitting	Sound difference on the ASAD console (within participants and across groups)

adopted from [70–72], and have reported a normal BMI and level of physical activity, no or very mild discomfort in various locations of the body, and having foot dexterity and a footwear size in the common range are reported.

We discarded the data from one participant due to an incomplete questionnaire, leaving 30 volunteers of age between 18 and 55 years (mean = 31.43; SD = 10.31) of which 17 were females and 13 males. Among the volunteers, seven were regular wearers of high heels, and twenty-three were nonwearers. Further recruitments were not possible due to COVID-19 lockdown and the need for the study to meet people face to face; however, we found significant results which are reported below. Participants on average were in the normal weight category (body mass index (BMI) mean = 24.06, SD = 4.82), with a normal to fit level of daily activity (time seated mean = 5.72 hrs, SD = 3.045; time walking mean = 2.67 hrs, SD = 2.023; 76.6% exercise at least once a week; 10% did not exercise) and a footwear size (mean = 7.23 UK size, SD = 2.26) with a minimum of 4 and a maximum of 11. In terms of discomfort before the study's fatigue test, participants reported an overall discomfort not higher than very mild on average in various locations (20% lower back, 6.7% abdominal area, 10% foot and ankle, 3.3% leg, and 3.3% hip), thus were included in the study.

3.3. Tools

3.3.1. Prescreening Questionnaire. Participants had to complete a prescreening questionnaire, adapted from the risk identification questionnaire [70] and excluded if at risk. The criteria for the development of this self-assessment tool were adopted from [70–72]. Finally, we assessed their levels of discomfort during movement before the fatigue test in the prequestionnaire.

3.3.2. Self-Reported Discomfort with the ASAD Console. The ASAD console was used to assess discomfort in the various part of the body involved in the test, before and after fatigue. A volunteer would report a sound by selecting any button on the ASAD console, before and after the intervention, and the absolute difference in pitch variation was calculated as a measure of the change that has taken place due to fatigue in the various muscles under inquiry (Figure 2).

3.3.3. Self-Reported Discomfort with Combined Questionnaire. Seven well-known scales were utilized such as (i) Numerical Rating Scale (NRS), (ii) Visual Analog Scale (VAS) comfort [73–77], (iii) Color Analog Scale (CAS), (iv) Faces Pain Scale, (v) pain drawing [78], (vi) Verbal Rating Scale (VRS) [79], and (vii) McGill Pain Questionnaire-short form or SF-MPQ [80].

The combination of several scales for the measurement of discomfort and pain allows us to combine on a single scale, several unidimensional measures of pain intensity as an estimation of pain severity, and the extent of pain (Figure 3).

3.3.4. Movements before and after the Fatigue Test. First, volunteers had to walk in a straight line for four meters, turn around, and come back to the start line (walking movement). Following, they had to walk towards a stool located 3 meters away, sit for 4 seconds, stand up, and walk back to the initial position (sitting and standing movement). Finally, they had to walk again 3 meters towards a small object lying on the floor (7.5 cm in diameter, 4 cm of thickness, and a weight of 380 g), pick it, turn around, and come back to the initial position (picking object movement) (see Figure 4).

3.3.5. Muscular Fatigue Test. The muscular fatigue exercises were adopted from Lunsford and Perry [68]; they required a few repetitions of eccentric-concentric muscle contractions to be completed. These exercises have been shown to reflect muscular endurance to fatigue, rather than strength [68, 81]. This is a standard methodology for inducing muscular fatigue in a laboratory setting, with the objective to stress walking patterns [68]. Afterward, the volunteers made several repetitions of forced contraction (to load the subject foot as at midstance and push-off), with the possibility to end the test in case of self-report exhaustion [69]. This method to reproduce muscular fatigue only affects the lower limb and requires a few repetitions of heel inclination to be completed. In the experiment reported here, participants were asked to make a minimum of 25 repetitions and following as many more repetitions as possible until they felt fatigued or had a burning sensation in the lower limbs' muscles to an upper of 40 repetitions for the fatigue test and then rested for a few seconds and repeated the movements for a second time (Figure 5).

3.3.6. Statistical Tool. IBM SPSS was utilized to conduct the statistical analysis.

3.4. Setting. The experiment was conducted at the Immersive Virtual Laboratory at University College London, in the United Kingdom.

3.5. Data Collection. After undergoing the prescreening, fitness questionnaire, and reporting existing discomforts, participants had to perform a set of movements before the fatigue test and perform the fatigue test. Following the fatigue test, volunteer high heel wearers were allocated to the condition WE-HH, while nonwearers were allocated at

Figure 2: Participants using the questionnaires and the ASAD console.

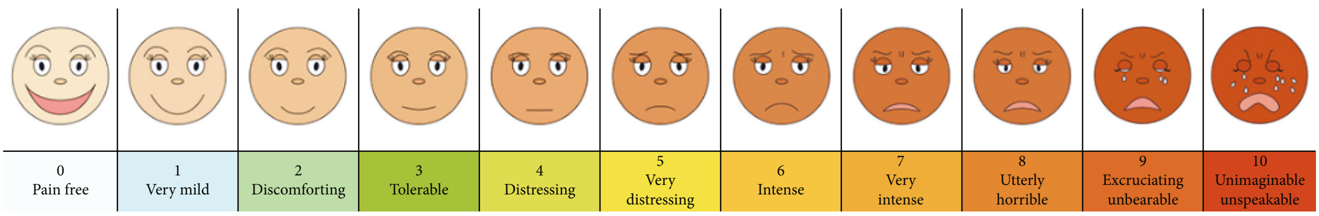

Figure 3: Format of the combined questionnaire.

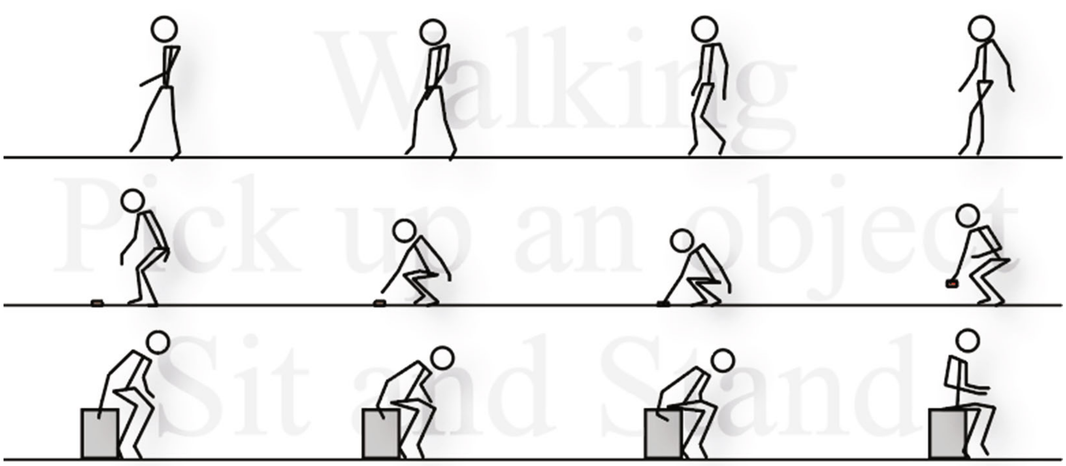

Figure 4: Movements before and after the fatigue test.

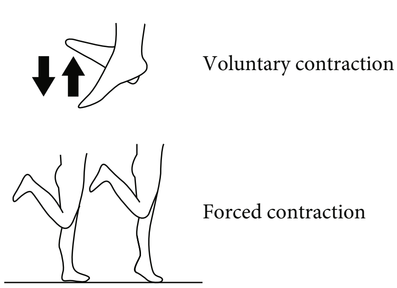

Figure 5: Fatigue tests; voluntary and forced contraction exercises.

random to one of the two conditions: no heels (NW-NH) or high heels (NW-HH) and performed the post fatigue test movements (see Table 2).

3.6. Statistical Methods. The questionnaire scores for each participant were calculated, and a Shapiro-Wilk test of normality was applied, revealing the data was skewed. Thus, the pre- and postresponses to the self-assessment questionnaire (as pairs) were analyzed with a nonparametric-related design (same subjects) using Wilcoxon signed test in areas of interest (right and left legs), balance issues (right, left, front, and back), discomfort areas (lower limb, lower back, abdominal, knee, and foot and ankle), energy cost, average

Table 2: Experimental procedure.

Prescreening	Discomfort before fatigue	Prefatigue movements (no heels)	Fatigue test	Postfatigue movements (footwear according to condition)	Discomfort after fatigue
Prescreening questionnaire (i) Fitness questionnaire	(i) Combined questionnaire (ii) ASAD console questionnaire	(1) Walking (2) Sitting/standing (3) Picking object	(4) Voluntary contraction (VC) (5) Forced contraction (FC)	(6) Walking (7) Sitting/standing (8) Picking object	(i) Combined questionnaire (ii) ASAD console questionnaire

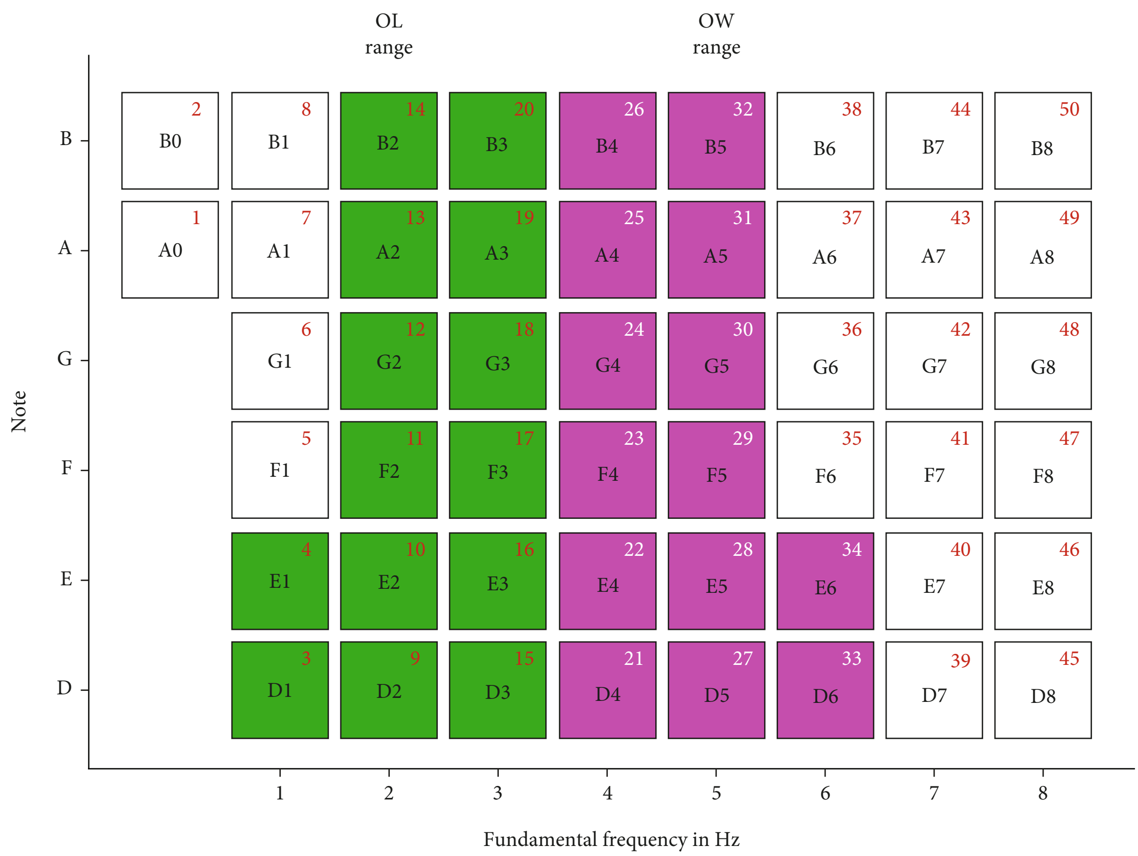

Figure 6: ASAD console heat map of the most used keys, where the balloons with the letter (A) represent mean results before the fatigue test, balloons with letter (B) represent mean results after the fatigue test, and the colors indicate the degree of significance; white balloons are not significant, blue were mildly significant, and yellow balloons were significant.

discomfort (overall, overall best, and overall worst), motor control problems, and balance issues.

We also analyzed the sound patterns in the ASAD console by calculating the descriptive mean values and the total of the cohort.

Finally, we analyzed the data as independent groups using two ways: as pre- and postvalues or as the difference (Dif) between pre- and postvalues and also using a Kruskal-Wallis H test for 3+ conditions (WE-HH, NW-HH, and NW-NH).

3.7. Ethics. The study was approved by the University College London, Research Ethics Committee (REC) with data protection number 15487/001.

4. Results

4.1. RQ1: Combined Questionnaire Results Compared with the ASAD. We run a within-subject comparison between the combined questionnaire results versus the ASAD ability to capture pain and discomfort considering the difference between the pre- and postresponses reported with both tools with a Wilcoxon signed test.

With the combined questionnaire, a significant difference was found for nonwearer in high heels for the lower limbs ($Z = -2.496$, $p = 0.013 < 0.05$), abdominal muscles ($Z = -2.356$, $p = 0.018 < 0.05$), knees ($Z = -2.724$, $p = 0.006 < 0.05$), and foot and ankle ($Z = -3.426$, $p = 0.001 < 0.05$). No other result was significant.

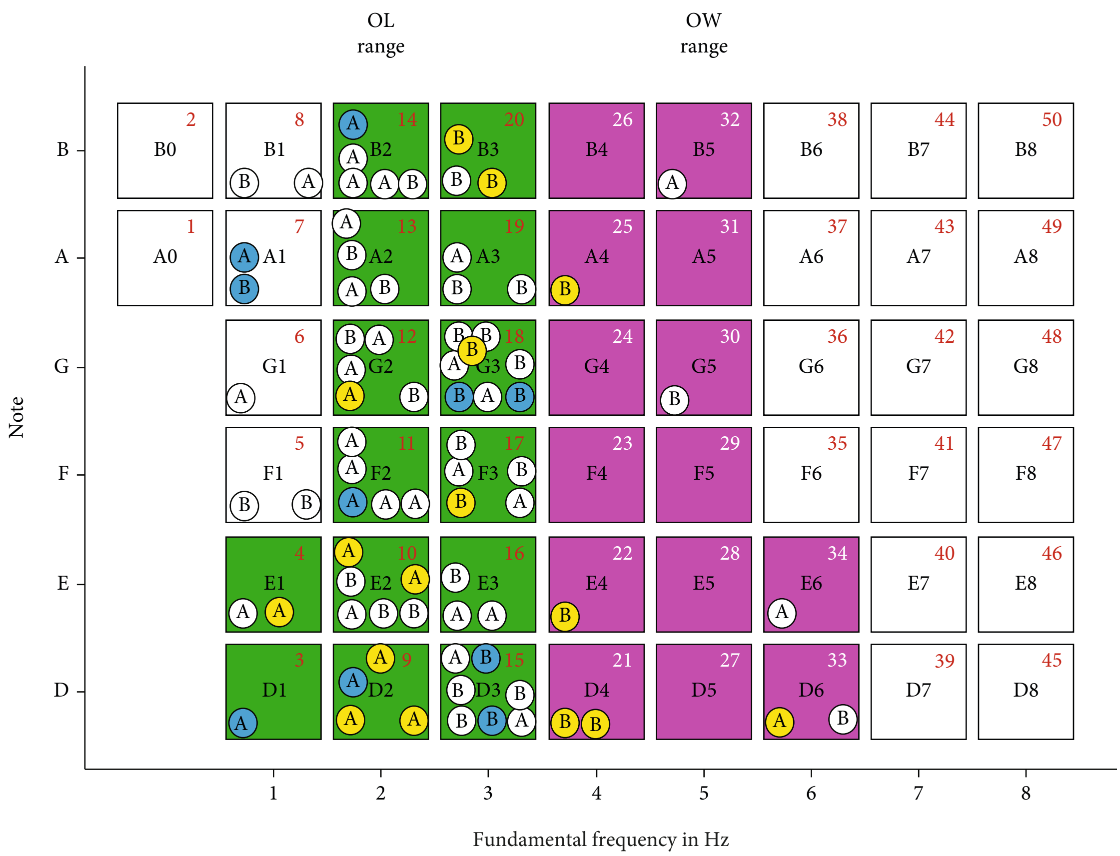

Figure 7: ASAD console of overall lowest (OL) and overall worst (OW) ranges in all cohorts. The balloons with the letter (A) represent mean results before the fatigue test, balloons with letter (B) represent mean results after the fatigue test, and the colors indicate the degree of significance; white balloons are not significant, blue were mildly significant, and yellow balloons were significant.

For nonwearer with no heels, a significant difference was found for foot and ankle NW-NH (F&A) ($Z = -2.041$, $p = 0.041 < 0.05$). No other result was significant.

For wearers in high heels, there was no significant difference.

Considering the pain and discomfort reported with the ASAD, we found all the same results as before, plus additional significant results.

For nonwearers in high heels, a significant difference found on the lower limbs ($Z = -2.614$, $p = 0.009 < 0.05$), abdominal muscles ($Z = -2.237$, $p = 0.025 < 0.05$), foot and ankle ($Z = -3.486$, $p = 0.000 < 0.05$), left leg ($Z = -2.672$, $p = 0.008 < 0.05$), and a mildly significant difference on the right leg ($Z = -1.837$, $p = 0.066 < 0.08$); a significance was found for overall discomfort when pain is at its lowest ($Z = -3.424$, $p = 0.001 < 0.05$), while all other cases were not significant.

For nonwearer with no heels, a significant difference was found for the foot and ankle ($Z = -2.023$, $p = 0.043 < 0.05$), a mild significance on the lower limbs ($Z = -1.826$, $p = 0.068 < 0.08$), and a mild significance in the lower back ($Z = -1.826$, $p = 0.068 < 0.08$) and left leg ($Z = -2.023$, $p = 0.043 < 0.05$); a significance was found for overall discomfort when pain is at its lowest ($Z = -2.023$, $p = 0.043 < 0.05$). No significance was found for abdominal muscles and knees.

When considering heel wearers in high heels, there was a mild significance for the abdominal muscles ($Z = -1.841$, $p = 0.066 < 0.08$), overall discomfort at its worst ($Z = -1.997$, $p = 0.046 < 0.05$), and overall average discomfort ($Z = -1.802$, $p = 0.072 < 0.08$). Mild significance was found in wearers for the balance on the right ($Z = -1.826$, $p = 0.068 < 0.08$). No other significant difference was found.

4.2. RQ2: Difference across Groups with ASAD. When comparing the three independent groups of participants, WE-HH, NW-HH, and NW-NH, the self-reported response difference on the ASAD console was considered by subtracting the postfatigue test response from the pretest response.

A Kruskal-Wallis was conducted, and the results showed a mild significance for the difference in left leg pain ($\chi^2(2) = 7.753$, $p = 0.051 < 0.08$), a mild significance for the difference before and after the fatigue test in the right leg pain ($\chi^2(2) = 7.134$, $p = 0.068 < 0.08$), a significant difference in the foot and ankle difference ($\chi^2(2) = 8.162$, $p = 0.043 < 0.05$), and a statistical significance in the overall discomfort when pain is at its lowest ($\chi^2(2) = 8.191$, $p = 0.042 < 0.05$). No other body areas showed significant results.

4.3. RQ3: Note Pattern on the ASAD Console. We analyzed how significant results translate into patterns the ASAD

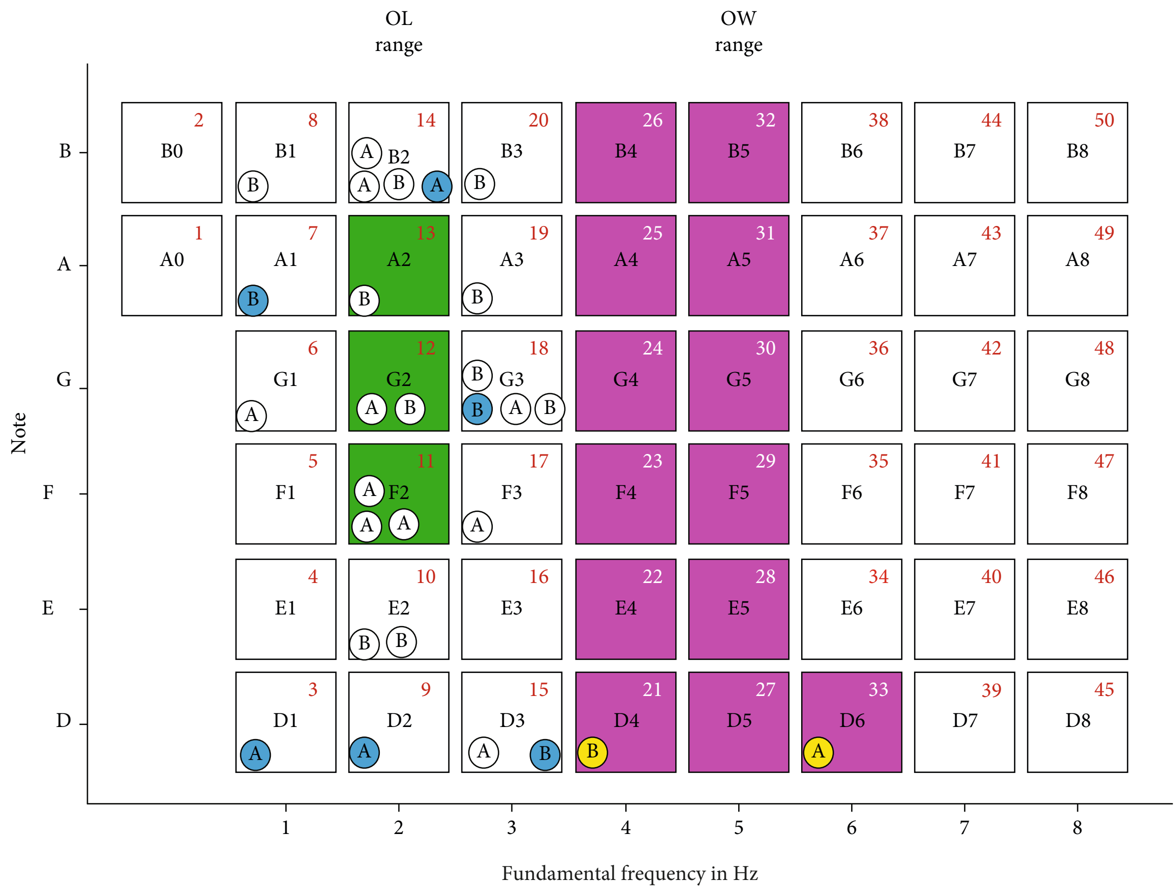

Figure 8: WE-HH. The balloons with the letter (A) represent mean results before the fatigue test, balloons with letter (B) represent mean results after the fatigue test, and the colors indicate the degree of significance; white balloons are not significant.

console. As shown in Figure 6, significant results have a variation of ±5 as mean key-value change of note before and after the fatigue test, while mildly significant results have a variation of ±4 (see Table 4 to 8 in the Additional Material).

We were able to observe that the average category of discomfort had the highest pitch ranges on the ASAD console for overall discomfort at its worst in all cohorts (between 21 and 34 in fundamental frequency), while the overall discomfort at its lowest was the smaller pitch ranges (between 4 and 20 in fundamental frequency) (see Figure 7). If we use this information to analyze each of the groups individually, we can observe that, under discomfort, overall worst in nonwearers moved from overall lowest to overall worst in foot and ankle in both conditions (high heels and no heel) (see table 6 in the Additional Material). This was also true for nonwearers with no heels on the left leg (see table 4 in the Additional Material).

When analyzing the ASAD responses, it is possible to observe that the main heat area is under overall lowest being the most used ASAD area, between 9 and 20, which is the limit of overall lowest. We can also observe that G3 and D3 were the most used keys in the ASAD console (frequency level 3 in Figure 6). On the other hand, the most used key on significant results is D2 with 3 results (see Figure 6), indicating a tendency towards overall lowest ranges in the ASAD console.

When analyzing the ASAD movement segmented by cohort, we can observe that wearer of high heel in heel (see Figure 8), overall lowest range only encompasses frequencies between 11 and 13 (level 2 of the frequency domain), and it is concentrated in between F and A notes, in comparison with overall worst (OW), which is almost the same as in Figure 7. This indicates that discomfort utilized a large range OW, and the lowest range overall lowest (OL) is a smaller range, indicating a more focalized discomfort in the most skilled cohort WE-HH.

When there is low discomfort, high-heel wearers have a shorter range of OL and larger range of OW.

When there is *high discomfort* (see Figure 9), OL ranges are larger, and OW becomes shorter. This implicates that as discomfort is incremented, the responses in OW have a more focalized range of responses towards higher frequencies. On the contrary, in OL, the opposite happens; under *low discomfort*, the frequency range is shorter and under high discomfort is larger.

In nonwearer with no heels (see Figure 10), we can observe that OW frequency range is incremented in comparison to the previous cohort; also, (OL) range is larger, due to the absence of heels (skilled action), where low discomfort starts from a lower frequency (4).

It is possible to observe that when discomfort is present, OW ranges are shorter but in high frequency (frequency

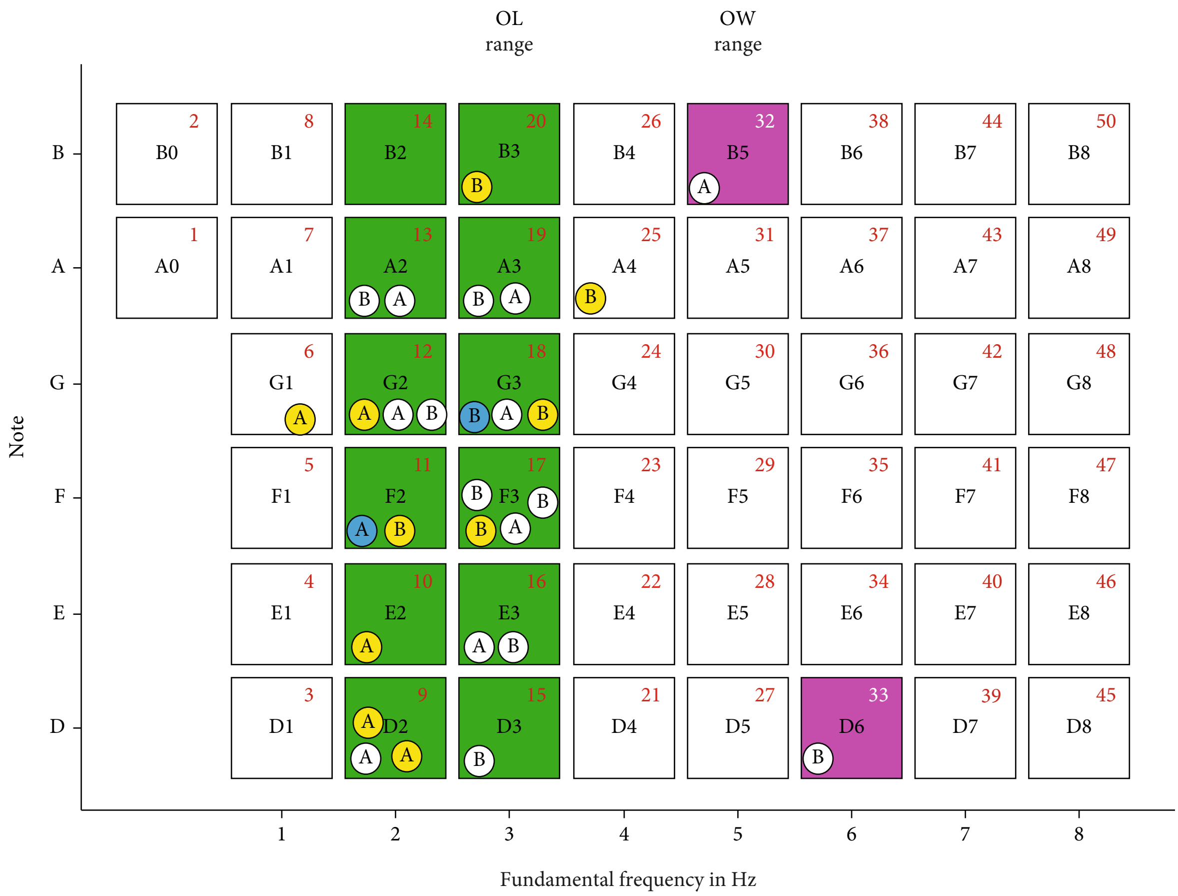

Figure 9: NW-HH. The balloons with the letter (A) represent mean results before the fatigue test, balloons with letter (B) represent mean results after the fatigue test, and the colors indicate the degree of significance; white balloons are not significant, blue were mildly significant, and yellow balloons were significant.

levels 5 and 6). As discomfort decreases (less skilled action), the OW range starts to move to lower frequencies.

When analyzing significant results, we can observe that wearers have a low note OW range (D note) (see Figure 8), while nonwearers had a larger spectrum (frequency levels 2 and 3) and in note, covering the whole spectrum (notes A to D). But with no heels, nonwearers showed a concentration in their responses towards the lower notes (E and D) and low frequency.

When analyzing mild significant results, we can observe that wearers utilized more the OL range, using a large range in notes and lower frequencies (1 to 3) which are concentrated in the OL spectrum. In contrast with NW-HH, the difficulty of the exercise focalized their responses into mid-notes (G and F) in a low frequency (2 and 3), which allow us to observe a concentration of responses in the OL range when a skilled action is required. When the skilled action is out (no heels), nonwearers show a lower note (D note) and but same frequency tendency (2 and 3). Therefore, *high discomfort* follows a midnote tendency on frequency level (between 2 and 3) and under *low discomfort* follows a low note (D) tendency. NW concentrate their mild significance in comparison with WE that had a larger range (not concentrated).

5. Discussion

This study investigated whether the ASAD captures the same construct as the self-reported combined questionnaire of discomfort, which allows scoring bodily sensations with faces, quality with the color and intensity with the number. Our findings show that the ASAD console is able to capture fine-grained changes in bodily perceptions in a more susceptible manner than the self-reported combined discomfort questionnaire and through sound. Thus, we speculate that the ASAD console records the same constructs as the combined questionnaire, addressing the estimation of pain.

Also, the ASAD is able to replicate the results in the literature, and differences were found in various parts of the body between wearers and nonwearers of high heels, exposed to the fatigue test. In particular, the findings indicate that nonwearers of high heels are the most affected cohort after the fatigue test (whether or not they are wearing high heels), and if balance is compromised due to muscle fatigue using high-heels, there is a tendency to compensate on the other leg. This difference between wearers and nonwearers of high heels reassures us that the ASAD console is a valid tool for measuring discomfort able to replicate previous literature findings in lower limb muscular fatigue

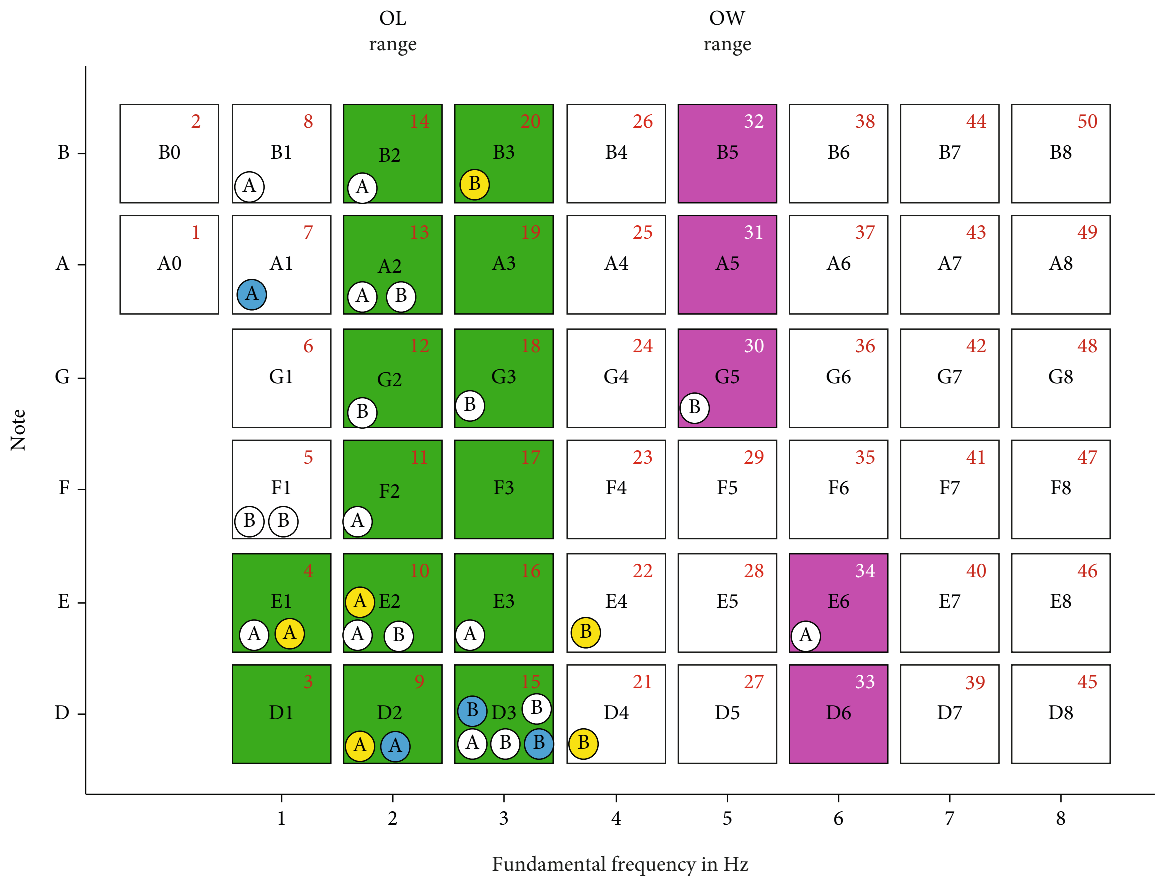

Figure 10: NW-NH. The balloons with the letter (A) represent mean results before the fatigue test, balloons with letter (B) represent mean results after the fatigue test, and the colors indicate the degree of significance; white balloons are not significant, blue were mildly significant, and yellow balloons were significant.

during high-heeled movement control [69, 82, 83] (see Table 3, hypothesis 2).

In addition, we found that there are clear visual patterns on the ASAD console in correspondence with significant results. Results showed that a significant difference between the pre- and postlower intervention mean values translate on the ASAD console as a variation of ±5 in key-value change while mildly significant results translate in a variation of ±4 in key-value change (thus, hypothesis 1 is accepted; see also Tables 4 to 8 in Additional Material) (see Table 3, hypothesis 1). We suggest that the applicability of such patterns might be further investigated in future discomfort studies.

When analyzing the ASAD patterns of sounds segmented by cohort, we were able to observe that the overall worst discomfort increases; responses are more focalized in a short frequency range for nonwearers (the group most affected), while the opposite happens to wearers (group less affected by the fatigue exercise; see also 4 to 8 in Additional Material). In particular, wearers on high-heels utilize lower notes and have a larger frequency range spectrum, covering the whole spectrum. Similarly, nonwearers with no heels showed a concentration in their responses towards the lower notes (E and D) and low frequency. Thus, it appears that skilled participants show a concentrated range of responses in lower notes and low frequency on the ASAD console. Again, we suggest that the applicability of such patterns might be further investigated in future discomfort studies.

In this study, we have extended the state of the art by showing the possibilities of using audio to report acute discomfort by introducing a wider matrix scale, capable of identifying smaller changes in discomfort as compared to the most traditional scales used in care settings. We have identified differences on how different cohorts of participants utilize the console. Analysis of these differences shows that the physical condition of the participants is a strong predictor in the range of pain described.

We present a system that provides further data than traditional scales in the analysis of pain and discomfort in movement.

The impact of these findings opens a new thread of possibilities in the development of new feedback techniques using audio, where the feedback is bespoken to the characteristics of the user for new pain rehabilitation systems.

5.1. Study Limitations. This study was limited by the COVID-19 lockdown, as had to reduce the number of participants when the lockdown occurred. We were able to

Table 3: Summarizing hypothesis, statistical test utilized, and significant results from this study.

Hypothesis 1: we hypothesized significant differences in questionnaires' responses before and after the fatigue test to translate into differences on the ASAD console (within subjects and across groups).	
Statistical text utilized: Wilcoxon	Cohort: wearers vs. nonwearers (body areas)
Combined questionnaires results	A significant difference was found for nonwearer in high heels for the *lower limbs*, *abdominal muscles*, *knees*, and *foot and ankle*, and some being mildly significant for nonwearer with no heels, a significant difference was found for *foot and ankle*.
ASAD console results	When considering individual body areas on the ASAD console, we found more results. A significant difference was found for nonwearers in high heels on the *lower limbs*, *abdominal*, and *foot and ankle*. Also, a significant difference was found for nonwearer with no heels on the *foot and ankle* and a mild significance on the *lower limbs* and *lower back*. When considering heel wearers in high heels, there was a mild significance for the *abdominal muscles*. In addition, nonwearers have reported more significant areas of discomfort using the ASAD console (*lower limb*, *lower back*), which in comparison with the combined questionnaire results, the ASAD console provided further results. In the ASAD console, significant changes in discomfort are reported as 5 frequencies change in any direction (lower or higher sound frequency), while mildly significant results have a variation of 4 frequencies in any direction.
Statistical text utilized: Wilcoxon	Cohort: wearers vs. nonwearers (legs)
ASAD console results	A significant difference was found for nonwearer (NW) in high heels (HH) on the *left leg* and a mildly significant difference on the *right leg*. A significant difference was found for nonwearer (NW) in no heels (NH) on the *left leg*. For wearers (WE) in both high heels (HH) and no heels (NH) and on the right or left leg, there was no significant.
Hypothesis 2: the ASAD is able to reproduce the literature findings.	
Statistical text utilized: Kruskal-Wallis	Cohort: WE-HH, NW-HH, NW-NH
ASAD console results	A significant difference was found in foot and ankle and in the overall discomfort when pain is at its lowest. Also, results showed a mild significance for the difference in left leg pain and for the right leg pain. In particular, we identify differences between the three groups of participants, the findings indicate that nonwearers of high heels are the most affected cohort after the fatigue test (whether or not they are wearing high-heels), and if balance is compromised due to muscle fatigue using high heels, there is a tendency to compensate on the other leg as shown in [69, 82, 83].
Hypothesis 3: we hypnotized that significant discomfort after the fatigue test would translate into recognizable patterns.	
Statistical text utilized: Wilcoxon	Cohort: wearers vs. nonwearers (overall discomfort)
ASAD console results	There is a significant difference between wearer and nonwearer self-report of discomfort on high heel when considering the whole body overall lowest, average overall, and overall worst.
ASAD console results	When considering the whole body, on the ASAD console, high discomfort corresponds to significant high pitch in all cohorts (wearer and nonwearers). Also, there is a different pattern of reporting across the cohorts. Wearer on high heel keeps the overall low discomfort range within 3 low frequencies (11, 12, 13) on the ASAD console (level 2 of the frequency domain), and it is concentrated in between F and A notes, while the overall worst reporting is spread across 13 higher frequencies (21 to 33). Nonwearer on high heels spread their overall low discomfort range within 8 low frequencies (9-20), while the overall worst reporting is kept within 2 specific higher frequency (32 and 33). Nonwearer on no heels spread overall low discomfort within 14 low frequencies (4 to 20), while the overall worst reporting is kept within 5 higher frequency (30 to 34). Results show that wearers overall worst have a low note range (D note), while nonwearers covered the whole spectrum (A to D notes) to report pain. Without heels, nonwearers showed a concentration in their responses towards the lower notes (E and D). The ASAD console is a more sensitive tool when reporting overall body discomfort as compared to a questionnaire. At the same time, it provides clear patterns in the concentration of the responses for each cohort that displays the impact of the test in the report of pain and discomfort.

complete the study and found significant results even with only 30 participants. Future studies might want to test further the ASAD console and benefit from the ability to capture all dimensions of discomfort with one sound.

6. Conclusion

We presented the ASAD console as a tool for assessing pain and discomfort and demonstrated that it is capable of assessing discomfort as well and better than a questionnaire, and it is able to discriminate among groups with different characteristics as in literature. We have identified patterns of key-change values and specific frequencies that can be useful in future studies looking to utilize only the ASAD console as an assessment and communication tool for pain and discomfort. In addition, our findings indicate that the ranges utilized to describe the discomfort depend on the participant's fitness level, where wearers had a larger overall worst zone in frequency, versus nonwearers who had larger overall lowest ranges. Results indicate that wearers in high heels and nonwearers with no heels who were skilled in the use of such footwear used the lower notes (E-D), while nonwearers in high heels felt uncomfortable with such footwear utilized the whole spectrum of notes to report discomfort. Future research could investigate wider uses of the ASAD console also with patients with communication or interpretation difficulties with the traditional tools.

Data Availability

The quantitative (continuous) data used to support the findings of this study are included within the supplementary information file.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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Supplementary Materials

The supplementary material reports the analysis of the patterns in the responses of the participants using the ASAD console on each cohort in all areas under exploration (Tables 4-8). *(Supplementary Materials)*

References

[1] X. Xu, K. D. Craig, D. Diaz et al., "Automated pain detection in facial videos of children using human-assisted transfer learning," in *International Workshop on Artificial Intelligence in Health*, pp. 162–180, Springer, Cham, 2018.

[2] J. Hauer, "Identifying and managing sources of pain and distress in children with neurological impairment," *Pediatric Annals*, vol. 39, no. 4, pp. 198–205, 2010.

[3] G. Zamzmi, D. Goldgof, R. Kasturi, Y. Sun, and T. Ashmeade, "Machine-based multimodal pain assessment tool for infants: a review," 2016, http://arXiv.1607.00331.

[4] K. Sikka, A. A. Ahmed, D. Diaz et al., "Automated assessment of children's postoperative pain using computer vision," *Pediatrics*, vol. 136, no. 1, pp. e124–e131, 2015.

[5] M. Aung, A. Min, S. Kaltwang, and N. Tyler, "The automatic detection of chronic pain-related expression: requirements, challenges and a multimodal dataset,," *IEEE Transactions on Affective Computing*, vol. 1, pp. 1–1, 2016.

[6] B. L. Quinn, E. Seibold, and L. Hayman, "Pain assessment in children with special needs," *Exceptional Children*, vol. 82, no. 1, pp. 44–57, 2015.

[7] J. G. Zwicker, S. P. Miller, R. E. Grunau et al., "Smaller cerebellar growth and poorer neurodevelopmental outcomes in very preterm infants exposed to neonatal morphine," *The Journal of Pediatrics*, vol. 172, pp. 81–87.e2, 2016.

[8] J. Vinall, S. P. Miller, V. Chau, S. Brummelte, A. R. Synnes, and R. E. Grunau, "Neonatal pain in relation to postnatal growth in infants born very preterm," *Pain*, vol. 153, no. 7, pp. 1374–1381, 2012.

[9] G. G. Page, "Are there long-term consequences of pain in newborn or very young infants?," *The Journal of Perinatal Education*, vol. 13, no. 3, pp. 10–17, 2004.

[10] M.-M. W. Karlsen, M. A. Ølnes, and L. G. Heyn, "Communication with patients in intensive care units: a scoping review," *Nursing in Critical Care*, vol. 24, no. 3, pp. 115–131, 2019.

[11] H. Shanthanna, N. H. Strand, D. A. Provenzano et al., "Caring for patients with pain during the COVID-19 pandemic: consensus recommendations from an international expert panel," *Anaesthesia*, vol. 75, no. 7, pp. 935–944, 2020.

[12] D. Vargo, L. Zhu, B. Benwell, and Z. Yan, "Digital technology use during COVID-19 pandemic: a rapid review," *Human Behavior and Emerging Technologies*, vol. 3, no. 1, pp. 13–24, 2021.

[13] R. Nieto, R. Pardo, B. Sora, A. Feliu-Soler, and J. V. Luciano, "Impact of COVID-19 lockdown measures on Spanish people with chronic pain: an online study survey," *Journal of Clinical Medicine*, vol. 9, no. 11, p. 3558, 2020.

[14] C. Eccleston, F. M. Blyth, B. F. Dear et al., "Managing patients with chronic pain during the COVID-19 outbreak: considerations for the rapid introduction of remotely supported (eHealth) pain management services," *Pain*, vol. 161, no. 5, pp. 889–893, 2020.

[15] M. D. Buffum, E. Hutt, V. T. Chang, M. H. Craine, and A. L. Snow, "Cognitive impairment and pain management: review of issues and challenges," *Journal of Rehabilitation Research and Development*, vol. 44, no. 2, pp. 315–330, 2007.

[16] M. McCaffery, *Nursing practice theories related to cognition, bodily pain, and man-environment interactions*, UCLA Students' Store, Los Angeles, 1968.

[17] C. A. Marco and A. P. Marco, "Assessment of pain," in *In Emergency Department Analgesia: An Evidence-Based Guide*, S. H. Thomas, Ed., Cambridge University Press, Cambridge, 2008.

[18] C. L. Von Baeyer, L. J. Spagrud, J. C. McCormick, E. Choo, K. Neville, and M. A. Connelly, "Three new datasets supporting use of the Numerical Rating Scale (NRS-11) for children's self-reports of pain intensity," *PAIN®*, vol. 143, no. 3, pp. 223–227, 2009.

[19] C. L. von Baeyer and C. L. Hicks, "Support for a common metric for pediatric pain intensity scales," *Pain Research and Management*, vol. 5, no. 2, Article ID 640173, p. 160, 2000.

[20] H. Breivika, "Fifty years on the visual analogue scale (VAS) for pain-intensity is still good for acute pain. But multidimensional assessment is needed for chronic pain," *Scandinavian Journal of Pain*, vol. 11, no. 1, pp. 150–152, 2016.

[21] H. Breivik, P. C. Borchgrevink, S. M. Allen et al., "Assessment of pain," *BJA: British Journal of Anaesthesia*, vol. 101, no. 1, pp. 17–24, 2008.

[22] A. Williamson and B. Hoggart, "Pain: a review of three commonly used pain rating scales," *Journal of Clinical Nursing*, vol. 14, no. 7, pp. 798–804, 2005.

[23] O. Karcioglu, H. Topacoglu, O. Dikme, and O. Dikme, "A systematic review of the pain scales in adults: which to use?," *The American Journal of Emergency Medicine*, vol. 36, no. 4, pp. 707–714, 2018.

[24] S. Zwakhalen, R. E. Docking, I. Gnass et al., "Pain in older adults with dementia," *Der Schmerz*, vol. 32, no. 5, pp. 364–373, 2018.

[25] K. Herr, K. Bjoro, and S. Decker, "Tools for assessment of pain in nonverbal older adults with dementia: a state- of-the-science review," *Journal of Pain and Symptom Management*, vol. 31, no. 2, pp. 170–192, 2006.

[26] S. Fuchs-Lacelle and T. Hadjistavropoulos, "Development and preliminary validation of the pain assessment checklist for seniors with limited ability to communicate (PACSLAC)," *Pain Management Nursing*, vol. 5, no. 1, pp. 37–49, 2004.

[27] J. Abbey, N. Piller, A. D. Bellis et al., "The Abbey pain scale: a 1-minute numerical indicator for people with end-stage dementia," *International Journal of Palliative Nursing*, vol. 10, no. 1, pp. 6–13, 2004.

[28] M. Atee, K. Hoti, R. Parsons, and J. D. Hughes, "A novel pain assessment tool incorporating automated facial analysis: interrater reliability in advanced dementia," *Clinical Interventions in Aging*, vol. 13, pp. 1245–1258, 2018.

[29] C. L. Von Baeyer, "Children's self-report of pain intensity: what we know, where we are headed," *Pain Research and Management*, vol. 14, no. 1, Article ID 259759, pp. 39–45, 2009.

[30] S. LeBaron and L. Zeltzer, "Assessment of acute pain and anxiety in children and adolescents by self-reports, observer reports, and a behavior checklist," *Journal of Consulting and Clinical Psychology*, vol. 52, no. 5, pp. 729–738, 1984.

[31] R. R. Pillai Riddell, M. A. Badali, and K. D. Craig, "Parental judgments of infant pain: importance of perceived cognitive abilities, behavioural cues and contextual cues," *Pain Research and Management*, vol. 9, no. 2, Article ID 150463, p. 80, 2004.

[32] B. G. Samolsky Dekel, A. Gori, A. Vasarri, M. C. Sorella, G. Di Nino, and R. M. Melotti, "Medical evidence influence on inpatients and nurses pain ratings agreement," *Pain Research and Management*, vol. 2016, Article ID 9267536, 11 pages, 2016.

[33] R. R. Pillai Riddell and K. D. Craig, "Judgments of infant pain: the impact of caregiver identity and infant age," *Journal of Pediatric Psychology*, vol. 32, no. 5, pp. 501–511, 2007.

[34] R. R. Pillai Riddell, R. E. Horton, J. Hillgrove, and K. D. Craig, "Understanding caregiver judgments of infant pain: contrasts of parents, nurses and pediatricians," *Pain Research and Management*, vol. 13, no. 6, Article ID 694745, p. 496, 2008.

[35] C. Miller and S. E. Newton, "Pain perception and expression: the influence of gender, personal self- efficacy, and lifespan socialization," *Pain Management Nursing*, vol. 7, no. 4, pp. 148–152, 2006.

[36] K. K. Sekhon, S. R. Fashler, J. Versloot, S. Lee, and K. D. Craig, "Children's behavioral pain cues: implicit automaticity and control dimensions in observational measures," *Pain Research and Management*, vol. 2017, Article ID 3017837, 10 pages, 2017.

[37] B. Martinez, M. F. Valstar, B. Jiang, and M. Pantic, "Automatic analysis of facial actions: a survey," *IEEE Transactions on Affective Computing*, vol. 10, no. 3, pp. 325–347, 2017.

[38] M. M. Monwar and S. Rezaei, "Pain recognition using artificial neural network," in *2006 IEEE International Symposium on Signal Processing and Information Technology*, pp. 28–33, Vancouver, BC, Canada, 2006.

[39] Z. Hammal and J. F. Cohn, "Automatic detection of pain intensity," in *in Proceedings of the 14th ACM international conference on Multimodal interaction*, pp. 47–52, Santa Monica, California, USA, 2012.

[40] D. Liu, D. Cheng, T. T. Houle, L. Chen, W. Zhang, and H. Deng, "Machine learning methods for automatic pain assessment using facial expression information: protocol for a systematic review and meta-analysis," *Medicine*, vol. 97, no. 49, 2018.

[41] T. R. Dawes, B. Eden-Green, C. Rosten et al., "Objectively measuring pain using facial expression: is the technology finally ready?," *Pain management*, vol. 8, no. 2, pp. 105–113, 2018.

[42] K. Wolf, T. Raedler, K. Henke et al., "The face of pain - a pilot study to validate the measurement of facial pain expression with an improved EMG method," *Pain Research and Management*, vol. 10, no. 1, Article ID 643075, p. 19, 2005.

[43] G. Zamzmi, C.-Y. Pai, D. Goldgof, R. Kasturi, T. Ashmeade, and Y. Sun, "An approach for automated multimodal analysis of infants' pain," in *2016 23rd International Conference on Pattern Recognition (ICPR)*, pp. 4148–4153, Cancun, Mexico, 2016.

[44] D. B. Corbett, C. B. Simon, T. M. Manini, S. Z. George, J. L. Riley, and R. B. Fillingim, "Movement-evoked pain: transforming the way we understand and measure pain," *Pain*, vol. 160, no. 4, pp. 757–761, 2019.

[45] F. Haider, P. Albert, and S. Luz, "Automatic recognition of low-back chronic pain level and protective movement behaviour using physical and muscle activity information," in *2020 15th IEEE International Conference on Automatic Face and Gesture Recognition (FG 2020)*, pp. 834–838, Buenos Aires, Argentina, 2020.

[46] B. W. Schuller, D. M. Schuller, K. Qian, J. Liu, H. Zheng, and X. Li, "COVID-19 and computer audition: an overview on what speech & sound analysis could contribute in the SARS-CoV-2 corona crisis," *Frontiers in Digital Health*, vol. 3, p. 14, 2021.

[47] A. Singh, A. Klapper, J. Jia et al., "Motivating people with chronic pain to do physical activity: opportunities for technology design," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 2803–2812, Toronto, Ontario, Canada, 2014.

[48] J. W. Newbold, N. Bianchi-Berthouze, N. E. Gold, A. Tajadura-Jiménez, and A. C. Williams, "Musically informed sonification for chronic pain rehabilitation: facilitating progress & avoiding over-doing," in *in Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, pp. 5698–5703, San Jose, California, USA, 2016.

[49] A. Singh, N. Bianchi-Berthouze, and A. Williams, "Tracking, analysis and sonification of movement and breathing for supporting physical activity in chronic pain using the go-with-the-flow framework," *Frontiers in Public Health*, vol. 4, 2016.

[50] L. Neubauer, N. Gold, T. Olugbade, A. Williams, and N. Berthouze, *Functional musical sonification for chronic pain support*, Ubiquitous Music 2021, 2021.

[51] D. Cesarini, T. Hermann, and B. Ungerechts, "An Interactive Sonification System for Swimming Evaluated by Users," in *Sonification of Health and Environmental Data*, York, England, 2014.

[52] N. Schaffert, K. Mattes, and A. O. Effenberg, *The Sound of Rowing Stroke Cycles as Acoustic Feedback*, International Community for Auditory Display, 2011.

[53] J. Petrofsky, "The use of electromyogram biofeedback to reduce Trendelenburg gait," *European Journal of Applied Physiology*, vol. 85, no. 5, pp. 491–495, 2001.

[54] J. C. Christensen, P. C. LaStayo, R. L. Marcus et al., "Visual knee-kinetic biofeedback technique normalizes gait abnormalities during high-demand mobility after total knee arthroplasty," *The Knee*, vol. 25, no. 1, pp. 73–82, 2018.

[55] G. Schmitz, J. Bergmann, A. O. Effenberg, C. Krewer, T.-H. Hwang, and F. Müller, "Movement sonification in stroke rehabilitation," *Frontiers in neurology*, vol. 9, p. 389, 2018.

[56] J. W. Newbold, N. Bianchi-Berthouze, and N. E. Gold, *Musical Expectancy in Squat Sonification for People Who Struggle with Physical Activity*, Georgia Institute of Technology, 2017.

[57] I. Wallis, T. Ingalls, T. Rikakis et al., "Real-time sonification of movement for an immersive stroke rehabilitation environment," in *Proceedings of the 13th international conference on auditory display*, pp. 26–29, Canada, 2007.

[58] A. Tajadura-Jiménez, M. Basia, O. Deroy, M. Fairhurst, N. Marquardt, and N. Bianchi-Berthouze, "As light as your footsteps: altering walking sounds to change perceived body weight, emotional state and gait," in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pp. 2943–2952, Seoul, Republic of Korea, 2015.

[59] G. Rosati, A. Rodà, F. Avanzini, and S. Masiero, "On the role of auditory feedback in robot-assisted movement training after stroke: review of the literature," *Computational Intelligence and Neuroscience*, vol. 2013, Article ID 586138, 11 pages, 2013.

[60] D. C. Turk and R. Melzack, *Handbook of Pain Assessment*, D. C. Turk and R. Melzack, Eds., The Guilford Press, New York, 2011.

[61] R. Sigrist, G. Rauter, R. Riener, and P. Wolf, "Augmented visual, auditory, haptic, and multimodal feedback in motor learning: a review," *Psychonomic Bulletin & Review*, vol. 20, no. 1, pp. 21–53, 2013.

[62] J. H. Flowers, "Thirteen Years of Reflection on Auditory Graphing: Promises, Pitfalls, and Potential New Directions," in *Proceedings of ICAD 05-Eleventh Meeting of the International Conference on Auditory Display*, Limerick, Ireland, 2005.

[63] B. Dürrer, *Investigations into the design of auditory displays[M.S. thesis]*, Institute of Communication Acoustics, Ruhr University Bochum, Germany, Berlin, 2001.

[64] H. J. A. Van Hedel, M. Biedermann, T. Erni, and V. Dietz, "Obstacle avoidance during human walking: transfer of motor skill from one leg to the other," *The Journal of Physiology*, vol. 543, no. 2, pp. 709–717, 2002.

[65] M. A. Schechter, S. A. Fausti, B. Z. Rappaport, and R. H. Frey, "Age categorization of high-frequency auditory threshold data," *The Journal of the Acoustical Society of America*, vol. 79, no. 3, pp. 767–771, 1986.

[66] S. A. Gelfand, *Hearing: An Introduction to Psychological and Physiological Acoustics*, Informa Healthcare, London, 2016.

[67] S. A. Gelfand, *Measurement principles and the nature of hearing*, Essentials of audiology, New York, 1997.

[68] B. R. Lunsford and J. Perry, "The standing heel-rise test for ankle plantar flexion: criterion for normal," *Physical Therapy*, vol. 75, no. 8, pp. 694–698, 1995.

[69] A. Gefen, M. Megido-Ravid, Y. Itzchak, and M. Arcan, "Analysis of muscular fatigue and foot stability during high-heeled gait," *Gait & Posture*, vol. 15, no. 1, pp. 56–63, 2002.

[70] C. J. Main, M. J. Sullivan, and P. J. Watson, *Pain Management: Practical Applications of the Biopsychosocial Perspective in Clinical and Occupational Settings/Chris*, Elsevier Health Sciences, Edinburgh, 2008.

[71] G. Waddell, *The back pain revolution*, Elsevier Health Sciences, United Kingdom, 2004.

[72] G. Waddell, A. K. Burton, and C. J. Main, *Screening of DWP Clients for Risk of Long-Term Incapacity: A Conceptual and Scientific Review*, Royal Society of Medicine Press, London, 2003.

[73] A. Mündermann, B. M. Nigg, D. J. Stefanyshyn, and R. N. Humble, "Development of a reliable method to assess footwear comfort during running," *Gait & Posture*, vol. 16, no. 1, pp. 38–45, 2002.

[74] D. D. Price, F. M. Bush, S. Long, and S. W. Harkins, "A comparison of pain measurement characteristics of mechanical visual analogue and simple numerical rating scales," *Pain*, vol. 56, no. 2, pp. 217–226, 1994.

[75] E. C. Huskisson, "Measurement of pain," *The Lancet*, vol. 304, no. 7889, pp. 1127–1131, 1974.

[76] F. Dexter and D. H. Chestnut, "Analysis of statistical tests to compare visual analog scale measurements among groups," *Anesthesiology: The Journal of the American Society of Anesthesiologists*, vol. 82, no. 4, pp. 896–902., 1995.

[77] E. J. Gallagher, M. Liebman, and P. E. Bijur, "Prospective validation of clinically important changes in pain severity measured on a visual analog scale," *Annals of Emergency Medicine*, vol. 38, no. 6, pp. 633–638, 2001.

[78] R. B. Margolis, R. C. Tait, and S. J. Krause, "A rating system for use with patient pain drawings," *Pain*, vol. 24, no. 1, pp. 57–65, 1986.

[79] Ö. Karcioğlu, "An eternal challenge: assessment and documentation of acute pain in the emergency setting," *Journal of Anesthesia & Intensive Care Medicine*, vol. 5, no. 3, 2018.

[80] R. Melzack, "The short-form McGill pain questionnaire," *Pain*, vol. 30, no. 2, pp. 191–197, 1987.

[81] U. Svantesson, U. Osterberg, R. Thomeé, and G. Grimby, "Muscle fatigue in a standing heel-rise test," *Scandinavian Journal of Rehabilitation Medicine*, vol. 30, no. 2, pp. 67–72, 1998.

[82] C.-M. Lee, E.-H. Jeong, and A. Freivalds, "Biomechanical effects of wearing high-heeled shoes," *International Journal of Industrial Ergonomics*, vol. 28, no. 6, pp. 321–326, 2001.

[83] D. J. Stefanyshyn, B. M. Nigg, V. Fisher, B. O'Flynn, and W. Liu, "The influence of high heeled shoes on kinematics, kinetics, and muscle EMG of normal female gait," *Journal of Applied Biomechanics*, vol. 16, no. 3, pp. 309–319, 2000.