Embracing Calibration in Body Sensing: Using Self-Tweaking To Enhance Ownership and Performance

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ABSTRACT
Calibration is a necessary step in many sensor-based ubicomp applications to prepare a system for operation. Particularly when dealing with sensors for movement-based interaction calibration is required to individualize the system to the person's body. However, calibration is often viewed as a tedious necessity of a purely technical nature. In this paper we argue that calibration can be used as a valuable and informative step for users molding a technology for their own use. We explain this through two case studies that use body sensing technologies to teach physical skills. Our studies show that calibration can be used by teachers and pupils to set goals. We argue that demystifying calibration and designing to expose the intentions of the technology and its functioning can be beneficial for users, allowing them to shape technology to be in tune with their bodies rather than changing their body to fit the technology.

Author Keywords
Calibration, body movement, body posture, appropriation.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Design, Human Factors, Measurement, Performance.

INTRODUCTION
Many UbiComp technologies require calibration in order to work optimally, [e.g. 2, 15, 19] and to give sensor measurements meaning. For example, an inertial motion capture suit needs to be calibrated to a default position before sensors can measure movement accurately [2]. However calibration is often viewed as a tedious necessity, which detracts from the overall user experience e.g. [13]. This paper argues that in some cases the process of calibration can be beneficial for users, giving a sense of control and ownership and showing how the technology works. At its core calibration is about collecting data that will enable a system to function and interact with people in a meaningful way. This covers many things: from tuning sensors [2], to finding an individual baseline [18], to making output accessible to individual needs – e.g. measuring color perception to tune a display [13].

Calibration is essential to many technologies, perhaps increasingly so as new sensors find their way into every corner of our lives and movement-based input technologies like Kinect [30] expose computing to the wide variations in physical abilities of users. To address the time-consuming and potentially cumbersome nature of calibration processes, many systems have tried to minimize user involvement by automating it where possible [e.g. 12, 19]. Alternatively, others have proposed to turn the calibration process into a game [13]. Both these approaches act to obscure the intention of calibration from the user in order to make it more pleasant. The question this raises, however, is whether this is always the best approach to take - to remove the pain of calibration? Is masking the process of calibration desirable or is it detracting from users' ability to understand and engage with the technology? Here, we propose an alternative approach, namely, to embrace the process of calibration by giving users power to change the way they interact with a system. Far from concealing calibration we should design it in a way that lets users appropriate and learn from it.

BACKGROUND LITERATURE
There are a number of different approaches to calibration. Within ubiquitous computing, calibration of sensors and sensor networks is often automated. Self-calibrating sensors which can calibrate to their optimal setting and configure themselves into pervasive networks that become a part of the everyday environment are often considered the ideal [e.g. 12]. Much research has gone into making this into a reality [e.g. 19]. For this kind of application, automation is well justified because it is a very technical form of calibration largely concerned with how sensors communicate with one another and interpret the environment.

Other types of calibration, however, are much more closely related to user interaction. In particular, calibration can individualize technology to the characteristics of a particular user. Here, an automated approach may be impossible. An alternative is to use the motivating power of games to make the process more enjoyable. Flatla et al. [13] describe three examples of calibration games, to calibrate for user color perception, mouse responsiveness and respiration rate. They show that for lengthy calibration processes, reframing them as games made users find them significantly more enjoyable and users put more effort into the calibration tasks.

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Calibration is very important for certain user groups. For example, older people can have a wide variety of mobility constraints and there can be pronounced differences between individuals. Gerling et al. [14] designed motion-based games for older adults and found that calibrating for a range of motion and strength was essential to make the games accessible. To calibrate for this they asked players to collect flowers on the screen to measure their range of motion and then hold them in certain positions to measure their strength. Geurts et al. [15] designed games to encourage and help disabled children carry out their physical therapy exercises. For each game, the physical therapist calibrated it to suit the needs and abilities of the individual child. This was vital to ensure that the game provides the desired health benefits for the child and makes it challenging. Alankus et al. [1] designed games to help stroke patients practice their rehabilitation exercises. They also calibrated the game for the individual's range of movement and this was done by asking patients to do example movements. The therapist decided the exercises and difficulty level, so that the games were appropriate and beneficial for the patient.

In these cases of physical therapy, the therapist is the one who calibrates, but in other areas, such as personal health and fitness, it is up to the user to calibrate their equipment, for themselves. For example the iPosture device [18], which gives a vibrotactile buzz to nudge people into a straight posture, requires a button press to set the correct posture for the device to use as a baseline. This is a very simple calibration step but does pose difficulties because there is no explanation of what a good posture is to help the wearer set it in the first place.

Nijhar et al. [22] show that movement recognition precision of full body game controllers in Nintendo Wii [23] should be calibrated by taking into account not only the body structure of the players, but also their motivations. People playing a tennis game to challenge themselves adapt their movement to those needed to control the game, no matter whether the movements are tennis-like or not. More precise movement recognition was welcomed by them as it offers more challenges and a wider set of movement strategies to master. Conversely, people that play to relax are looking to enjoy their own tennis style. Calibration in this latter case should aim to respond to players' gross movements rather than force the player to master the execution of predefined actions.

Configuring, customizing and tailoring

Somewhat overlapping with the idea of calibrating for individual differences, is configuring computing technology to the needs of an individual or organization. Balka and Wagner [4] describe this customizing and tailoring as being part of "appropriation work" – i.e. the process of "users actively integrating technology into their actions". This process of "making things work" is essential to being able to effectively use the full functionality of a system. In the hospital wireless call system they describe [5], configuration was not easily accessible to users and as a result the technology was not used to its full potential.

Another type of tailoring is computer-tailored healthcare information [20] which aims to make patients more motivated to read and act on health information by making it relevant to them and reducing redundant content. Computer-tailoring by an expert system based on patient data and questionnaire responses has the potential to make personalized healthcare much more widely available than tailoring by a healthcare professional.

In "appropriation work" [5] the user engages with tailoring; whereas in computer-tailoring [20] the computer makes the decisions about what is relevant with the intention of making the content more engaging. However, the drawback is that, whilst users are given a finished product that should be suited to their needs, they have no sense of how it was reached or how their choices control its outcome. Such lack of understanding and involvement of the user in the tailoring process may be even more critical with body sensing technologies. This is because the user's body is much more closely linked with a sense of self and ownership and also because motor experiences strongly affect cognitive and affective processes [6, 11, 21].

Adaptive systems

In ubiquitous computing, research looks beyond tailoring systems for a single situation to creating adaptive systems that can adjust dynamically to a changing environment [9]. Adaptive systems learn about their environment or user and adapt the way they function accordingly. Rather than gathering information directly from users they make inferences from sensor data and user behavior. This places less workload on the user than traditional tailoring. The learning element of an adaptive system means that if the context or patterns of use change the system can adapt without user participation.

One example which demonstrates both these capabilities is Yau and Joy's personalized mobile learning application [29]. This system provided tailored exercises based on the learner's context (e.g. whether they are in a noisy café or quiet library) and their learning preferences. Details of context were inferred from sensor data; GPS for location and the mobile's microphone for noise levels. Learning preferences, such as where and when they like to work were based on an initial questionnaire. By combining these sets of information the application aimed to provide learning tasks suited to the user context. As this example shows, adaptive systems have the potential to give specialized and context appropriate services to users with minimal effort. However, automation can present potential drawbacks. As Norman [24] describes, automation without intelligent feedback can lead to problems. Just like the airplane pilots Norman describes, users need to feel "in the loop"; they need feedback that gives them a mental model of how the system works. Without this, and when the system makes mistakes, users may not recognize them and will not know how to account for them. Because adaptive systems can be particularly complex there is a danger that users may view them as mysterious and unyielding; whereas "what is needed is a soft, compliant technology," [24, p.592].

Designing for appropriation
One way to make technology more soft and compliant would be to follow Dix's guidelines for designing for appropriation [10]. When users appropriate they "adapt and adopt the technology around them in ways the designers never envisaged". For example, emailing an URL to yourself as a way to save a page when browsing rather than using a bookmark. By appropriating technology users can create unique and specified solutions to problems that work for them as individuals in a particular setting. Moreover, this creative control over the use of technology gives a sense of ownership of the technology [10].

If users are able to appropriate calibration then they are able to take ownership of a fundamental mechanism which a system uses to interact with the world. However, many calibration processes are not easy to understand and appropriate. Dix gives seven general guidelines for designing for appropriation. Two of these are especially relevant to the design of calibration systems, these are: expose intentions and provide visibility. Expose intentions by showing what the calibration is for lets users make judgments about whether and in what way they want to appropriate it. Provide visibility by showing a clear link between the information the user gives for calibration and the system behavior afterwards. This lets them understand how to appropriate. Here, we explore how embracing the process of calibration required in a motion sensing technology can be beneficial for the user in terms of helping them understand its role, and subsequently, learning the art of self-tweaking the calibration to help achieve goals such as improving violin bowing or posture. We present two case studies where calibration is necessary in order for accurate real-time feedback to be provided when learning to play an instrument using body sensing technology.

CASE STUDY 1: MUSICJACKET – TEACHER CALIBRATION
The first case study relates to a previous study [28] of violin lessons where a vibrotactile feedback jacket, known as the MusicJacket, was deployed to help pupils to improve their bowing. In this case study, calibration became an important topic for discussion between researchers, teachers and pupils. In order to achieve the exact feedback the teacher required, the researchers resorted to exploiting the calibration process in an unanticipated way, eventually resulting in more personalized feedback. To describe this example we first explain the context of the study and then specifically how calibration played an important role.

Context
The aim of the case study was to investigate how real-time vibrotactile feedback could be effectively integrated into children's violin lessons. The prototype used to explore this was the MusicJacket (see Fig. 1) which combined an inertial motion capture suit that tracked the child's movement while they played with vibration motors positioned on the body to give feedback when they moved outside certain parameters. If the children moved their bow too far forward from the reference stroke then the vibrator on their wrist was triggered. Conversely, if they moved too far back then the vibrator on their elbow was triggered. The leeway the pupil could deviate from the bow stroke could be adjusted to make the feedback more or less strict. The reference stroke was recorded using a calibration process described in the next section. The ideal position to bow is approximately central between the bridge (light wood holding the strings up) and the edge of the fingerboard (black wood on neck of violin).

The study took place in a home setting with four pupils aged between 10 and 13 years, who each had about three years' violin playing experience. The teacher and two researchers met with each pupil individually for five sessions over a period of two months. In four of these sessions the MusicJacket was deployed. Further details of this study can be found here [28].

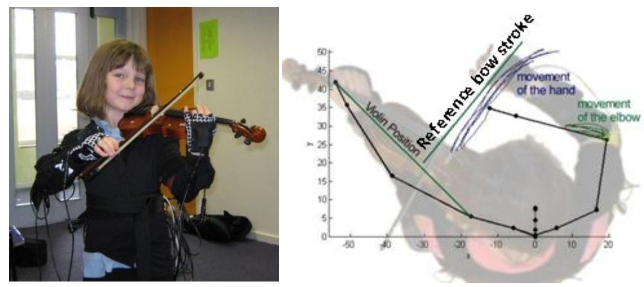

Figure 1: The MusicJacket (Left) tracks the player's bowing and compares it to a reference stroke (Right)

Calibration
The MusicJacket required several layers of calibration. First the motion capture suit had to be calibrated to function properly. Before using the suit each participant had to be photographed standing in a cube of specific dimensions in order to calibrate for their individual limb lengths. When the suit is switched on it must be kept stationary for several minutes while the inertial motion sensors calibrate for drift. Once the jacket has been put on, the wearer must face north standing up straight for a moment so that the sensors can orientate themselves.

After this, a reference bow stroke (see Fig. 1) was recorded to show the system what the ideal playing movement would be. This was done in two ways. The teacher would either guide the pupil's hand in several bow strokes, or the teacher would hold the bow on the string and the pupil would run their hand up and down it. In both cases the teacher was deciding where the pupil should be bowing. This reference stroke was the basis for the system to decide when to give feedback; if the pupil moved their hand off the reference path in either direction they would feel a vibration.

In the fourth session, a lively discussion ensued around this process of calibration. It began with the teacher noticing that her pupil was playing too close to the bridge of the violin. After talking to the pupil about it she ascertained that near the bridge the feedback "*should really have been going off […] and it wasn't.*" and she brought this to the researchers' attention. The teacher and researchers together experimented with several different bow positions where the feedback was or was not triggered and the teacher pointed out when the feedback ought to be coming on. For example, she instructed her pupil to *"put it closer to the bridge"* and then asked *"is that buzzing now?"* She then explained to the researchers *"we need to get it buzzing there,"* effectively stating her calibration requirements.

In response, the researchers made the margin for pupil error smaller so that if the pupil only moved their hand off the reference path by a small amount the vibrations would be triggered. However, this resulted in making the area near the fingerboard too strict for her bowing style while not making a big enough difference at the bridge. Next, they recalibrated to ensure the reference stroke was in the correct position. However, the problem remained that even on a strict setting the feedback was not sensitive enough for the needs of this particular pupil around the bridge and simply making the feedback stricter would have inhibited her freedom of movement too much. Finally, the reference stroke was recalibrated again but positioned so that the stroke was closer to the fingerboard than the bridge. This reference stroke was not the perfect position to play in but it meant that the vibrations were triggered more easily near to the bridge than at the fingerboard, since the margin for pupil error on each side of the reference stroke is symmetric.

This 'misuse' of the calibration of the reference stroke enabled the pupil who had a particular "bridge problem" to get feedback that met her specific needs. Moreover, in the course of the discussion that led to this calibration, the teacher also learned more about how the system worked. It caused her to ask questions about what the system was able to measure and how it did it; and what this meant when using the system – e.g. that it was easier to give feedback on poor bow angle than a straight bow in a bad position. It also made her clearly state where the bow should and should not be positioned, effectively setting a goal for her pupil. The calibration was then used to implement this goal.

CASE STUDY 2: TWINKLY LIGHTS AND BUZZY JACKET – LEARNER CALIBRATION

Whereas in the previous case study, the teacher and researchers calibrated the system and set the goals, in this second case study, learners calibrated the system themselves. The findings show that this gave the learners more power over their learning, resulting in a greater sense of ownership and engagement. To begin, we describe important details of the context of this study, including the design and setting, so that the findings relating to calibration can be more easily understood.

Context

The aim of providing real-time feedback in this setting was to improve the posture of a group of children, who were learning to play the third violin and viola sections of a high school orchestra. The study lasted for a period of 14 weeks. In order to get maximum benefit from the technology intervention, the children needed to be able to use it in their home practice as well as during ensemble practice at school. Therefore, building a technology that could be easily calibrated and used by children, without researcher supervision, became a key design objective.

Design Method

The design approach adopted for this study was rapid-prototyping. We built the feedback systems while the initial stages of the user study were being conducted. This enabled maximum responsiveness to how the children participated and used the prototype system. The designs were hence adapted and changed in reaction to the ongoing findings.

The design work began with seeking to address an initial observation that showed that many of the school orchestra's players in the string section did not hold their instruments high enough and often sat with a hunched posture. The MusicJacket had shown that real-time vibrotactile feedback is effective for improving upper body posture [28]. Here, the goal was to design a feedback system which could be used by children in home practice, as well as during lessons. For this reason a robust, cheap and portable *Buzzy Jacket* which gave feedback about the posture of the upper body using vibrotactile actuators was developed.

Requirements continued to be specified while the baseline data for the user study was collected. In the course of working with the children, a second problem with posture was also identified, namely foot positioning when playing in the orchestra whilst seated. This postural problem needed to be overcome before the Buzzy Jacket could be effectively introduced. To address this, a visual system was developed which gave feedback in the form of twinkly LEDs coming on if the feet were not correctly positioned. Lights as feedback were selected as a complimentary modality to vibrotactile feedback as overuse of vibration can be overloading for learners [17]. A multimodal approach, on the other hand, offered the opportunity to give feedback about the foot position and upper body posture at the same time with the contrast in modality allowing the player to be able to make a distinction between the two. Each of these designs is described in the following sections.

Buzzy Jacket

The Buzzy Jacket was designed to encourage players to hold the violin higher and sit up straight. The vibrators were sewn into the jacket on the ribs which were activated when the player slouched, with the objective of 'telling' them to sit up straighter. Another vibrator was positioned underneath the elbow, which was triggered when the player let their violin droop too far down, nudging them to lift the violin. The placement of these vibrators was based upon the findings from the MusicJacket [28]. In addition, another motor was added to indicate to the player if their elbow came out too far to the side; however, this was rarely used as it was confused with the one underneath the elbow.

The Buzzy Jacket used a very minimal sensor set-up compared to the MusicJacket [28]. Rather than mapping the whole upper body, this system only used two accelerometers to infer the key details about posture needed to give feedback about slouching and violin position. This enabled a number of jackets to be made at an affordable cost of approximately $100 each, one for each of the 5 participants to take home. This set up was very responsive to violin position but only responded to pronounced slouching. The jackets were specially made for each child. They were given a selection of styles, colors and sizes to choose from to make it more engaging.

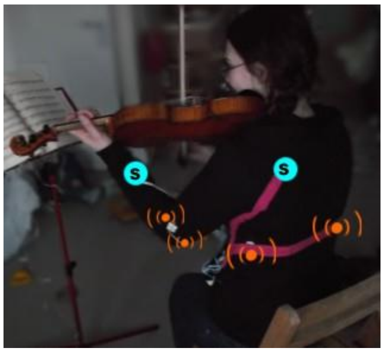

Figure 2: Buzzy Jacket showing vibrators and sensors

Vibrator Position	Meaning	Priority
Left and right Ribs: activated together	Straighten up back: triggered by slouching	Top of hierarchy
Elbow, near funny bone	Lift up violin: triggered by drooping violin)	Bottom of hierarchy
Left side of Elbow	Move elbow under violin: triggered by elbow moving to side	Middle of hierarchy

Table 1: Vibrators positions and corresponding instructions

Implementation

The Buzzy Jackets had two accelerometers connected to an Arduino pro mini [3]. One accelerometer was positioned on the inside of the forearm and the other on the left shoulder blade as shown in the diagram (see Fig. 2). In this design, the accelerometers were used as inclinometers (measuring angle of tilt) to measure details of the player's posture. This was only possible because the parts of the body the sensors are placed on would not be accelerating rapidly, so the accelerometer is mainly measuring gravitational force. The accelerometer on the forearm was used to measure the angle and orientation of the arm, allowing the system to infer whether the player was holding their violin up correctly. The accelerometer on the shoulder blade was designed to pick up on whether the shoulders were straight or hunched.

Four 10mm coin vibrators [26] were used to give feedback about posture. These were positioned as shown in Figure 2 and were used to indicate to the child that they needed to improve their posture as described in Table 1. Three metal poppers were used as switches so that participants could control which vibrators were active. If the children chose to have several vibrators switched on at once, then there was a hierarchy about which one would be activated, so that only one set of vibrators could be on at a time – this hierarchy is shown in Table 1. This was chosen to avoid the participants feeling overloaded by multiple vibrators activating at the same time [17].

Footboard and Twinkly Lights

The Footboard and Twinkly Lights (Figure 3) were built to nudge the participant to put their feet back on the floor if they lifted them while playing. A board with sensors was built which the children placed on the floor in front of them. Attached to this was a set of colored Christmas lights (with inbuilt twinkly effect) which the children draped around their music stand. When the feet were positioned correctly the lights would be switched off to prevent them distracting the children from their playing. When the children made a mistake (i.e. moved their feet) the feedback would be activated in order to catch their attention and allow them to correct their foot position.

Figure 3: Footboard and Twinkly Lights – the lights are activated when the child moves her feet off the footprints

Footboard and Lights - Implementation

To save on cost and work, the design combined two off-the-shelf products. On the sensor side it used the contents of an electronics project kit for school children to make a light sensor circuit. This contained the necessary PCB (Printed Circuit Board) ready-made and was adapted by adding further LDRs (Light Dependent Resistors) in parallel and adjusting the value of the resistors in the circuit. This was then connected up to a set of battery powered LED Christmas lights. These had a built in digital twinkling effects setting which made the lights flash in different combinations to make them more salient.

The LDRs were set into an A3 size piece of card onto which the children's footprints had been carefully drawn. There were two LDRs for each footprint, one under the ball of the foot and one under the heel. When the children's feet were in the correct position they would cover the LDRs thus preventing them from being exposed to light. The circuitry of the twinkly lights was combined with that of the LDRs, so that if the children moved their feet off the footprints the LDRs would be exposed to light causing the twinkly lights to be switched on.

In-the-wild User Study

An in-the-wild user study was conducted with five children from a state school orchestra. The aim of the study was to evaluate how the children used the two feedback systems to motivate their playing and improve their posture when playing. The children met with the researcher for 14 weekly ensemble practices (in term-time) and collected data about their home practice using a video camera. During this time they were given feedback about their posture while playing, initially verbally and later using the feedback prototypes. In the next section this study is explained in further detail, with a focus on how the children calibrated the prototypes during practice both at home and in school.

Calibration

Both prototypes needed to be calibrated to match the most suitable posture for individuals. We describe here how each prototype was calibrated, then later in the findings section what happened when they were used in the wild. In particular, we examine how calibration contributed to the process of putting the children in control of their learning.

Calibrating the Buzzy Jacket

An initial calibration of the ideal playing position was required in order for the sensors to be able to judge whether the future playing positions were correct or not. It took two iterations to design a way for the children to be able to calibrate the jacket easily by themselves. To calibrate the final version of the jacket, players pressed a button in the middle of the jacket near the zip. The jacket would then buzz five times to give them time to get into the ideal position, after the fifth buzz their current position was recorded as the calibration.

The five buzzes and the central position of the button were improvements after difficulties were encountered in the first iteration of the jacket. Initially the button had been located on the left hand side and the calibration was recorded as soon as the button was pressed – this caused a lot of usability issues as participants tried to hold their violin in the ideal position while pressing the button on their left side with their right hand. This led to many bad calibrations. After observing this difficulty we moved the button near to the midline of the body to make it easier to find and added the five buzzes to give enough time for the children to get into position after pressing it.

The children were taught to calibrate their jackets when they were first given out. The researcher pointed out where the calibration button was and then explained there would be five buzzes in which time they had to get their violin and hold it up straight. The researcher then got them to practice this process two to three times and explained the reason for calibration by saying "you have to teach it [the jacket]" how to hold the violin.

The importance of this calibration processes is that the children had to calibrate the Buzzy Jacket themselves and choose what their correct posture was. This meant they were responsible for their own learning. During the six ensemble practices leading up to the introduction of the Buzzy Jacket the children had been learning about how to sit up straight and how to hold their violin through discussions of what good posture meant, and with exercises and visualizations. Therefore, when the Buzzy Jacket was introduced they had the domain knowledge needed to set their own ideal posture. They all understood what a good seated posture was, knew how to hold their instruments up well and understood that the Buzzy Jacket was intended to help them maintain this posture while playing.

Calibrating the Footboard and Twinkly Lights

The footboard and twinkly lights also had to be calibrated to position each participant's feet correctly in a comfortable place appropriate for their physique. In the first ensemble practice, the children were taught where to position their feet and given different options to try to see which were most comfortable (either feet evenly spaced or left foot forward right foot back). The children also learnt a game to test their foot position in which they competed to stand up as quickly as possible – those who could do this had their feet correctly positioned. In the second ensemble practice they drew around their feet onto a sheet of A3 paper to record their foot position. In the subsequent two practices, they used their footprint to remind them where to place their feet, and redrew them if they felt the footprints were wrongly positioned. After the fourth ensemble practice the footprints were copied onto the new footboard and the sensor placement was based on the position of the footprints.

Participants

Five children (Alice, Bea, Carl, Daphne and Esme) participated in the study, three played in the third violin section of the school orchestra and two in the viola section. In this orchestra, the viola section and third violin section played the same part although sometimes an octave apart. The participants were aged between 11 and 13 years and comprised four girls and one boy with abilities ranging from experienced beginner to intermediate level.

Home Practice

One of the aims of this study was to investigate how real-time feedback can be used by children in self-directed practice at home - whether they would choose to use it at home and what for. Participants were asked to film themselves practicing. Each participant was given a low cost video camera and encouraged to involve their families in the videoing process. Videos were chosen rather than a written diary so that the children didn't feel like they were being given extra homework by taking part in the study.

Ensemble Practice Sessions

There were nine ensemble practice sessions. The sessions were weekly with breaks for half term and Easter holidays. Each session lasted an hour and fitted between the end of school and the start of orchestra practice at five o'clock. Sessions began with warm-up exercises focused on posture and then went on to practicing pieces of music together. Although posture was the focus for the technology intervention, much time in these sessions was spent learning the notes and rhythm as well. The motivation for the sessions from the children's perspective was to support them in learning the pieces for an upcoming concert while helping them to play them with good posture. This made the sessions more directly useful to the children and was a more naturalistic representation of music learning than only focusing on posture. The sessions were videoed from two different angles. Videos of the sessions, plus researcher notes written before and after the sessions are the main basis for descriptions in the next section about how the calibration process was used by the children.

Researcher Role

Previous studies have found that the researcher's role can be instrumental to how the technology is used and appropriated during in the wild deployments [16]. Therefore, we give an account of her participation in the study.

The researcher running the study organized and led all the ensemble practice sessions and attended all the school orchestra rehearsals as a helper playing with the third violin section. As an adult working with children in a school, it was natural that she should act like a teacher during the ensemble practices (although not a qualified teacher). The children automatically treated her in this way and the conductor and music teachers treated her as a colleague around the children. In the role of teacher she gave feedback and comments about playing, answered student queries about music, led the ensemble by playing or conducting, managed behavior and kept them focused.

In this role, she set up the motivation for the study by explaining the importance of posture and teaching them what to aim for. When giving them verbal feedback, she pointed out areas where they could improve their posture so that later when they took the Buzzy Jackets home they could see how they could use them. As such, student engagement with the prototypes was influenced by how the researcher presented the issue of posture to them and their respect for her expertise and authority. It was also part of her role to explain how to use and calibrate the new technologies.

Findings

The children practiced at home with the prototypes regularly and reported only minor changes to their practice routine. Every child did not come to every ensemble practice session as demands of other school activities such as choir practices etc., drew them away; the mean attendance was between three and four participants. Similarly, once the feedback equipment had been handed out they did not always manage to remember to bring it to every ensemble practice session.

Calibration at home and school

The children quickly learned how to calibrate the Buzzy Jacket during the first ensemble practice using it. They were also given instructions on a sheet of paper to remind them how to do it at home. However, no calibration was caught on the videos of home practice because the children only chose to video themselves performing their pieces rather than setting up. Alice chose to write about her practice. In this she mentions "I did the buzzers" in reference to calibration.

The findings showed how the children used the calibration mechanism to take control of their learning. For example, during the first session with the Buzzy Jacket, Carl recalibrated three times during the practice in order to get the level of strictness he was wanted. Only Carl came to this session because the other participants had to attend a choir rehearsal. This meant the researcher was able to discuss with Carl what he was doing. He felt the initial calibration was too lax because it did not vibrate at all while he played his piece so he recalibrated higher. At this point he realized he hadn't turned the feedback on and that it had not been a calibration issue after all. After playing with the very high calibration he felt that the feedback was pushing him uncomfortably high so he recalibrated a little lower. After playing two pieces he chose to recalibrate lower again to give himself the flexibility to sway while playing.

These choices were considered important because one potential drawback of giving feedback on posture is that it might make a player keep their body rigid, so recalibrating to accommodate movement while playing is healthy. Moreover, by choosing when he wanted strict feedback and when he didn't Carl was taking more responsibility for his learning than simply doing things because he was told to.

In ensemble practices it was harder to ascertain how children were using calibration because it was not discussed directly. They all calibrated the Buzzy Jacket independently during the ensemble sessions and reported feeling comfortable using the feedback and that they were able to respond to it showing that they were able to calibrate it successfully in a position that was challenging but achievable. The children reported no difficulties about calibrating the Buzzy Jacket at home. Daphne talked about problems with the vibrotactile feedback "when they weren't, like, set right" which shows awareness of the way a good or bad calibration can affect how the system works.

Footboard and Twinkly Lights

The participants enjoyed playing the feet games (standing up quickly) when choosing the foot positions to calibrate the Footboard and Twinkly Lights. The element of competition encouraged them to play against each other.

The low-tech approach using paper and pens also had a number of advantages. It allowed the children to set the foot position in a way that was easy for them to understand and directly mapped on to their body. This meant as soon as they saw the new prototypes they understood how they worked and where to place their feet. Through the process of choosing their own foot position they also learnt about what they were aiming for in terms of positioning feet and distributing their weight. Using individual footprints gave a sense of ownership of the technology. The process of drawing around their feet also had an interesting side effect. When participants had their feet on the drawings they moved their feet much less while playing than without the drawings. Showing that even without feedback the presence of footprints can be effective in reducing foot movement.

DISCUSSION

The studies described in this paper show that calibration can be more than just fulfilling a functional requirement of a particular technology. The example of the MusicJacket showed how it can be used by a teacher to set learning goals with a student. The Buzzy Jacket showed that it can also be used by students to set their own goals and give them the flexibility to play in a way they feel comfortable with, rather than fitting a rigid model. The Footboard and Twinkly Lights demonstrated that the process of calibrating can become part of learning something new and useful.

In the kind of calibrations reported in these two case studies – namely calibrations which individualize the system to the particular needs of the user – helping users to engage with and understand the calibration process was found to be beneficial. Approaches which try to minimize user involvement in this type of calibration through automation would not be advisable because they deny users the chance to engage with how the system is individualized for them. Similarly approaches such as gamification of calibration [13] - while engaging users in the calibration tasks - also run the risk of preventing users from understanding the purpose of calibration.

Calibration can potentially give users control over the key functions of the system, for example, calibrating the Buzzy Jacket let them control where the vibrations were triggered. However it is often a technical process where little emphasis is placed on helping users understand it. By de-mystifying calibration we enable users to appropriate it and take ownership of what the system is doing. In the field of education, this is particularly important because taking ownership and responsibility for learning is key to learner development. More generally, in the field of sensing it gives users control and ownership and allows them to mold the technology to their body rather than vice versa. In the rest of the discussion we look at reasons why understanding calibration for individualization is important for users. We then examine how calibration can be designed to make it more comprehensible.

Why is understanding calibration important?

First, there are many applications where regular recalibration is necessary to keep up with the changing needs of users. Motor-skills change over time. For example, in learning to play the violin the calibration may change as the child's skills improve. In stroke rehabilitation, therapy can help the patients improve their range of motion. Games designed for their therapy [e.g. 1] will need to keep progress with them. In any goal type activity, one hopes for improvement and progression and recalibration may be necessary to keep abreast with this.

People also change from day to day and moment to moment. The children playing the violin may feel tired of holding it high and need to give themselves a rest toward the end of a practice. People with chronic pain will have to exercise during good days when the pain is low and during bad ones [27]. People have different motivations at different times and this changes how they want to interact with technology – for example, whether they play sports video games for relaxation or achievement [7, 22, 25]. Such variations over time are not predictable and only users know how they are feeling, therefore, in many applications it is desirable to allow users the control to adjust the system to their current needs. In addition, by understanding how the technology and its calibration work, they are better equipped for addressing new needs as they arise.

Second, the body is closely coupled to a person's sense of self. How a person sees and experiences their body interacting with the environment is what makes them decide what is part of them and what is exterior to them [8]. When it comes to interacting with the body, a poor fit with technology may have a large impact. For example forcing someone to interact with their right hand when they are left-handed would feel alienating; whereas, ideally, technology needs to feel part of their skin. This may seem only like an argument for having a good calibration rather than giving users an understanding of calibration. However, what makes a good calibration in this case is down to the feelings of the user, which may not easily be specified and as we have already argued can change from day to day on the basis of developmental, physical and psychological needs. Therefore, placing calibration within the control and understanding of users allows them to feel that they are shaping the technology to be in tune with their bodies rather than changing their body to fit the needs of the technology.

Third, allowing users to participate in calibration is not enough; users need to understand what they are doing. For example, in the case of the iPosture [18] no support was given to teach users what good posture was to allow them to calibrate knowledgeably, this left them feeling unsure whether they had set the device to a healthy posture. Whereas, in the Buzzy Jacket study the children were given the knowledge about posture they needed first so that they were able to calibrate with confidence. Accordingly, user calibration does not give control unless they also have understanding.

How do we design to help people understand calibration?

Expose intentions and provide visibility [10]. Interaction design guidelines like these can help designers think about the purpose of calibration for the applications they are building. Taking the MusicJacket as an example, the intention of calibration became clearer to the teacher as the discussion with the researchers unfolded, so that quickly it was understood that the purpose of calibration was to position where the feedback should come on. Visibility came from the teacher's systematic approach of testing where the vibrations were and were not triggered after each calibration. In that case the two criteria were met through discussion, but they could be designed for.

Familiar mappings. The calibration of the Footboard and Twinkly Lights is an example where the students were able to understand easily that they were setting their desired foot position by drawing around their own feet and could see how this was going to link to the functioning of the prototype. Two particular properties of this calibration process made it more accessible to the children. First, it used familiar materials like pens and paper. Second, it used a very visible and direct mapping of the body, namely drawing feet. In calibration relating to the body, drawing around the body or with the body, may be a way of recording a measurement that is meaningful to the user.

Learning through tweaking. Another element of the study with the Twinkly Lights and the Buzzy Jacket is that learning about calibration was an incremental process for the children. This enabled them to learn and understand each step of the calibration before moving to the next one. Breaking down calibration into steps and scaffolding the learning of calibration by teaching it incrementally potentially allows users to become confident in calibration even when the process is complex.

Contextualize in the domain knowledge. This can help users set for themselves an appropriate baseline or goal using calibration. The children needed to understand how to sit well in order to calibrate the Buzzy Jackets to a good posture. This requirement for additional knowledge either needs to be designed into the calibration process so that users are informed when they calibrate or needs to accompany it in another way, for example, the children in the Buzzy Jacket study learnt about posture before using the technology.

Generalizability

User engagement with calibration worked well in these cases but will this generalize to other domains? In some cases expecting users to spend time learning about calibration may not be appropriate, for example if users are only going to use the system once. However, in cases where there will be long-term use, there are good arguments for getting users involved in calibration of body sensing equipment, despite specific challenges some domains may pose. Even though calibration may involve setting a complex assortment of parameters within the system, potentially creating a large search space, a well-designed calibration should be able to overcome this by allowing users to understand and express calibration in terms of their own body. A large search space should be problematic if users are not searching but simply communicating what they require in a way they understand. To demonstrate this, we present some examples where it may be applied and discuss the extra challenges faced in these cases.

Healthcare

Body sensing applications in healthcare will be particularly challenging because they are safety critical and require expert domain knowledge. For example, the physical therapy applications discussed in the literature review could cause patients to strain themselves if improperly calibrated. However, this shouldn't be a deterrent to engage users with calibration, only that the way calibration is designed should take this into account. For example, when calibrating for a range of movement, the patient could calibrate this themselves, within a range which the therapist has previously set as being safe. Although patients may not have the domain knowledge that the doctors treating them have, they are experts in their own bodies and the way that they feel that day. Moreover, people with long term illnesses often become expert in their own condition and the way it affects their body. Calibration should be designed to capitalize on what patients can contribute. If patients have only limited domain knowledge perhaps they only tweak within confines of an expert calibration. As their knowledge develops more leeway can be given.

In some cases an automatic calibration process is necessary to provide the right support to patients, but careful design can still allow patients to contribute. For example, [4] proposes an emotion-aware system for self-directed rehabilitation that adapts at run-time the exercise plan and feedback to address the psychological needs of the patient as they arise (e.g. increase in anxiety level). This automatic tailoring is necessary to avoid negative reinforcement of fear of movement. However, by providing the space for post-reflection on the calibration process, the system may allow the patients to better understand themselves and to take control over their condition [27].

Games

Gaming is an area where users may feel that calibration is uninteresting and detracts from the experience. Minimizing user input and automating calibration may be advisable here. However, this does not mean that users should not be given the option to contribute to calibration. For example, calibrating a tennis game to better represent their body may make a person identify more with the achievements of the character on screen. An invisible automatic calibration would not make this personalization explicit even if it achieved the same level of accuracy. Thus, even in cases where users are uninterested in carrying out lengthy calibrations, making the purpose and outcome of calibration more explicit and allowing people to tweak and personalize it further may be engaging for users.

Training Physical Skills

In applications that aim to train people in physical skills, it is beneficial if users engage with a system to understand what movements they are trying to learn. In these cases, like those described in this paper, calibration will often take the form of teaching systems which movements are desirable and which are not. By learning to calibrate the system, users are forced to consciously learn about what movements they are aiming for as they learn their skill. The challenge here is to design a calibration method that supports this process of learning. For example, calibration could be scaffolded by using average, automated or expert calibrations in the early stages with the user gradually learning to calibrate different elements over time.

CONCLUSION

Allowing users to individualize interaction with technology through a calibration process has advantages: it allows technology to be adapted to the changing needs of the user and it gives users a sense of control and ownership of the technology. However, this requires us to design calibration in a way that not only involves users in calibration but also allows them to understand it. Rather than seeing it as a burden, self-tweaking through gesturing, pointing, drawing, or other input can transform calibration into an informative and technology shaping process.

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