“Don’t follow them, look at me!”: Contemplating a haptic digital prototype to bridge the conductor and visually impaired performer

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Abstract

This paper reports on an exploratory research-and-development project concerning a device for conveying a conductor’s gestures wirelessly to a visually impaired (blind or partially sighted) performer as a haptic signal. The research team developed this device from January to July 2017 under a University College London (UCL) Institute of Education “seed-corn” grant. As a platform for its development, they firstly observed and analysed video footage of conductors at the Royal Academy of Music, London using Elan software to create a gestural model. Subsequently, through gaining blind end-users’ feedback on the device, as well as an experiment to compare their timing using either (i) a two-dimension haptic signal or (ii) a metronomic pulsation, it is suggested that the development of technologies for this purpose should focus on the meaning the conductor intends to convey coupled with haptic signals blind end-users themselves deem suitable, rather than adopting a “sighted perspective” in attempting faithful transference of two-dimensional captures of arm movements from one medium to another. Reasons for this assertion are explored.

THE ENSEMBLE EXPERIENCES OF THE VISUALLY IMPAIRED

Visually impaired musicians participate in some music ensembles with limited or no reference to the conductor’s gestures by contrast with their sighted counterparts. These musicians navigate the experience variously depending on particular sight conditions and personal approaches; these are not without challenges.

> I’ve done those “Come and sing” events, so “Come and sing Mozart’s requiem, come and sing Messiah” just for fun. …They [the sighted singers around me] are obviously just reading their music and not watching the conductor. Sometimes conductors say “Don’t listen to them, go in time with me, look at me” and I think “Maybe I should just go home then” (laughs). (Felicity, keyboard player and singer, blind)

Felicity[1] is a visually impaired[2] singer who performs in choirs alongside sighted musicians. Her remark above highlights a perennial issue: Integration into many types of conducted musical

[1] Pseudonyms have been used in this paper for every respondent.
[2] We have used the term “visually impaired” as an umbrella term to denote those with sight health problems or the absence of sight such that they meet the requirements of UK registration by an ophthalmologist. Under this umbrella there may be people who the layperson may describe as “blind” or “partially sighted”, and we use those terms too. Other terms in common usage include “sightless”, “sight impaired”, “low vision”, etc. with

experiences in our wider communities, or into the music profession as a performer, relies on learning, preparation, and practices within rehearsals and concerts that bypass the conductor’s gestures. Yet every person should have the right to engage in music, and we need to develop strategies and resources for those with differing abilities, including those with visual impairments. Ensemble playing, or choral participation as in Felicity’s case, with its reliance on a conductor, can be particularly challenging for those with visual impairments. Devices to convey this information using other senses may be advantageous, hence the focus of the current article. Jason performs in ensembles and is another example. Jason relies on deep memorisation of his scores from Braille music cross-referencing with audio ahead of rehearsals. He explains the perceptual “gap”:

> It’s a bit like jumping into a swimming pool. Anyone can jump into a swimming pool on a whistle, but it’s what you do when you are in there underwater and you can’t hear or see anyone until you come up at the other end. It’s that bit where a lot of people who say they can’t see a conductor might say that they struggle. …There is the relationship you have with your score and, then, the relationship you have with your conductor. Because, unless you know what you are playing, as a blind person in an orchestra you are just not going to be able to function. And, whatever the conductor does is going to be, in a way, secondary to your relationship to the score and the music that is going on around you. (Jason, recorder player, blind)

Jason reports that his relationship with the conductor is less important than for a sighted person, due to gestures he simply cannot access, as compared to memorization of the score ahead of rehearsals. Memorization is often foregrounded by visually impaired musicians who play in conducted ensembles:

> You need to know the music really, really well in advance. So, instead of being 100% prepared, you’re 150% prepared. You know your part but also it fits in with the others. You can pick up, during rehearsals, what the cuing instruments are going to be and you need to know your tempo relationships too. Once you know all that, you’ve got a map. (Adam, composer and guitarist, blind)

> I just memorize the music. I listen to the music loads of times and I focus on the instruments that give me my cues. (Veronica, singer, blind)

Aside from the Braille memorisation and audio used e.g. by Jason, some musicians, depending on particular sight conditions, also use large print or modified stave notation (even using software and other devices to view it), some play by ear, or they learn their music by a combination of approaches

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various benchmarks for registration worldwide. “Visually impaired” relates to a continuum from no light perception, through non-functional visual perception i.e. as it relates to daily life, to visual fields or acuity affected to a smaller extent but still severe enough for registration. We acknowledge that terms such as “impairment” (used here), “disability”, and “handicap” are often used interchangeably in casual dialogue, with the last one largely discarded a few decades back, and these tend to imply a problem or a lack, and as such may be understood as contributing to a “deficit model” of people’s differing needs and capabilities (see Silvers et al., 1998). We use the term “visual *impairment*” in this paper simply because it is widely used (even by our respondents) and recognisable in the UK.

(see Baker and Green, 2017, for details of technologies and learning approaches). Regardless of the range of tactics that are used by these musicians, what bonds them in these contexts is reliance on memorization and, within the rehearsal or performance, audible and tactile cues in an attempt to address the perceptual shortfall in receiving information from conducting gestures, which most people would see. Paul and Felicity explain this:

> I listen to breathing. I’ve got a bassoon on my left ear and I’ve got a flute in front. You deliberately breathe in that group, and I’ve stuck my left foot out towards the bassoonist and he’s tapped on it. (Paul, clarinettist, blind)
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> I had someone tap introductory pulses on my arm. She [the conductor] trusted me to come in with the right note, but she wanted to convey what the speed was. (Felicity, keyboard player and singer, blind)

Felicity explains how, even so, audible cues in her choir setting, i.e. inhalations, could go awry and, as such, she is disadvantaged as compared to sighted people who can see their conductor:

> It was hard to come in on time because the orchestra was so loud [when I was singing] and I couldn’t listen to the people near me [i.e. fellow singers] breathing. When singing in a church with an organ, I’d hear the hear everyone breathing in. The conductor normally does some signal that means take your big in-breath now, because you are about to sing. And it’s that kind of thing that I need. (Felicity, keyboard player and singer, blind)

Felicity’s point is that, even with deep score memorization, there is often crucial information for performing, here an entry, that she cannot access without additional support. Bajo, Sánchez, Alonso, Berjón, Fraile and Corchado (2010) note that visually impaired ensemble performers “…can experience serious problems in responding to incidents or changes in the normal thread of the score, or synchronizing with the other musicians…” (p. 8509). The “voices” of Felicity, Jason, Paul, Adam, and Veronica come from the research on which this article is founded (as explained later). Digital technologies may be a way to offer them the support needed. Indeed, the use of technology is becoming more prevalent for visually impaired people. Csapó, Wersényi, Nagy and Stockman (2015) write that “A large number of visually impaired people use state-of-the-art technology to perform tasks in their everyday lives. [However]...one of the most important and challenging tasks in developing such technologies is to create a user interface that is appropriate for the sensorimotor capabilities of blind users,..” (p. 275). Against the challenges faced by visually impaired choir and instrumental ensemble members, along with the research team’s conviction that musical participation should be the right of everyone, this article discusses the development of a prototype device to convey the conductor’s gestures and meanings (those normally transmitted visually) by haptic means. With it, we consider whether a digital technology can effectively close the perceptual “gap” between the conductor and visually impaired performer, the initial development of such a tool, and ramifications of the development process for social inclusion.

An important part of this developmental process is how important assistive information is conveyed to the visually impaired. In the field of Human Computer Interaction (HCI), possibilities have been broadly divided into "sonification" and "haptification" (see e.g. Csapó, Wersényi, Nagy and Stockman, 2015). Aside from sonification as verbal instruction (as in screen reader software technologies for computing, e.g. JAWS, NVDA, etc.), Blattner, Sumikawa and Greenberg (1989) write of "earcons" or non-verbal audio messages used to convey information to the visually impaired about some computer object, operation, or interaction. This is the sonification of key information at high abstraction, for instance as patterns of tones. In similar fashion, haptification (the approach used in this project) could entail attempting to mirror (in their velocities, dimensions and directions, etc.) e.g. conducting gestures a person would normally understand through sight, or, instead, employing a far higher level of abstraction as "haptic icons", or "hapticons", i.e. as tactile signals that are meaningful and helpful for the visually impaired person, but which do not directly resemble what would be seen (see Csapó, Wersényi, Nagy and Stockman, 2015, p. 276; also see Brewster and Brown, 2004 on "tactons"). We return to the matters relating to this later in the article.

Visual impairment, its extent and inclusive musical practice

The World Health Organization's 2010 global estimates are 285 million visually impaired, with 39 million of these "blind" and the rest "low vision" (WHO, 2012). Visual impairment comes from congenital, or "from birth" conditions and genetics (e.g. Leber's congenital amaurosis or ocular albinism), disease (e.g. diabetic retinopathy), the over-administration of oxygen to babies in incubators (e.g. retinopathy of prematurity), accidents and ageing.[3] In UK's RNIB reports that there are almost 2 million people living with "sight loss", equating to 1 person in 30, and they estimate that by 2050, this will increase to nearly 4 million.[4] In the US, there are over 6.6 million visually-impaired people according to the National Federation of the Blind.[5] In Australia, there are an estimated 357,000 people who are "blind" or have "low vision".[6] The Canadian National Institute for the Blind (CNIB) reports that 479,083 Canadians have "vision loss" or "partial sight".[7] Approximately 125,000 New Zealanders have "vision loss", with an additional 12,000 "blind".[8] The commonest causes of sight loss

[3] We were supported in understanding medical terminology by Vasuki Sivagnanaval FRCOphth, MD, BSc, MBBS, PG Cert, a consultant ophthalmologist and surgeon from the Royal Eye Unit, Kingston Hospital, London.
[4] From http://www.rnib.org.uk (accessed 9 September 2014).
[5] Refer to https://nfb.org/blindness-statistics (accessed 9 September 2014).
[6] Refer to http://www.and.org.au/pages/disability-statistics.html (accessed 6 January 2015).
[7] Refer to http://www.cnib.ca/en/about/media/vision-loss/Pages/default.aspx (accessed 6 January 2015).
[8] Refer to http://blindfoundation.org.nz/learn/blindness/statistics-on-sight-loss (accessed 6 January 2015). One problem with collating worldwide figures on visual impairment is the array of overlapping terms used, with e.g. "sight loss" (and even where sight has not been "lost") or "visually impaired" sometimes utilised to mean "partially sighted" as distinct from "blind"; and medical registration benchmarks for blindness or partial sight

worldwide include cataracts and age-related macular degeneration with a large amount of preventable sight problems.

Musical participation for children and young people has long been considered beneficial, but it contributes to older people's wellbeing and social lives too (Hallam, Creech, and Gaunt et al., 2011; Hallam, Creech, and Pincas et al., 2010). This can extend beyond school walls into communities as lifelong learning (Myers, 1995, 2008; Roulston, 2010). Sight loss is more likely later in life too and this affects someone who already participates in conducted music ensembles as a professional or amateur. Ensuring that children and adults can participate, or continue to participate, alongside sighted peers is a matter of inclusive practice.

Traditions of visual impairment and music

Across history, there have been visually-impaired musicians and musical groups in Europe, the Middle East, Africa and Asia entrenched in lore concerning "special dispensations" of heightened musical abilities and spirituality (e.g. in itinerant minstrels), as well as society deeming music a viable occupation for the blind (see Baker and Green, 2017; De Ferranti, 2009; Groemer, 2012; Kononenko, 1998; Lubet, 2011; Meeker, 2006; Ottenberg, 1996; Silvers, Wasserman and Mahowald, 1998). Early US gospel, blues and jazz had notable performer-composers too, e.g. John William "Blind" Boone, "Blind Tom" Wiggins (Tom Bethune), "Blind Willie McTell" and the vocal group The Blind Boys of Alabama (e.g. see Batterson, 1998; Fuqua, 2011; Gray, 2008; Harrah, 2004; Rowden, 2009; Southall, 1999). More recently, there have been jazz and popular artists, e.g. Rahsaan Roland Kirk, George Shearing (Shearing & Shipton, 2005), Art Tatum (Lester, 1994), Ray Charles (Charles & Ritz, 1978; Evans, 2005) and Stevie Wonder (Williams, 2002; Ribowsky, 2010). These have been "oral [sic] traditions" (McLucas, 2011), i.e. of learning and (re)producing music by ear sometimes in the absence of notation. This is suggestive of visually-impaired people gravitating towards certain genres today, and away from those spotlighting notation or/and participation in conducted ensembles, yet there have been acclaimed classical musicians, e.g. the composers Frances McCollin (DiMedio, 1990) and Michael Stimpson, flautist James Galway (Galway, 1979), concert pianist Nobuyuki Tsujii, the opera singer Andrea Bocelli (Bocelli & Pugliese, 2002) and the organist David Liddle (see Farlow, 1956 on London and Parisian church organists).

The focus of this article

The current research was funded under a University College London (UCL) Institute of Education "seed-corn" grant in 2017. It builds on an earlier project called "Visually impaired musicians' lives"

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are not comparable across nations. With this paper, we use "visual impairment" for the full range of conditions that relate to voluntary registration by an ophthalmologist.

(VIML) funded by the UK's Arts and Humanities Research Council (2013–15, Ref. AH/K003291/1) (see Baker and Green, 2014; Baker and Green, 2016; Baker and Green, 2017; Baker and Green, 2018). A smaller follow-up study in 2016 in India was funded by the British Council and Arts Council England (Grant ref. 29237470) for fieldwork in Chennai, Bangalore, and Calcutta.[9] VIML resulted in a co-authored book, *Insights in sound: Visually impaired musicians' lives and learning* (Baker and Green, 2017). It gathered interview and questionnaire data from 231 people, including visually impaired musicians and learners, and specialist music teachers working with them. Responses came from English speakers in a wide range of countries, i.e. Argentina, Australia, Austria, Brazil, Burundi, Canada, Chile, Colombia, Croatia, Denmark, Egypt, Estonia, Fiji, Ghana, India, Indonesia, Italy, Japan, Kenya, Malaysia, New Zealand, the Philippines, the Republic of Ireland, Russia, the Slovak Republic, the United Kingdom, and the USA.

Given the "aural/oral" traditions mentioned above, a great surprise in VIML was the diversity of the musicians' engagement in terms of contexts, genres and instruments. Indeed, 53.93% of the questionnaire respondents indicated that they performed classical music, and 16.75% early music, and some of these participated in conducted ensembles with the sighted regularly. One reason for this was the broad range of digital technologies that have been developed, including those commercially produced and designed primarily for the sighted (e.g. digital audio workstations, engraving software [some of which will render large print or modified stave notation], etc.), with these sometimes used in tandem with specialist accessibility hardware and/or software (e.g. screen reader programs [such as JAWS, NVDA], zooming software, Optical Music Recognition, braille displays and embossers, etc.). Yet, although technology has unlocked opportunities for learning notation for various genres, as Felicity and James explain above, there remain challenges in negotiating conducted ensembles; accordingly, the development of devices to convey gesture by haptic means may be particularly helpful.

Consequently, our research questions were:

- What meanings are conveyed in conductors' gestures?
- How might a prototype digital technology involving "haptification" be formed to aid the visually impaired performer in receiving those meanings?
- What views do visually impaired end-users have on the nature of this device?
- What are the implications of their responses for future technology development in this arena?

[9] The authors are grateful to the Baluji Music Foundation, a UK registered charity. They were the British Council/Arts Council England grant holders who invited David Baker to travel with them for this additional data collection in relation to his AHRC funded work.

PROJECT DESIGN[10]

The project had three key elements, as follows:

- Video observations of conducting classes and creation of a gestural model
- Prototype technology development with the aim of effective coverage of the above
- Testing and feedback from visually impaired musicians

Conductors gestures were first captured as video footage and software used to code it along with seeking confirmation of the coding process from an experienced conductor-participant (the first item above); this led to a model (Figure 2). The model then allowed the researchers to make an assessment about how best to develop a device for visually impaired performers to convey the meanings within it through haptic means (the second item). Visually impaired users subsequently tested this prototype device during four testing days, including an experiment on two types of haptic signal it could convey on the fourth. This experiment called for them to perform a simple piece and attempt to keep in time with various tempo changes in response to the two signal types. Audio files of those attempts were independently appraised by experienced musicians and a t-test statistic used to assess if there was a significant difference between their responses (the third item). Across the four testing days and gradual development of the prototype, the visually impaired participants provided their viewpoints on the technology, its development, their needs and also the experiment through semi-structured interviews, with data analysed using commonplace approaches to qualitative research. The methodological approach across the various elements of the project, (including references to key literature), is discussed at length below.

ETHICS

Our research underwent University College London (UCL) ethical review and was approved by panel (Project number: REC 905; Data protection registration number: Z6364106 2017 03 146). We adhered to benchmarks of e.g. "informed consent" (Gregory, 2003; Silverman, 2017) and "confidentiality" (e.g. see BERA, 2011; BPS, 2009). Participants were sent an information sheet by e-mail (a Word document), which the visually impaired people accessed using screen reader software.[11] After digesting the document, they gave their consent by agreeing to attend our events. Asking visually impaired people for a signed statement of consent may have caused embarrassment for some. Participants were made aware that they could withdraw from the project at any point by sending us an e-mail. Pseudonyms have been used in this article, and data were kept on a password-protected computer within UCL's firewall.

[10] We are immensely grateful to Emerita Professor Lucy Green of the University College London Institute of Education for her guidance in designing and conducting this project, as well as with writing this article.

[11] Screen reader software packages (e.g. JAWS, NVDA) read the text in digital files and webpages, including other visually-displayed elements, as synthetic speech.

VIDEO OBSERVATIONS AND DEVELOPMENT OF A GESTURAL MODEL

Four conducting classes at the Royal Academy of Music, London were filmed in January and February 2017. These were led by Sian Edwards, a world-renowned professional conductor.[12] The classes were two hours long, including discussions, listening to recorded music, and practical activities in which four student conductors supported by Sian worked with two rehearsal pianists. In total, we collected 1 hour, 12 minutes and 27 seconds of footage paying special attention to Sian's demonstrations. Video in research facilitates access to facial expressions, habits, postures, and gestures (Mondada, 2006) and thus to the ''…habitualized knowledge implicit in social action…'' (Knoblauch & Tuma, 2011, p. 12). Our footage was captured in High Definition using a Canon 5D Mark II D-SLR camera with a mounted Rode microphone. This was mounted on a tripod, such that the lens could be pointed in different directions e.g. when Sian demonstrated from the back or front of the room. The resultant digital files were entered into Elan, a software package developed at the Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands (Lausberg and Sloetjes, 2009);[13] although intended for linguistics, its functionality fitted our purposes well. We used it to code visual data alongside annotations (Figure 1).

[12] Sian Edwards is Head of Conducting at the Royal Academy of Music. She has worked: with the Scottish Opera; at Glyndebourne; at the Royal Opera House, Covent Garden; with the English National Opera; and the London Sinfonietta; among other appointments.

[13] Elan software is available from The Language Archive, The Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands at http://tla.mpi.nl/tools/tla-tools/elan/ (accessed 18 July 2017).

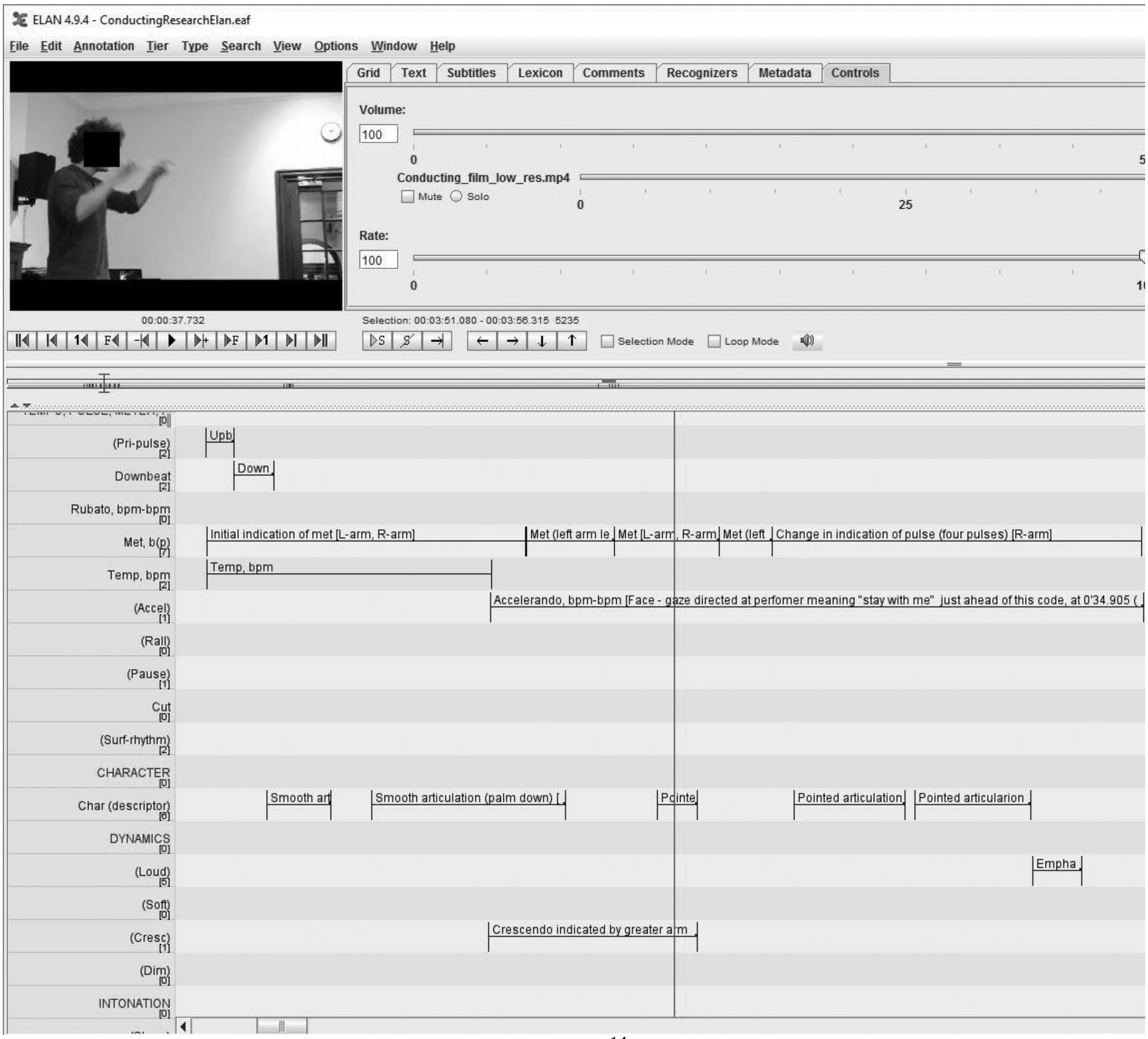

Figure 1. *Screen capture taken from the Elan software*[14]

Collecting observational data, coding it, and producing a tentative model of conducting was a way in which: (i) to explore systematically what the conductors were doing gesturally; (ii) to consider the most comprehensive way to provide a "bridge" between the conductor's gamut of gestures and the visually impaired performer (i.e. as the basis of our prototype device); and (iii) to assess the prototype that emerges in terms of its coverage.

Gestures conductors use are idiosyncratic, based in part on traditions of conducting, training experiences, and so on. Although certain intended meanings are consistent across different conductors, e.g. a gesture to abate volume, or an upbeat to prompt the performers' entry, the gesture itself (as a physical movement, or direction or momentum of action, posture, expression, etc.) for any of those meanings will be various across practitioners. As such, it is important to note that our coding

[14] The conductor's face is obscured with a black square for confidentiality.

scheme paid attention to the *gestural intention* (meaning) rather than the *physical movement* (to convey that meaning) to systemise what conductors, as a collective body, do.

The coding process commenced with broad “conveyor” and “consumer” codes within the software, subsequently breaking these down into categories relating to “tempo, pulse, meter and rhythm”, “dynamics, interpretation”, and “character” (see below). More densely populated segments of the footage (e.g. where both arms had independent meanings) could be revisited repeatedly by the coder, isolated and slowed. In the same way that qualitative researchers working with text from interviews will take e.g. findings back to their respondents (e.g. see Delamont, 1992; Huberman and Miles, 1994; Silverman, 2015) for “respondent validation”, “feedback” or “authentication” of preliminary findings, it was necessary to work closely with Sian whose conducting we filmed. Hall (2000) has argued that there is often a mistaken expectation that video recordings are, in some way, objective. Mason (2005) has continued “…it should be recognized that claims to realism…may often in fact be a distortion of events with a portrayal purposively selected in order to achieve persuasion” (Mason, 2005, p. 329; also see Jacobs, Hollingsworth and Givvin, 2007). Doubts on the “faithfulness” of video have contributed to its low status in social research (Prosser, 1998). Consequently, Sian had a significant role in assessing the codes applied to video footage, through face-to-face meetings and via e-mail, in identifying the absence of significant gestures/meanings, and in ensuring against distortion with respect to her intentions. Bailliard (2015) has argued that engaging participants as co-creators of knowledge in video-based research increases its validity. In some ways (i.e. in the constant reassignment of codes until agreed upon), the process paralleled approaches to the analysis of qualitative data (e.g. see Bernard and Ryan, 2010; Bernard, Wutich and Ryan, 2017; Mason, 2017; Ravitch and Carl, 2016; Silverman, 2015, 2017).

The final scheme on which the model is based (Figure 2) includes codes of tempo (including changes to this), meter, pulse (including prior indications of pulse) and also any surface rhythms that are conveyed at times by a conductor for added character. It also accounts for overall musical character, dynamics, and intonation. In physical terms, these meanings are conveyed variously by different conductors, but the model illustrates how these codes/meanings, starting with a prior indication of pulse (left-hand side), move from left to right with the passage of time, perhaps circling back to earlier points/codes in the model at times, before finally arriving at a “cut” at the end of a piece or movement (right-hand side). This is explained further below.

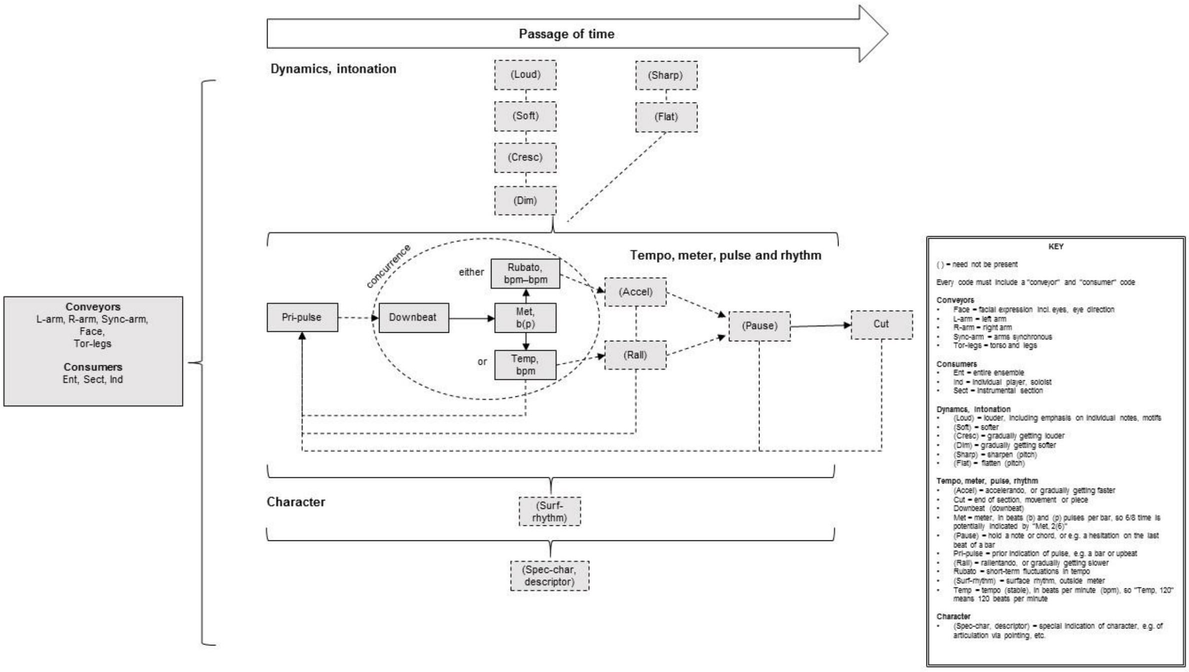

Figure 2. *Model of a conductor's gestures*

In Figure 2, codes that are in parentheses (and inside boxes with dotted lines) need not be present at any point in time, although they might be. The diagram can be understood thus:

Tempo, meter, pulse, and rhythm

Pieces commence with a "prior indication of pulse" (see "Pri-pulse"). This is manifested in a spectrum from the subtlest gestures, e.g. a facial expression, through e.g. an upbeat, to half or whole bars indicated before a performance starts. Next, in any given passage, gestures will convey concurrently a significant first downbeat (with subsequent others marking the start of bars) then indications of meter (in beats and pulses, i.e. "b[p]"), along with *either* tempo in beats per minute (i.e. "bpm") or *rubato* where there are fluctuations in tempo over shorter periods of time (i.e. within a range, "bpm–bpm"). Beats, pulses or beats per minute can be given numerical values too when coding video, e.g. 6/8 time (compound duple) could be indicated by two beats in a bar and six pulses, so "2(6)" or 4/4 with "4(4)". Stable tempi, or alternatively those with rubato (i.e. more subtle fluctuations in tempo), can, sometimes, give way to a prior indication of pulse marking new sections ("Pri-pulse" again), with this new section again having its own downbeat, meter, and tempo. Sian remarked that this was always the case, even if the cues were the subtlest. Alternatively, a section can move onto accelerations or decelerations in tempo over longer periods hence "(Accel)" and "(Rall)", say, arriving at a pause, or simply coming to a pause without those lengthier tempo changes (i.e. skipping over them in the diagram). There may be a cut too, either with or without those tempo shifts and/or a pause. All that might happen before a prior indication of pulse (however subtle or obvious) setting up a new passage. Thus, the coding scheme can be applied to video flexibly with the passage of time indicated from left to right, but potentially with multiple iterations as codes return repeatedly to "(Pri-pulse)" as new passages of music commence before the movement or piece finally concludes.

Dynamics

There are other codes that can happen simultaneously with those that occur under the heading "Tempo, meter, pulse and rhythm". The dynamic quality of the music is often conveyed, more generally, by e.g. the physical momentum or size of a conductor's gestures, shown initially by an upbeat or first downbeat in any passage. This could, arguably, be indicated by a "Vol(dB)" code indicating decibels, but this was not measurable accurately from video footage and unnecessary for our purposes. However, special emphases on notes or figures (e.g. pointing, or the palm of the left hand facing downwards) can be indicated, where applicable, by the codes "(Loud)" or "(Soft)" where that is his or her intention. Similarly, progressive change (either increasing or decreasing in volume) could be coded "(Cresc)" or "(Dim)" respectively. Occasionally too, a conductor may wish to flag intonation (pitch) issues to a performer, i.e. "(Sharp)" or "(Flat)", perhaps by pointing a finger vertically for the former.

Character and surface rhythm

Musical character is gestured through the overall physical demeanour of the conductor (including facial expression, posture, other movements), some of which are, for instance, concerned with articulation (e.g. legato, staccato, combinations thereof), momentum (e.g. visual impressions of resistance, or impacts), and so on. These cannot be captured with a single code and are beyond the scope of the current scheme. However, we became aware of moments in the footage where the conductor was picking out moments of special character e.g. articulation via pointing or tenuto (smooth, weighted) with a floating open hand. We have given these the code "(Spec char, descriptor)", where the "descriptor" could be given qualitatively such as "floating". This code can occur simultaneously with others in any coded timeline. Surface rhythms, beyond meter and pulse, were also sometimes indicated, e.g. two quavers followed by two crotchets in a 3/4 bar, by wrist or arm movements. These have been given the code "(Surf-rhythm)" and again occur simultaneously with other codes.

Conveyors and consumers

The gestural codes described thus far will simultaneously have a "conveyor" code. In Figure 2 (left-hand side), "L-arm", "R-arm", "Sync-arm", "Face", "Tor-legs" indicate the left arm, the right, both arms acting synchronously, facial expression and clear movements of the torso driven by the legs respectively. Similarly, the codes offered thus far will simultaneously have a "consumer" code. "Ent", "Sect" and "Ind" refer to the whole ensemble, an instrumental section (e.g. the strings, brass, etc.) or an individual within the ensemble respectively. So, by way of an example, a conductor throwing his or her left arm downwards, palm downwards and quickly spreading the fingers all in the direction of the violin section for a chord emphasis would be coded “(Loud) [L-arm, Sect]”.

We acknowledge the limitations to any attempt to encapsulate the immense complexities of gesture in conducting, which comprises the tiniest movements to more obvious ones, sometimes overlapping and unfolding variously, and sometimes entailing the human body’s entire kinetic chain. These intricacies are about mutually-understood expressions between the conductor and performer(s), with some part of wider human experience, some part of a person’s prior music-making experience, and others agreed verbally e.g. during a rehearsal. It became clear that, in order to produce a device for the visually impaired person, certain aspects of this complex model would need to be omitted to avoid cognitive overload (e.g. the information associated with the conveyor codes of “L-arm”, “Sync-arm”, “Face”, “Tor-legs”); whereas most of the other aspects could be addressed through capturing and conveying right-arm gestures in a two-dimensional plane. Our concern about overloading the performer was particularly so for someone with no prior experience of conductors’ gestures. That is, the research team believed that, by seeking to present e.g. the movements of both arms, and/or facial expressions or eye directions (i.e. where a conductor signifies the specific “consumers” within the ensemble) any system rendering gestures by haptic means would rapidly become unmanageable and unintelligible for the user. We believe that this coding scheme went some way to enhancing our understanding thus permitting a better platform for the technology development, its assessment and consideration of further advancements.

PROTOTYPE DEVELOPMENT TO ADDRESS THE GESTURAL MODEL

It was decided by the researchers that the best way to capture and transmit the widest gestural gamut seen in the model (Figure 2) was to track the conductor’s right-arm gesturing in two dimensions and to transfer this to the performer as a two-dimensional haptic (tactile) signal. This would account for information conveyed on: the tempo, meter and pulse; any dynamics or special emphases indicated by swing size or shape; and information on musical character and surface rhythm (see the coding in Figure 2), that is, where the right arm is responsible for providing such information. We do acknowledge that information on musical expression comes from the overall movement and deportment of the practitioner, not a single limb. We also acknowledge that this approach assumes the dominance of the right arm and, in experienced conductors, that is not always the case dependent on particular approaches, pieces and the musical material within them. We considered this the best possible way of conveying the maximum amount of information to the visually impaired ensemble performer, however, without producing cognitive overload. Another approach, if this too was over-complicated for the user to decipher, would be to transfer these two-dimensional right-arm movements to the performer as metronomic haptic signals, a pulsation, i.e. simply to indicate tempo, pulse and meter. The ramifications of our approach are discussed later in this article. The resultant technology was developed by Ann Fomukong-Boden, an electronic engineer and Director of Kakou.[15] From January to July 2017 we developed: a “ring” to be worn by the conductor; and a “vibration matrix” for the visually impaired performer. As this prototype developed, we also invited five visually impaired musicians to four testing days held at the UCL Institute of Education (April–June 2017), where they used and discussed the equipment with us (Figure 3).

Figure 3. *A visually impaired musician touching the vibration matrix*[16]

The visually impaired musicians who attended the testing days

Pseudonyms have been used for the five testing day participants: Veronica, age 35 years, was a congenitally blind, with glaucoma, detached retinas and cataracts; she was a professional soprano. Jason, also age 35, had Leber’s congenital amaurosis with non-functional light perception; he was an accomplished professional-level woodwind player. Three of the respondents (all adults) asked that their ages were withheld for confidentiality: Paul had experienced sight loss in mid-life, with some light perception but no peripheral vision. He played the clarinet to diploma standard remembering conductors and stave notation; he considered himself “an amateur musician”. Felicity was an accomplished congenitally blind keyboard player and singer, with residual light perception and photophobia. Adam was a professional composer and guitarist. All performed regularly in conducted

[15] Kakou is “a social enterprise looking to identify and remove barriers that exclude disabled musicians from accessing mainstream music participation”, see http://www.kakou.org.uk/ (accessed 20 July 2017).
[16] The respondent’s face has been obscured for confidentiality.

ensembles. After an e-mail-out to the network from our earlier work (Baker and Green, 2016; Baker and Green, 2017; Baker and Green, 2018), they all volunteered to participate.

The prototype system

Figure 4 outlines the system.

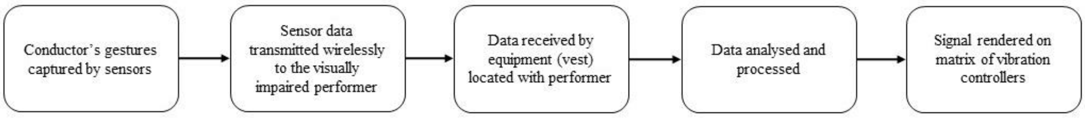

Figure 4. *Design brief*

The conductor's "ring"

A watch-like device was initially created to be worn by a conductor, using the STMicroelectronics STEVAL-WESU1 evaluation kit but, through discussions with the conductors on the project including Sian and Janet Oates,[17] it was decided that a ring-like device would capture a more intricate range of movements. This "ring" was constructed from the following components:
A Bosch BNO055 9 Degree of Freedom System in Package, integrating a tri-axial 14-bit accelerometer, a tri-axial 16-bit gyroscope with a range of ±2000 degrees per second, a tri-axial geomagnetic sensor and a 32-bit microcontroller running the company's BSX3.0 FusionLib software.
An Arduino Micro unit, i.e. all the features of an Arduino Uno but in a miniature form; and an HC-06 Bluetooth Classic Module.

The performer's "vibration matrix"

This matrix consisted of a microcontroller board and a 20-by-20 matrix of 10mm vibration motors (200 by 200mm, n = 400, Figures 5 and 6). This could track the conductor's gestures in two dimensions or offer other pre-determined computer-controlled patterns (see "An experiment within the testing" below). The matrix was worn on the performer's chest (Figure 7). An Arduino Uno microcontroller was used, which had ethernet, Wi-Fi and Bluetooth connectivity. It was essentially a small computer capable of real-time operations. The Arduino received Bluetooth data from the conductor, analysed and processed it, then controlling the vibration matrix.

[17] Janet Oates, conductor of an amateur orchestra including a blind performer, joined us for one of the testing days. We are grateful for her advice.

Figure 5. *Vibration controller*

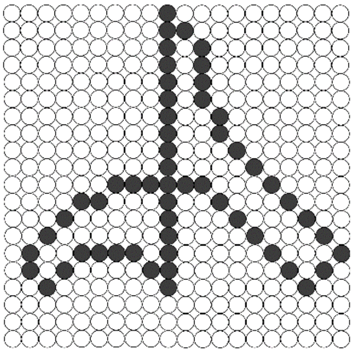

Figure 6. *A gestural pattern on the vibration matrix*

The vibration controllers were Linear Resonant Actuators (LRAs); these were similar to the components in mobile phones. Coupled with the Texas Instruments DRV2605L Haptic Driver, these LRAs were capable of complex vibration signals. The Arduino Uno microcontroller could also control up to 1024 slave devices, including LRAs, via its I2C bus, therefore giving us flexibility for onward research and development.

Figure 7. *Lucy Green wearing the prototype technology*

INTERVIEWS AND FEEDBACK FROM VISUALLY IMPAIRED USERS OF THE PROTOTYPE

It was important to gain the visually-impaired musicians' perspectives at the testing days. These were gathered through semi-structured interviews with the five musicians. In total, we collected 1 hour, 2 minutes and 11 seconds of audio data. The breadth of themes that emerged in the qualitative data were broad; and threaded into this article are just a few salient points relating to our technology.

Analysis of the interview data

The interviews were transcribed in verbatim fashion and the qualitative data were stored and coded in an NVivo software database.[18] Speed and comprehensiveness were advantages of computer software (Coffey and Atkinson, 1996; Kelle, 2004; see also Lee and Fielding, 2004, Tesch, 1990). In a similar way to the video analysis, initial broad codes such as "Ensemble playing, cues" were gradually refined into subcategories such as "Haptic cues from sighted performers" and "Audible cues", etc. Inter-coder agreement (Hinds, Vogel and Clarke-Steffen, 1997), searching for "negative evidence" (that which might contradict our emerging account) and the replication of concepts (Miles and Huberman, 1994), both within and across accounts, were part of our approach (on searching for contradictory cases, also see Ryan and Bernard, 2000; Patton, 1990; Seale et al., 2004). Where disagreement amongst the researchers occurred on the coding, these were discussed and the software permitted rapid revisions to be made in the "node tree" (see Richards and Richards, 1994; Weitzman,

[18] Information on NVivo11 software can be found at http://www.qsrinternational.com/nvivo-product/nvivo11-for-windows (accessed 19 July 2017).

2000). It was not possible to iterate between data collection and “respondent authentication” or “validation” of provisional findings as commonplace in qualitative strategies due to the project time-span and time some visually impaired people need to digest texts and return comments thus having certain parallels with “secondary data analysis” (see e.g. Hinds, Chaves and Cypess, 1992; Hinds, Vogel and Clarke-Steffen, 1997; Lobo, 1986; McArt and McDougal, 1985; McCall and Appelbaum, 1991; Murphy and Schlaerth, 2010). Ruggiano and Perry (2017) have argued analysis of data without complex interactive strategies “...is one way to advance this goal while minimizing the burden on research participants” (p. 15).

AN EXPERIMENT WITHIN THE TESTING

During our testing days, the musicians wore the haptic vibration matrix and received various types of signals, e.g. a single pulsating controller in its middle, or moving representations of a conductor’s gesture. Several of their comments intrigued us and led to an experiment. Veronica remarked:

> I feel like the ticking [the single pulsating vibration controller] is better for me. Your reaction is a bit more immediate and, if things get faster, it might be more difficult to follow the other type of pattern. Many blind people do not know what they should be seeing [from the conductor] and, if you try to explain that, it’s like trying to explain why the colour red is bright to someone who has never seen red before so the sooner we accept that, the easier it is for us to move forward [with the technology development]. So, it’s better to work from the blind person’s perspective of what they consider the conductor is doing. We also need to think more about what the blind person *needs* to know at *a* particular point. Yes, so less is more. Less is more. (Veronica, singer, blind)

Felicity noted that it was unnecessary to transmit interpretive information about the music that was being absorbed through other means:

> There is plenty that we already know from the rest of the choir and the orchestra. …In the Vaughan Williams [when I was singing with the orchestra], there were just a couple of bits I just totally missed. If I could have had something to prompt me. I don’t know how you would do that “and” [the upbeat] with a [haptic] signal, but that would be brilliant. The vibrations [in a two-dimensional moving pattern] reminded me of what a drunk conductor might be like. Which bit of that is *actually* the beat? (laughs) (Felicity, keyboard player and singer, blind)

As a result, three of the musicians (Paul, Veronica, and Felicity, see above) agreed to help us assess the viability of haptic (tactile) signals with an experiment during the fourth and final testing day (June 2017). Two computer-generated patterns were rendered on the vibration matrix for comparison, i.e.: (i) one pulsating vibration controller in the centre of the matrix; and (ii) a moving, two-dimensional gestural tracking mimicking a 4/4 pattern (see Figure 8). The musicians (keyboard, clarinet, voice) played or sang “Twinkle, twinkle” by ear (twice through) with these two signals for comparison. The two signals (i, ii) included the same tempo changes (e.g. accelerando and rallentando marks, sudden changes). The musicians were also told to observe two introductory bars of signal before starting to play. They had no awareness of others’ attempts. The subsequent performances were recorded using a Zoom H6 digital recording machine.

The exercise produced 10 audio files of solo performances. The audio tracks belonging to each “haptic signal group” (i, ii) (n = 5 in each) were then overdubbed to form duet performances using Audacity software[19] in every permutation possible. This resulted in 20 audio tracks (10 in each group). Put another way, only responses to the single pulsation were combined with those resulting from the same pulsation, and performances from the two-dimensional tracking with others from that group. The tracks were then given a random order.

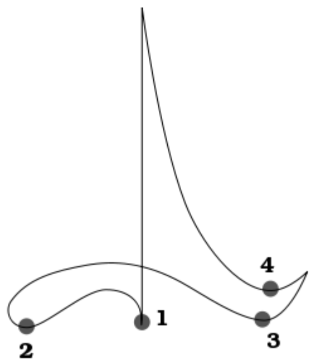

Figure 8. *4/4 time-signature (moving pattern on vibration controllers)*

These 20 audio tracks, available as .WAV or MP3 formats, were uploaded to a Google drive[20] and made accessible by a link. Appraisers with considerable musical experience (Table 1) were provided with an assessment document by e-mail concerned with the musicians’ timing; they were asked to listen to the audio files giving a score for seven items (Table 2). The appraisers could listen to the files as many times as they wished and were not aware of the “haptic signal group” to which each track belonged. If the musicians on the recordings were completely synchronised, they were likely following their haptic signal well and, if not, they were possibly not responding well to the type of haptic signal. The combining of solo tracks into duet form in every permutation meant that any spurious timing mishaps would be mitigated against in the resultant statistics; it also meant that, without being privy to the haptic signals, the assessors could gauge performer synchronisation and thus ensemble timing in line with those signals.

Musician and assessor samples

OVERALL CHARACTERISTICS				CROSS-TABULATIONS
No.	**Age***	**Instruments**	**Music qual.***	**Gender**

[19] Audacity is free, open-source audio software for multi-track recording and editing, see http://www.audacityteam.org/ (accessed 20 July 2017).
[20] Google Drive is cloud data storage, which wherein users can access files or folders by a hyperlink sent to them, see https://www.google.com/drive/ (accessed 20 July 2017).

9	[min., max.] mean (st. dev.)**	[22, 46] 29.50 (9.06)	Bass guitar (1) Chinese flute (1) Clarinet (1) Guitar (1) Flute (1) Piano (9) Violin (2) Voice (3)	Doctorate (1) Masters (3) Undergrad. (6) Diploma (1) Other (0)	 No. Prof. musician HE music student	Male 1 1 1	Female 8 6 7

*Please note that there was one no response to these questions. **The standard deviation is the average distance of the raw scores from the arithmetic mean, a measure of score dispersion.

Table 1. *Assessor sample*

The assessors were academics known to the researchers as well as some music education Masters students.

Assessment document

The assessment sheet collected the demographic information in Table 1 and, then, called for assessments on timing using 11-point ratio scales (see Table 2). We labelled the start of the scale “Completely incorrect” (0), the mid-point “Average” (5) and its end (10) “Completely correct” (10). We opted to commence with a “0” to avoid confusion from respondents on which side of the scale was positive or negative. We found, in earlier work with e.g. five-point scales (numerically 1–5), that respondents could misconstrue “1” as “high” and “5” as “low”. The 11-point variety offered a true mid-point or “Average” score (5, “50% correct”). Although the collected scores were assessor perceptions, the scale also offered absolute end-points (i.e. there is no value less than “Completely incorrect”) in addition to proportional points along the scale (i.e. 10%, 20%, 30% correct, etc.). The longer scales also provided significant latitude for the assessors to express differentiation; no respondent remarked on difficulties with applying scores, with only 4.13% of the items receiving non-responses (52).

Results

The results for this experiment can be seen in Table 2.

		HAPTIC PATTERN **Pulsation**		**4/4 pattern**	
Item		No.***	Mean (st. dev.)	No.	Mean (st. dev.)
1	The two performers’ capacity to start together	90	9.36 (1.28)	86	7.91 (3.13)
2	The two performers’ capacity to keep in time for the first two bars (and before any tempo change occurs)	89	8.97 (1.21)	82	4.36 (3.47)
3	The two performers’ ability to keep together throughout the piece (as evidenced by playing relatively synchronously)	88	5.86 (1.67)	84	2.12 (2.37)
4	The performers’ continuity (i.e. the capacity of both players to keep going	90	8.06 (2.28)	84	2.36 (2.59)

	without stopping even if they become out of time)				
5	The extent to which the performers seem to be following the same tempo indications (i.e. even if they get a beat or so out of time)	90	7.12 (2.04)	82	3.63 (3.50)
6	The performers' capacity to come back together when getting out of time	89	6.09 (2.28)	83	1.37 (2.30)
7	The performers' ability to finish together	89	5.46 (2.93)	82	0.91 (2.09)

***This is the number of ratings made on the audio files.

Table 2. *Assessments of the musicians' responses to the two haptic patterns*

We also ran a t-test for independent samples using SPSS[21] for the mean total score achieved for responses to the two "haptic signal groups" (out of 70, i.e. seven items, each with a total score of 10 achievable). There were considerable differences between the mean scores for the "pulsation" (mean = 50.56, standard deviation = 9.83) and "4/4 pattern" groups (mean = 21.12, st. dev. = 13.52). Levene's test resulted in F = 7.279, p = 0.008 so equality of variances (homoscedasticity) cannot be assumed. There was a significant difference between the two groups, with $t_{(162.554)} = 16.709$, p = .001.

Surprisingly, the musicians had some success at starting accurately after following either type of haptic signal for two bars before playing (refer to Table 2). Thereafter, and before any tempo changes occurred, the difference between the two patterns became more pronounced. The situation worsens with the other items assessed (i.e. "keeping together throughout", "continuity", "the extent to the musicians are following the same tempi", "coming back together after mishaps", and "finishing together"). The last, "finishing together" receives only a slightly above average score (5.46) for the "pulsation" group, but a meagre 0.91 for the "4/4" pattern.

DISCUSSION, REFLECTIONS AND FUTURE RESEARCH

This project commenced by exploring the meanings conveyed by conductors through their gestures. A model was developed from video observations of conductors, which was then considered when designing a prototype haptic technology to assist visually impaired performer in receiving those meanings. Across four testing days feedback was sought from participant visually impaired musicians who used the developing technology; this was done as they trialled the device and through semi-structured interviews. On the final day, an experiment was conducted to test respondents' assertion, which emerged through the analysis of interviews, that two-dimensional haptic representations mirroring the conductor's gesturing were simply too difficult to comprehend given their background experiences. This assertion appeared to be upheld by the outcomes of the experiment and the independent appraisals of their use of the device.

[21] Information on SPSS software can be found at https://www.ibm.com/analytics/us/en/technology/spss/ (accessed 20 July 2017).

Our respondents' feedback, i.e. the analysis of the semi-structured interviews and the experiment suggest that attempts to mirror a conductor's gestures as a haptic signal (a "sighted perspective" on technology development in X and Y axes) have limited use. This is the case even with the necessarily partial translation into haptics of the gestural model we developed (Figure 2), as we discussed earlier. Our device sought only to convey those codes from the model on tempo, meter and pulse, alongside e.g. aspects of character, emphases and rhythm as conveyed by the right arm. It in no way covers the entire gamut of the conductor's gesture therefore. As Jason put it in relation to our testing of two-dimensional haptic signals "The learning curve might be too steep for adults who have never seen, let alone seen a conductor". This is a significant point in our view, particularly when one considers onward development of a prototype of this nature. Csapó, Wersényi, Nagy and Stockman (2015) remark on technology development for the visually impaired that "…the task of creating and deploying useful [auditory or haptic/tactile] representations is a multifaceted challenge which often requires a simultaneous reliance on psychophysical experiments and trial-and-error based techniques [with]…the former source of knowledge…important in describing the theoretical limits of human perceptual capabilities…" (p. 276). Our test, which needs to be run again with a larger sample, merely offered a "snapshot" of initial responses too and, with longer exposure, these performers might have responded more favourably to the two-dimensional "4/4" pattern. Participants were also likely to have been exposed "pulsation-type" methods of responding to music hence favouring these, e.g. through their teachers or others counting the pulse and meter, or through using a metronome to practise. Certainly, Bajo, Sánchez, Alonso, Berjón, Fraile and Corchado (2010) reported gains in visually impaired ensemble performers' satisfaction with similar pulsation methods over the course of their testing. They developed a technology with an infrared LED located on the tip of the conductor's baton that transmitted to a wrist band worn by the performer. In relation to our experiment, we also must recognize that a musician's use of one haptic signal may have influenced his or her response to the other, so truly independent groups need to be considered in future testing. Moreover, the ramifications of e.g. on one hand, congenital blindness and, on the other, sight loss after experience of a conductor should also be investigated. Aside from these considerations, the chest, where the haptic vest was worn, is also a particularly resonant part of the human body and we do not know how a technology of this nature might be affected by alternative placement on the body or by playing different instruments. Additionally, future research might explore the difference a greater density of vibration controllers might make (e.g. 2mm LRAs in a similar-sized matrix would equate to n = 1,000). Bajo et al. (2010) also underscore the importance of testing within real ensemble settings and the "…different communication problems and errors that could arise in real scenarios…" (p. 8515). Various interesting lines of research enquiry have, therefore, surfaced from the current work.

Another direction in technology development would mean taking a more "performer-centred" approach with visually impaired people, e.g. for the performer him- or herself to agree with the conductor key moments in pieces and associated gestures to then be conveyed as haptic cues at a higher level of abstraction, that is, as the "hapticons" described earlier (Brewster and Brown, 2004; Csapó, Wersényi, Nagy and Stockman, 2015). Conducting is highly personal and idiosyncratic after all. Part of this picture is that some gestures are part of the wider "sighted world", such as when a person holds out a palm towards you in abatement. Gesture in conducting also does not occur in a two-dimensional plane, and is better represented in X, Y and Z axes as the entire human kinetic chain becomes involved (e.g. from the legs, the shoulders and elbows driving forward). Given the intricacies of conducting and challenges in receiving and understanding this complex information in haptic ways, research on "bespoke" signals identified *first* by performers as their specific need would, therefore, be helpful.

Although having good coverage of the gestural model (Figure 2), the prototype we developed has led to clear lines of future research, particularly leading us towards approaches that start from the visually impaired performer's needs (not the sighted person's preconceptions). Significantly, it has left residual questions about inclusion:

- Are technologies that necessitate the visually impaired person learning the meaning of diverse gestural intricacies, those driven by what designer-engineers, (mostly sighted people), have "seen" (a "sighted perspective"), inappropriate for many or, even, most of these musicians?
- Should a different developmental approach be taken, starting from the specific needs of the visually impaired performer, perhaps starting with the simplest of cues?
- Is a "sighted perspective" on access technology development another way in which disabled people are marginalised?

We leave these troubling questions to future developers and researchers and, no doubt, as the possibilities of digital technology increase, they will become increasingly pressing.

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