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Functions and Uses of Auditory and Visual Feedback: Exploring the Possible Effects of a Hearing Impairment on Music Performance

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ABSTRACT

Musicians with hearing impairments develop complex strategies for interactive performance relying on dynamic, or sometimes reduced, auditory attending and increased visual attending in music-making situations. Research suggests that there may be a relationship between auditory feedback and the use of visual cues by musicians with hearing impairments. To improve understanding of these processes, the present study explored the use of auditory and visual cues by examining the movement and looking behaviours of performing musicians. Four violinists with normal hearing were observed playing together as two duos in four experimental conditions involving the attenuation of auditory and visual information in which participants wore earplugs and/or faced away from their partner. Dependent measures were the duration and frequency of physical movements and looking behaviour as coded in Noldus Observer XT9. Analysis showed that auditory attenuation of the level used in this study had no effect on the violinists' movement or looking behaviour. The ability to see a co-performer did not affect movement behaviour but, where there was the possibility of eye contact, the amount of both movement and looking behaviour increased. Idiosyncratic, inter-player differences were far larger than intra-player differences resulting from the manipulation of experimental conditions, highlighting the uniqueness of individual playing styles. The results confirm that physical movement in music serves many purposes: it is used expressively by the player but can be consciously modified for the benefit of the co-performer.

I. INTRODUCTION

A. Movement and gesture in music

The study of musicians' physical movements in performance has become established alongside a 'movement away from a narrow focus on the musical mind towards a broader focus on the musical body' (Gritten & King, 2006, p. xix). While musicological studies have focused on the physical and metaphorical correlates of auditory 'gestures', studies using psychological methods have attempted to provide an understanding of the perception of physical movements and their use and function in music performance. But when can a movement be described as a gesture? Gesture exists in a wider context of non-verbal communication; we illustrate size, position and shape using actions of the fingers, hands, arms, body and face. Adam Kendon defines gesture as:

> …those actions or those aspects of another's actions that, having these features (of manifest deliberate expressiveness), tend to be directly perceived as being under the guidance of the observed person's voluntary control and being done for the purpose of expression rather than in the service of some practical aim (Kendon, 2004, p. 15).

Volitional control is therefore important but semantic content is less so; it is simply the perception of intended expressiveness that makes an action a gesture. Küle (2011) argues that '[the] most important, stable element in a musical semantics is the primary signification from musical phrase to gesture and from musical gesture to emotional content' (Küle, 2011, p. 129). Kendon's definition does not contradict Küle's but neither acknowledges that, in music, movements serve *practical* purposes. Visual information is relied upon by all musicians to maintain good temporal synchrony and stylistic cohesion (Davidson & Good, 2002), and is especially important for musicians with hearing impairments (Fulford, Ginsborg, & Goldbart, 2011). The boundary between movement and gesture is therefore blurred in musical performance. Musical influences on movement include the musical score itself which contributes to the repeatability of ancillary gesture production by musicians over successive performances (Wanderley & Vines, 2006). Expertise and familiarity between co-performers (King & Ginsborg, 2011) and musical performance conventions (Ginsborg, 2009) have been shown to affect musicians' movements, and ethnographic studies highlight the fact that movement cues that co-ordinate joint action in musical performance are socially constructed and embedded in the relationships between players (Moran, 2011).

Musicians' movements can be more effective in conveying the expressive manner of a piece to an audience than the audible sounds that correspond to the movements, especially to a non-musician audience (Davidson, 1993). Visual perception of the performer's head, upper torso and hands help audiences construct meaning in music by integrating auditory and visual information (Thompson, Russo, & Quinto, 2008). Expressive manners also have what might be thought of as altruistic utility for co-performers within musical ensembles. Davidson identified three kinds of gesture used by players in a string quartet: exit and entrance cues, dynamic cues (for loudness and softness) and circular body sway, and showed how the latter related to musical structure. '[As] each musician made an entry, s/he appeared to add an extra ripple to the wave of backwards and forwards movement that was passing between them' (Davidson & Good, 2002, p. 198).

B. The influence of auditory feedback on movement in music

The distinction between gesture in musical and non-musical contexts is especially clear when the role of auditory feedback is considered. The limits of auditory perception dictate the extent to which we can entrain to, and physically embody rhythmic patterns. The highest rate (fastest beats) we can perceive aurally is about 600 events/beats per minute (an inter-onset interval of 100ms) while the lowest rate (slowest beats) that can be entrained to psychologically is 30 events/beats per minute (IOI of 2000ms) (London, 2006). Furthermore, proponents of dynamic attending theory (DAT) suggest that we can only synchronise our attention and motor behaviour to aurally perceived rhythms within this range (Repp, 2005). Movements to music are therefore governed by our physiology, but also our psychology. Developmental research has shown that seven-month-old infants trained to bounce in either duple or triple time will subsequently listen longer to music accented in the trained meter, suggesting that vestibular-auditory interaction is intrinsically pleasurable; rocking or bouncing to music is a strong precursor of human musical behaviour and persists into adulthood (Phillips-Silver & Trainor, 2005, 2007). However, the expressive, ancillary gestures of performing musicians are clearly much more than basic physical responses to rhythmic, auditory input.

Keller has shown that 'auditory imagery facilitates interpersonal coordination by enhancing the operation of internal models that simulate one's own and others' actions during ensemble performance' (Keller & Appel, 2010). If auditory information is needed for the formation of auditory imagery, it implies that auditory information facilitates the regulation of physical movement. This being the case, how might the attenuation of auditory information, perhaps as the result of hearing impairment, affect a musician's movement production? More or larger movements during performance might indicate that they have a self-regulatory function, supporting or bolstering the performer's internal representations of the music. Perhaps musicians recruit movement to improve the integrity of auditory imagery impaired by the attenuation of auditory information? Conversely, less movement when auditory information is attenuated would confirm the universal, proportional relationship between musical stimuli and physical movement proposed by Hodges (2009).

C. The influence of visual feedback on movement in music

Laboratory research has shown that four- to seven-month-old infants produced less spontaneous rhythmic movement to music when visual information was presented simultaneously (Morgan, Killough, & Thompson, 2011). While this is evidence that if music is heard, it is moved to, Morgan et al. argue that their findings reflect the 'Colavita effect' of visual sensory dominance: human beings are more likely to rely on visual than auditory information when carrying out temporal processing tasks (Colavita, 1974), perhaps to compensate for the fact that information about the environment such as alerts and cues is conveyed more effectively via the auditory modality (Posner, Nissen, & Klein, 1976). However, while only the simplest rhythmic tasks tend to elicit auditory dominance, selective attention to other sensory modalities can modulate visual dominance (Sinnett, Spence, & Soto-Faraco, 2007). Visual information appears to be wholly unnecessary for tasks involving vestibular and/or proprioceptive feedback in the auditory encoding of musical rhythm (Phillips-Silver & Trainor, 2005, 2007).

Music performance is, however, a special case. Recent studies of cross-modal perception of music have demonstrated that it is possible to obtain emotional information (similar to Davidson's 'expressive manner') from the visual perception of solo singing (Thompson, et al., 2008) and instrumental playing (Vines, Krumhansl, Wanderley, Dalca, & Levitin, 2011). It is also possible to infer pitch relationships from solo singing using visual information (Thompson, Russo, & Livingstone, 2010). Performers, as well as audiences, use visual information for tasks such as sight-reading. Banton (1995) found no difference between the performances of pianists who were prevented from hearing what they were playing while sight-reading unfamiliar scores and those who sight-read as normal. Pianists who were prevented from seeing their hands on the keyboard, however, made significantly more errors. Thus, Colavita's visual sensory dominance not only affects the performance of simple motor tasks but also complex musical tasks such as sight-reading.

Returning to the question of the effect of a hearing impairment on music-making, there is evidence that musicians compensate for hearing impairments by recruiting the visual channel for information about timing and expressive manner (Fulford, et al., 2011). The sensory compensation hypothesis states that, for example, blind people have better hearing than people without visual impairments. However, people born with profound deafness develop different abilities at different times and cross-sectional research has shown that visual compensation for deafness may not develop until adulthood (Rettenbach, Diller, & Sireteanu, 1999). Nevertheless, deaf individuals 'possessed greater attentional resources in the periphery [of the visual field] but less in the centre when compared to hearing individuals' (Proksch & Bavelier, 2002, p. 687) and differences between profoundly deaf and hearing individuals have been found in the retina and optic nerve (prior to the visual cortex), responsible for peripheral vision (Codina et al., 2011). If musical situations present high attentional demands on looking behaviour of the kind that might foster enhanced visual perception in profoundly deaf adults (Proksch & Bavelier, 2002), increases in looking behaviour when auditory information is attenuated might reveal a broad human 'kneejerk' response whereby the visual modality is recruited to a greater extent, as suggested by theories of sensory compensation. Additionally, research suggests that visual dominance prevails in complex situations and that 'without an increase in attention to the auditory stimuli, visual stimuli remain prepotent' (Morgan, et al., 2011, p. 13).

D. Aims and research questions

The present study aimed to explore the relationship between, and effects of, auditory and visual information on musicians' movement and looking behaviours in musical performance. Research demonstrates a clear association between auditory feedback and movement to music via links between vestibular/proprioceptive feedback and auditory processing, but the influence of a hearing impairment on movement to music has not been addressed. Furthermore, the existence of sensory compensation mechanisms in the profoundly deaf alongside anecdotal evidence of increased looking behaviour in musicians with hearing impairments has not been tested in a musical context. Research has also demonstrated the expressive power of the musical performance that is perceived visually, yet very little attention has been paid to the use and function of visual perception of the performer on the co-performer, as opposed to the audience. To explore these issues it is necessary to observe performing musicians in groups while controlling for auditory feedback and visual contact with co-performers.

As it is not possible to fully control for the level of a naturally occurring hearing impairment in an experimental context (confounds include type and history of hearing loss and use of hearing aid technology), four violinists with normal hearing experienced the attenuation of auditory information defined as a reduction in the quality and/or absolute volume of sound. Visual information was manipulated by preventing one or both co-performers from seeing the other, resulting in the attenuation of visual information whereby the extent to which the other performer's movements could be seen was reduced. The dependent variables were 'movement behaviour' (the physical movements of the body) representing either a response to the music or communication with the other performer, and 'looking behaviour' (players' glances and gazes towards their co-performer during performance), given that musicians are likely to attend to visual cues that are useful to them and ignore those that are not. Finally, as movement and looking behaviours seem to be driven by the need to stay together and in time with other players in group music performance, ensemble synchrony was also measured. Two broad questions were formulated in light of the literature review, aims and rationale stated above:

Q1. What is the effect of attenuating auditory information on musicians' movement behaviour, looking behaviour and ensemble synchrony?
Q2. What is the effect of attenuating visual information on musicians' movement behaviour, looking behaviour and ensemble synchrony?

Six hypotheses were formulated as follows:

Hypothesis 1 was made on the basis that auditory information provides a stimulus for movement and that this movement can in turn facilitate the encoding of auditory information. It predicted that participants would make less movement when auditory feedback when was attenuated than when it was not.

Hypothesis 2 was based on the findings of interviews undertaken by the first author with musicians with hearing impairments and evidence of enhanced peripheral vision and attentional processing in profoundly deaf adults. It predicted that participants would look towards their partner more when auditory information (the sound of their own, and their partner's playing) was attenuated.

Hypothesis 3 predicted that ensemble synchrony would be better when auditory feedback was not attenuated.

Hypothesis 4 was based on research showing that physical movements carrying semantic meaning are produced for the benefit of co-performers. It predicted that participants would make more movements when they could see their co-performer than when they could not.

Hypothesis 5 predicted that participants would look towards their partner more when they had the opportunity to do so, i.e. when they were facing toward their partner and/or their partner was facing towards, rather than away, from them.

Hypothesis 6 predicted that ensemble synchrony would be better when players could see their co-performer than when they were facing away.

II. METHOD

A. Design

The study combined the use of observation and experimental methods in that the behaviours of each violinist while playing were observed, coded and counted in each experimental condition. The independent variables were the level of auditory input, either normal or attenuated, and visual contact between players, either possible or impossible. Players wore earplugs in 'attenuated-auditory' (hereafter 'attenuated') but not 'hearing' conditions. Players faced away from their partner in 'attenuated-visual' (hereafter, 'non-visual') conditions and towards each other in 'visual' conditions; players could not see their partner in non-visual conditions. As shown in Table 1, the four experimental conditions were therefore: hearing with visual contact (HV), hearing with no visual contact (HnV), attenuated with visual contact (AV) and attenuated with no visual contact (AnV). As there were two players, there were 16 experimental conditions including four 'same-condition' pairs (bold in Table 1).

Table 1. Condition matrix showing same condition pairs in bold

HV-HV	HnV-HV	AV-HV	AnV-HV
HV-HnV	**HnV-HnV**	AV-HnV	AnV-HnV
HV-AV	HnV-AV	**AV-AV**	AnV-AV
HV-AnV	HnV-AnV	AV-AnV	**AnV-AnV**

B. Participants

Two pairs of violinists were recruited. The four violinists were of similar levels of expertise being drawn from the MMus degree course at the RNCM. Their pseudonyms, ages, year of study and part played are shown in Table 2. None of the players had worked in a duo with their partner before, ensuring there were no differences in familiarity, a factor that has been shown to affect gesture production (King & Ginsborg, 2011).

Table 2. Participants

Duo		Age	Year	Part
1	Rebecca	24	First	1st
	Jess	23	Second	2nd
2	Rosemary	22	First	1st
	Sarah	23	Second	2nd

C. Apparatus and Materials

Video recordings of the duos were made using Panasonic NV-GS280 video recorders. Participants wore standard memory foam ear plugs by Moldex: Spark Plugs (soft) 7812 with a single number rating (SNR) attenuation of 35dB. These are easy to use, familiar and well tolerated by musicians, providing a good level of general attenuation across frequencies.

The composer Emma-Ruth Richards, a PhD student at the RNCM, was commissioned to write a short piece for the study (*Sketch*) to ensure that all players were equally unfamiliar with the piece. The commission included 'entry markers' and tempo changes for each player individually and both players.

D. Procedure

The participants were given *Sketch* one week in advance of the video-recordings and told to learn their parts until they were comfortable under the players' fingers, thereby avoiding the need for the researcher to control for participants' sight-reading ability and speed of learning. It was not possible to control for practice effects but these were addressed as follows: the recording sessions began with both the duos playing Sketch four times in the 'same-conditions', in the same order of increasing difficulty (HV-HV, HnV-HnV, AV-AV and AnV-AnV; auditory-attenuated conditions were deemed more challenging than non-visual conditions, since musicians regularly play with others who are out of their immediate sight line). They then played the piece in the 12 contrasting conditions in random order.

E. Analyses

Dependent measures were i) the duration and frequency of body movements ii) the duration and frequency of eye gaze directed at the playing partner (looking behaviour) and iii) the ensemble synchrony or 'togetherness' of the two players. Durations were reported in seconds and frequencies as events per performance. Body movements and looking behaviour were coded using Noldus Observer XT9 software (see below for coding scheme) and post-hoc lag sequential analyses were performed to explore the temporal relationships between movement and looking behaviour at and around entry markers. Ensemble synchrony was rated by trained musicians who were blind to experimental condition and listened to CDs containing the audio component only of the four same-condition performances while reading the musical score. They provided a tally of instances of asynchrony and rated overall performance synchrony using a 7-point Likert scale anchored by 1=good and 7=bad.

F. Coding Scheme

The movements that were coded were eyebrow lifts, scroll arm lifts where the left arm was raised away from the torso, head movements (with no simultaneous movement of the torso), torso curls either backwards and forwards or laterally, and movements in the legs caused by dipping the knees or lifting on the balls of the feet. The software provided data in the form of frequencies and durations per performance (in seconds) for each code. Co-performer-directed looking behaviour was not coded in non-visual conditions. Movements that were explicitly required to produce sound on the violin, for example, the movement of the right (bowing) arm, were not coded. The coding scheme was informed by prior literature on musicians' movements, specifically the coding of torso curl movements in string players (Davidson & Good, 2002) and of looking behaviour between the members of singer-piano duos (King & Ginsborg, 2011), which provided criterion (concurrent) validity.

III. RESULTS

A. Coding scheme and reliability

To establish inter-rater reliability an external researcher coded video footage from six performances representing 10% of the total data. Kappas ranged from .42 to .71 for individual observations with a figure of .61 achieved overall on 8.3% of the data, representing a substantial level of agreement between coders (Landis & Koch, 1977). Duration and frequency were significantly positively correlated for all movement behaviours (*rho* = .810, $p < .001$), but less so for looking behaviour (*rho* = .625, $p < .001$). Therefore, movement data was analysed using durations only whilst looking behaviour was analysed using both frequency and duration data.

1) Hypothesis 1: the effect of auditory attenuation on movement duration.

Hypothesis 1 predicted that participants would make less movement when auditory feedback was attenuated than when it was not. Data for head nods and leg movement were not spread sufficiently between players for useful comparisons to be made and were therefore excluded. There were no significant differences between the durations of eyebrow lifts ($M = 3.99$, SD = 2.19, $t = 0.41$, $df = 39$, $p = .681$), torso curls ($M = 4.00$, SD = 3.71, $t = 1.34$, $df = 49$, $p = .187$), scroll lifts ($M = 5.47$, SD = 3.48, $t = 0.11$, $df = 60$, $p = .912$) or total movement overall ($M = 12.82$, SD = 7.02, $t = 0.39$, $df = 62$, $p = .699$) in the hearing and auditory-attenuated conditions, so the hypothesis was not supported.

2) Hypothesis 2: the effect of auditory attenuation on looking behaviour.

Hypothesis 2 predicted that participants would look towards their partner more when the auditory feedback of their own, and their partner's playing, was attenuated. There were no significant differences between the frequency of glances ($M = 8.50$, SD = 3.83, $t = 0.64$, $df = 30$, $p = .528$) or the duration of gazes ($M = 5.87$, SD = 3.51, $t = 0.64$, $df = 30$, $p = .530$) in the attenuated conditions, so the hypothesis was not supported.

3) Hypothesis 3: the effect of auditory attenuation on ensemble synchrony.

Hypothesis 3 predicted that ensemble synchrony would be better when auditory feedback was not attenuated. Differences between mean tally scores and ratings in the hearing and attenuated conditions were not significant (tally, $M = 8.27$, SD = 4.83, $t = 0.85$, $df = 54$, $p = .396$; rating, $M = 3.65$, SD = 1.45, $t = 0.97$, $df = 54$, $p = .338$) so the hypothesis was not supported.

4) Hypothesis 4: the effect of visual attenuation on movement behaviour.

Hypothesis 4 predicted that participants would make more movement when they could see their co-performer than when they could not. There were no significant differences between the durations of eyebrow lifts ($t = 0.97$, $df = 39$, $p = .339$), torso curls ($t = 0.51$, $df = 49$, $p = .612$), scroll lifts ($t = 0.11$, $df = 60$, $p = .916$) or total movement overall ($t = 0.75$, $df = 62$, $p = .441$) in the visual and non-visual conditions, so the hypothesis was not supported. (Data for head nods and leg movements were excluded, grand means and SDs as above).

Differences between the durations of movement behaviours in the two visual conditions, one-way and two-way looking, were also investigated. There were no significant differences between the durations of eyebrow lifts ($t = 0.65$, $df = 20$, $p = .520$), torso curls ($t = 0.18$, $df = 27$, $p = .858$) or scroll lifts ($t = 1.48$, $df = 29$, $p = .149$), but there was a near-significant difference between total movement overall in the two conditions such that movement lasted longer when performers could see each other (M = 16.03, SD = 8.08 seconds) than when only one could see the back of the other (M = 10.98, SD = 6.05 seconds, t = 2.00, df = 30, p = .055).

5) Hypothesis 5: the effect of visual attenuation on looking behaviour.

Hypothesis 5 predicted that participants would look towards their partner more when their partner was facing towards rather than away from them. Excluding non-visual conditions reduced the number of permutations from 16 to 8 and therefore the group sizes for comparisons to 4 and 4. Significantly more glances were made in two-way than one-way looking conditions (two-way, M = 10.23, SD = 3.13; one-way, M = 6.75, SD = 3.75; t = 2.86, df = 30, p = .008). To this extent the hypothesis was supported. There was, however, no significant difference between the durations of gaze in the one- and two-way looking conditions.

6) Hypothesis 6: the effect of visual attenuation on ensemble synchrony.

Hypothesis 6 predicted that ensemble synchrony would be better when players could see their co-performer than when they were facing away. Differences between mean tally scores and ratings in the visual and non-visual conditions were not significant (tally, M = 8.27, SD = 4.83, t = 0.97, df = 54, p = .338; rating, M = 3.65, SD = 1.45, t = 0.58, df = 54, p = .553) so the hypothesis is not supported.

IV. POST-HOC ANALYSIS

A post-hoc, lag-sequential analysis was conducted to explore the possibility that lifting the scroll of the violin while playing may be partly functional because it is necessary to shift the hand on the fingerboard to a new position and to test the idea that looking behaviour is linked to ensemble synchrony because glances or gazes are made at the beginnings of phrases. In both cases, the lag sequential analysis tested the temporal associations between movement or looking behaviour and coded markers occurring at entry points in the musical score.

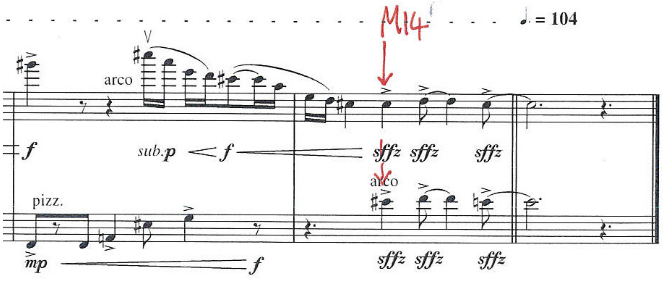

Figure 1. The musical context of entry marker 'M14'

As expected, the most common consistent behaviours (occurring with a probability > 25%) found around the markers were looking and scroll lifts (5 markers each). 80% of looking events and all scroll lifts occurred before entry markers rather than after. Looking behaviour before the entry markers was explained by the score. At 'M14', for example, the final three sforzando accents were preceded by a rest in the second part and it is likely that players felt it important to ensure the final three notes of the piece were synchronised (see Figure 1).

Behaviours captured in the lag-sequential analysis reflected idiosyncratic differences in the players' movements and looking. Table 3 below shows the total durations of coded movement and looking behaviours broken down by player and condition. While the mean of total movement duration was 205.22s (820.89/4), the SD was 84.94 across players, but was only 12.58 across conditions. The total duration of Sarah's physical movements (316.68s) was three and half times as long as Jess's (89.79s). Rosemary and Sarah often lifted their eyebrows while playing; Rebecca to a lesser extent and Jess not at all. Rebecca's most characteristic movement was lifting her scroll arm, the behaviour coded for the longest duration of all behaviours and players. Jess had a very controlled and physically restrained playing style, moving the least of all the players. Rosemary's eyebrow lifts were coded for a longer duration of time than any of her other behaviours. Sarah looked most often and for longer than any of the other players, and made the most expressive, ancillary gestures; her eyebrow lifts and torso curls were coded for the longest durations.

Table 3. Total and sum totals of duration (seconds) of coded movement and looking behaviour by player and condition

	Duo 1		Duo 2		Total
	Rebecca	Jess	Rose	Sarah	
Looking	49.68	37.47	21.35	79.53	**188.03**
Eyebrow	14.19	0.00	70.70	78.57	**163.46**
Scroll	154.73	66.83	59.76	58.11	**339.43**
Torso	65.86	22.96	29.83	136.16	**254.81**
HV	68.89	25.81	52.51	77.20	**224.41**
AV	57.61	20.66	44.10	85.51	**207.88**
HnV	56.15	24.07	40.29	76.52	**197.03**
AnV	63.97	19.25	30.90	77.45	**191.57**
Total	**246.62**	**89.79**	**167.8**	**316.68**	**820.89**

V. DISCUSSION

This study aimed to explore the effects of attenuating auditory and visual information on musicians' movement and looking behaviours to identify their functions for, and between, co-performers. It was predicted that there would be less movement behaviour and ensemble synchrony but more looking behaviour when auditory information was attenuated, and less movement behaviour, looking behaviour and ensemble synchrony when visual information was attenuated. More movement and looking behaviour was found where there was the possibility of eye-contact, but no differences in movement behaviour between the visual and non-visual conditions more generally. No significant differences were found between the violinists' movement or looking behaviour, nor ratings of their ensemble synchrony, in hearing and attenuated auditory conditions. It is likely that inconsistencies between the players contributed to the non-significance of the differences between the groups. For example, some players moved or looked more, and some moved or looked less. In short, inter-player variances were far larger than intra-player variances elicited by manipulating experimental conditions.

1) Hypothesis 1: Auditory attenuation and physical movement.

There were no significant differences between movement behaviour in the hearing and auditory attenuation conditions. While it should not be inferred that movement behaviour would always be the same in the two conditions, this has the important implication (certainly for the wider project) that there is little reason to suspect that musicians with hearing impairments will move or behave differently to other musicians, on the basis of auditory feedback alone. While changes in hearing level over the life span cannot be accounted for here, it is likely that variance in observed movement can be largely attributed to individual differences in playing or performance styles. This highlights the importance of acknowledging players' uniqueness: no one person will use their body in exactly the same way as another. Likewise, no one person will think in exactly the same way as another, and given that movements can be consciously altered or 'projected' (Davidson, 1993), individual differences in musicians' movement must be attributed to the uniqueness of their bodies and minds. Physical gestures in music may be in part a basic response to auditory input and in part a projected communication of intended manner to audiences and co-performers alike.

2) Hypothesis 2: Auditory attenuation and looking behaviour.

There were no significant differences between looking behaviour in the hearing and auditory attenuation conditions. It is likely that the attenuation provided by the ear plugs was not large enough to disturb normal looking patterns in group music performance. Earplugs of the type used in this study are distributed to musicians to mitigate the risk of noise induced hearing loss. While uptake of earplugs by professional musicians is typically low due to concerns about changes to the subjective perception of sound using the plugs (Hansford, 2011), these results are reassuring in that such ear plugs do not appear to cause players to alter their looking behaviour in performance.

3) Hypotheses 3 & 6: Auditory attenuation, visual feedback and ensemble synchrony.

There were no significant differences between ratings for temporal synchrony in the hearing and attenuated auditory conditions, or the visual and non-visual conditions. The level of auditory attenuation provided by ear plugs in this study was, reassuringly, not large enough to compromise ensemble synchrony. Ensemble synchrony is arguably the most fundamental of requirements for music-making in ensembles and is primarily an auditory task (Goodman, 2002). Musicians regularly perform in ensembles where sight lines do not allow for direct eye contact with other players. Furthermore, direct visual contact is not always possible in group music-making, for example, for singers on stage, or between orchestral musicians. However, other results in this study suggest that visual information facilitates ensemble synchrony as evidenced by the use of looking behaviour around entry markers (see discussion of Hypothesis 5 below).

4) Hypothesis 4: Visual feedback and physical movement.

There were no significant differences overall between the amounts of movement behaviours produced in the visual and non-visual conditions. However, there were differences between the players. For example, Rosemary's eyebrow lifts were coded for over three times as long as her gazing or glancing toward Sarah (Table 3). For all other players, eyebrow lifts were coded for an equal or shorter duration than looking behaviour overall. The frequency and duration of her eyebrow lifts increased significantly when they were facing each other (frequency: visual, $M = 4.88$, SD = 1.46; non-visual, $M = 3.63$, SD = 0.74; $t = 2.16$, $df = 14$, $p = .049$ and duration: visual $M = 5.40$s, SD = 1.17; non-visual, $M = 3.44$s, SD = 1.06; $t = 3.51$, $df = 14$, $p = .003$). Given Rosemary's tendency to glance often towards Sarah, a physiological link between the two behaviours might be proposed whereby partner-directed looking (not possible in non-visual conditions) is involuntarily accompanied by raising the eyebrows. In fact eyebrow lifts occurred independently of looking behaviour. They are likely to be a function of the musician's unique physical and performance style although Rosemary's eyebrow lifts, in particular, show that they can be used as an ancillary expressive gesture in music performance, as in normal conversation.

Subsequent comparisons between the amounts of physical behaviour in the one- and two-way looking conditions revealed stronger effects; the overall increase in total movement when players faced each other, enabling eye contact, approached significance and was consistent for all four players. Of the component movements, Rebecca lifted her scroll significantly more often when there was the possibility of eye contact with her partner Jess (one-way looking, 4; two-way looking, 8) coded for a significantly longer duration (one-way, 6.92 s; two-way, 11.9 s, in both cases U = 16.00, $N1 = 4$, $N2 = 4$, $p = .003$, two-tailed). The lag sequential analysis suggested that lifting the scroll was functional, at least in part, for all players, resulting from the necessary shifting of the hand on the fingerboard to a new position at entry points and beginnings of phrases. For Rebecca however, the use of the scroll lift movement was further used to keep the beat, facilitating ensemble synchrony with Jess at entry points. Rebecca exaggerated her scroll lifts for this purpose and for Jess's benefit as evidenced by their increased frequency and duration in two-way looking conditions where the two players were facing towards each other.

So were players consciously moving more or deliberately projecting their movement for the benefit of their co-performers? Or does the potential for eye contact produce an increase in physical movement as a response at a pre-conscious level in the sensory-motor process? The answer appears to be a bit of both. Rebecca's scroll lifts were more emphatic when eye contact with Jess was possible suggesting that she was using them consciously and in a communicative gestural way. This element of intentionality elevates such movements to the status of 'gesture' according to conventional definitions (Kendon, 2004), yet they are also functional in that violinists appear to lift their scrolls to produce sound. Conversely, as we have seen, Rosemary's eyebrow lifts were not made consciously for the benefit of her co-performer. This does not undermine the idea that eyebrow lifts in music performance could be a less conscious, ancillary movement that may be expressive of the performer's internal auditory representations of music, since they were observed in the present study even when musicians could not see their co-performers' faces. It is not implausible that they could even be perceived by co-performers as gestural.

5) Hypothesis 5: Visual feedback (including eye contact) and looking behaviour.

The effect of visual feedback on looking behaviour was explored by comparing its frequency and duration in one-way and two-way looking conditions. All four players looked at each other significantly more often when they had the opportunity to do so in two-way conditions but not for significantly longer. The potential for eye contact, therefore, appears to alter the kind of looking behaviour produced by players; there were more frequent glances but gazes were no longer in two-way looking conditions. This suggests that the potential for eye contact prompts, but does not prolong, eye contact. Perhaps it feels inappropriate to gaze directly into co-performers' eyes for too long when playing. It is known that long gazes, unless directed towards a lover, are usually taken as a challenge (Ellsworth & Langer, 1976) and that, in dyadic conversation, eye contact is used to regulate turn-taking with the talker looking up to 'hand over' when they have finished speaking (Kendon, 1967). It may be that the two-way looking condition in this study, where both players faced each other, added a conversational dimension to the situation whereby the intensity of direct eye-contact resulted in players looking towards each other more often but for less time.

Analysis of the frequency and duration of looking behaviours revealed the differences in looking style between and within the duos. Rebecca and Jess (Duo 1) looked towards each other for similar amounts of time in total, 49s and 37s respectively (Table 3), but it was Jess's looking that was captured more frequently around entry markers in the lag sequential analysis, indicating 'following' behaviour at entry points where she would look at Rebecca, her 'leader', to ensure synchrony. The different looking styles of the two players may reflect differences in their learning of the music or ability to read ahead. Their looking behaviour was not influenced by the potential for eye contact with the other player. Rather, it seems that, for Jess, maintaining ensemble synchrony by visually tracking the movements of her leader was more important than making eye contact per se.

There were more contrasts between the looking behaviours of the two players in Duo 2 than between those of Duo 1. Rosemary's looking behaviour was made up of relatively short glances towards Sarah that were consistent in duration. Sarah's looking behaviour was the most frequent and lasted longest of all the players. The contrast between their looking styles may again indicate leader-follower dynamics: Sarah used her eyes to maintain synchrony of timing and manner with Rosemary who, as leader, looked back far less. The duration and frequency of Rosemary's looking behaviour was significantly higher when Sarah was facing toward her enabling the possibility of eye contact (frequency: two-way, $Md = 12.00$, $R = 7.00$; one-way $Md = 2.00$, $R = 1.00$ and duration: two-way, $Md = 4.86$s, $R = 3.02$; one-way $Md = 1.12$, range = 0.13 and $U = 16.00$, $N1 = 4$, $N2 = 4$, $p = .028$, two-tailed, in both cases). Rosemary's looking was therefore augmented by visual contact with Sarah, perhaps because the desire for eye contact, as opposed to the need to maintain temporal synchrony, was more important for her. Sarah clearly enjoyed her moments of eye contact with Rosemary and, of all the players, seemed most able to play from memory, allowing her to look towards Rosemary instead of at the score.

Although there were more glances in the two-way conditions, looking behaviour was nevertheless maintained by all players in one-way conditions. The frequency of one-way looking was 66% of two-way looking, and the duration of one-way looking was 90% of two-way looking. Clearly eye contact is not the sole purpose of partner-directed looking. Rather, there is value for musicians in being able to perceive co-performers' movements and gestures, even if viewed from behind, or players would not need to look towards them at all. This supports the finding that co-performer-directed looking (including direct eye contact) helps musicians achieve performances that are both temporally synchronous and unified in manner (Davidson & Good, 2002). The lag sequential analysis in the present study supports this by showing that looking behaviour was the most common behaviour +/- 1s around entry markers. More frequent looking in two-way conditions might also be explained by the model of 'intimacy equilibrium' as proposed by Argyle and Dean whereby looking behaviour and physical proximity have an inverse relationship, both signalling intimacy. They propose that looking functions as both a channel for feedback and a signal that the channel is open (Argyle & Dean, 1965). Here, the increased frequency of looking events in two-way conditions may be a signal of increased intimacy between the players afforded by the face-to-face configuration. That the duration of looking events in one-way and two-way conditions was similar suggests that the potential for eye contact between players did not alter the way in which the players visually perceive information about their partner's movements. Rather, it is intimacy between players that is revealed by looking toward the co-performer more frequently, but not for longer.

VI. CONCLUSIONS

This study explored the use of movement and looking behaviour in violin duos in order to understand the possible uses of auditory and visual information by the players. Although the study began life as a pilot, reflected in the small sample size, the results extend current knowledge about how movements are visually perceived and used by musicians and their co-performers. Players used more movement and looking behaviour when they had the potential for eye-contact, but not when their auditory feedback was attenuated. This finding supports the idea that players' conscious knowledge of 'being seen' by co-performers adds intentionality to physical movement, regardless of their own sensory feedback. Movements required for the sound production (such as the scroll lift of a violinist) as well as ancillary gestures (such as torso curls and eyebrow lifts) both have the potential, therefore, to be perceived by co-performers (and the audience) as carrying the conscious intent of 'gesturalness' or a specific 'manner'. The influence of the visually-perceived co-performer on performers' movement and looking behaviour highlights the generative processes behind the execution and delivery of movement to music. Movements form as a response to auditory and visual stimuli. Yet they can be altered, augmented and projected for the benefit of co-performers. More research must be done with larger samples and ensembles to establish to what degree movements in interactive performance settings are altruistic and communicative.

The uniqueness of human bodies was highlighted. While the coding scheme encompassed general movements, it was clear that individual physiology, intentions and mental understanding of the music affect the ways in which movements are produced and expressed. Individuals also use and process sensory information in different ways. Further research with musicians with hearing impairments is necessary to explore the role of visual information in the idiosyncratic communicative processes that result from such musical collaborations. The importance of spatial location in relation to co-performers is important, not only for musicians with hearing impairments, but for those with normal hearing, given the effects of face-to-face orientation on player behaviour shown in this study. Furthermore, there remains a discrepancy between the conception of ensemble synchrony as a primarily auditory task, not affected by visual attenuation, and the reports of musicians with hearing impairments which state that visual information is crucial for its attainment.

Kendon's definition of gesture as 'manifest deliberate expressiveness' provided a useful foundation for discussion in this study. Yet the present results highlight the fact that, in music, the origin and function of movements are heterogeneous. Seemingly functional movements such as the violinist's lifting of the left 'scroll' arm may also be gestural if the mover intends them to be, as was the case for Rebecca. In the repertoire of violinists' movements coded in this study, each was found to be unique in its degree of functionality as auditory (sound-production), communicative (co-performer directed) and expressive or gestural. Head nods occurring on strong accents mirrored forceful down-bow motions in the opposite direction and were expressive in function but also linked to the physiology of sound production on the violin. Conversely, torso curls and eyebrow lifts, being ancillary to sound production on the violin, were expressive of internal representations of the music (Rosemary's eyebrows) yet could still benefit the co-performer (torso curls in one-way looking conditions).

Every movement in music performance can therefore be said to vary on a number of dimensions: i) the degree to which movement represents a response to (pre-conscious) internal auditory representations of music; ii) the degree to which the movement is requisite or facilitates sound production from an instrument or voice; iii) the degree to which the musician adds or mediates the element of consciously intended expression; and iv) the degree to which the movement is (consciously) perceived as being expressive, having an expressive manner or being expressive of something particular, by co-performers and/or an audience. The volitional generation of expressive gesture (iii) is subject to the influences of physiology and the cognitive processes of the individual performer as well as socio-cultural influences. A movement may be expressive regardless of what was consciously intended and there may be disconnect between the performer's intention and what the observer perceives. It may have been that Rebecca's consciously exaggerated scroll arm movements provided a useful visual cue for her co-performer, Jess, in facilitating ensemble synchrony. However, it is likely that an audience would perceive more expressivity in Rosemary's (apparently unintentional) eyebrow lifts given their role in the generation and perception of facial expression. There is a distinction, therefore, between the function of movement in conveying expressive meaning to the observing listener and to the observing co-performer. While most research has focused on the former, this study suggests that co-performer-directed physical expression may be just as salient for the performer as that which is audience-directed.

Jane Davidson has written that her most interesting work on co-performance cues took place while working with blind musicians where the power of proxemics and non-verbal cues was revealed. She states that a performer's capacity to deal with moment-by-moment processing of tempo changes or memory slips depends on 'an opening of ears and eye to hear and see cues' (Davidson, 2009). The present results support Davidson's observation by highlighting the value of visually-perceived information from co-performers in group music-making. Subsequent work with musicians with hearing-impairments will further explore the use of verbal and non-verbal communication in music performance; shaping gestures and rehearsal talk.

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