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How do conductors' movements communicate compositional features and interpretational intentions?

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Abstract

Conductors use body movements to communicate their interpretations of musical works though performance directions regarding selected musical features. The aim of this study was to examine how the kinematic features of conducting movements relate to compositional elements such as rhythmic patterns, melodic peaks, dynamic changes, and also how they relate to conductors' own interpretational comments. Six conductors with conducting experience of between four and 29 years were interviewed and asked to annotate a musical score (Eine Kleine Nachtmusik by W. A. Mozart, No. 13, K. 525, first movement, mm. 1-55) according to a number of interpretational intentions. They then performed the same piece of music with a string quintet, while their upper body movements were recorded using a nine-camera Qualisys motion capture system. Kinematic parameters including baton speed, acceleration, and jerk were extracted via Visual 3D and Matlab software packages. Cross-correlation confirmed that, as expected, within-conductor movement kinematic patterns were more similar than between-conductor patterns. A novel analysis method (Deviation Point Analysis) was developed, which revealed particular time-points in the score with distinctive movement features, including movement kinematic deviations and high movement variability between conductors, which related to specific melodic, rhythmic, dynamic structures and interpretational intentions.

Music theorists have conventionally held the view that the expressiveness of music originates from compositional features such as the arrangement of tonal and rhythmic structures (Rothfarb, 2002). More recently, it has been argued that the idea of music should not be constrained to the written score, but should also take into account the act of music-making (Doğantan-Dack, 2012). Deviation from existing compositional structures is an essential aspect of musical performance (Leech-Wilkinson & Prior, 2014), and each musician's musical interpretations of the score may also affect their body movement. (Davidson, 2007, 2012; Desmet et al., 2012). From this perspective, body movement in music performance appears to be one of the most important considerations. Wanderley, Vines, Middleton, Mckay, & Hatch (2005) categorised musicians' movements based on their functions including producing sound (instrumental movement), conveying expressive intention (ancillary movement) and communicating with their co-performers (communicative movement). These categories of musicians' movements bear a relationship to compositional structures. When musicians produce sounds according to the instructions in the score, their instrumental movement, such as cellists' bowing and percussionists' accented strokes, must be organised in relation to compositional structure (Dahl, 2000; Winold, Thelen, & Ulrich, 1994). Musicians' ancillary body movements are also associated with compositional features such as phrase structure (MacRitchie, Buck, & Bailey, 2013; Vines, Krumhansl, Wanderley, & Levitin, 2006). In addition to this, evidence has shown that music listeners' body movements reflect compositional structures of music including metrical hierarchical levels and rhythm (Burger, Thompson, Luck, Saarikallio, Toiviainen, 2013; Leman & Naveda, 2010; Toiviainen, Luck, & Thompson, 2010).

Conductors' movements direct the performance in relation to selected compositional features according to their interpretational intentions. The kinematic features of these movements including baton and hand position, velocity, acceleration, jerk, and trajectory can

regulate musicians' synchronisation (Luck & Nte, 2008; Luck & Sloboda, 2007, 2008; Luck & Toiviainen, 2006), as well as communicate expressive qualities to an audience (Gallops, 2005; Luck, Toiviainen, & Thompson, 2010; Mathers, 2009; Wöllner, 2008). In addition, as suggested by educational manuals concerned with the conducting and orchestral direction (e.g., Green & Malko, 1987; Rudolf, 1994), conductors use a particular gestural repertoire to communicate compositional features they have selected to highlight. However, such discussions of the correspondence between conducting movement and compositional elements have been based on subjective, qualitative descriptions of movement. It is still not clear how kinematic features of conducting movements deliver melodic, rhythmic, and dynamic aspects of a composition at particular time-points in the score. More research is needed to provide knowledge of how these kinematics in conducting movement can communicate such compositional features and the conductor's musical interpretations.

Conductors each display their own features in movement kinematics, and variability of movement between different conductors should be anticipated. Therefore, the present study aimed to examine the similarity level of kinematic features within and between conductors. Furthermore, the aforementioned studies have focused on the overall characteristics of the entire movement (e.g., Burger et al., 2013; Leman & Naveda, 2010; Toiviainen et al., 2010). The present study, on the other hand, sought to associate conductors' actual conducting movements with their stated expressive intentions of compositional structures at specific time-points in the musical score.

Accordingly, the research questions were: 1) In kinematic aspects, how do conducting movement kinematics vary within and between each conductor? 2) How do compositional features and conductors' stated expressive intentions account for kinematic deviations? 3) how do more frequently observed kinematic deviations reflect compositional features and conductors' intentions (compared to less frequently observed kinematic deviations)?

Based on findings of existing musical movement research, it was hypothesised that within-conductor kinematic patterns should be more similar than between-conductor patterns. Secondly, it was also hypothesised that the occurrence of conducting kinematic (speed, acceleration, and jerk) deviations should co-occur with distinctive compositional elements in melodic, rhythmic, and dynamic structures, as well as conductors' self-reported interpretational intentions. Finally, it was expected that across performances of the same musical excerpt, the most frequently observed movement deviations should reflect those compositional structures noted in advance of the performance by the conductors.

Method

The study received ethical approval by the College of Arts, Humanities and Social Sciences, University of Edinburgh.

Participants

Six male right-handed conductors based in Edinburgh, Scotland participated in the study (conducting experience: M=10.6 years, SD=9.37, Range=4-29; conducting hours per week: M=4.4 hours, SD=2.38, Range=3.5-8). Three respondents (conducting experience: M=16.3 years, SD=11.0, Range=10-29) described their conducting status as 'professional conductor' or 'professional music educator', whereas other three respondents (conducting experience: M=5 years, SD=1.7, Range=4-7) described themselves as 'advanced student'. The different conducting status and wide range of conducting experience of participants provided an overview of general conducting behaviour. At the point of recruitment,

conductors were advised on the music selection which they would be asked to rehearse and record with a small string ensemble.

Materials and procedure

Interview

Conductors were interviewed before the recording sessions took place, answering open questions about their interpretations of the music which they would rehearse and perform (Eine Kleine Nachtmusik by W. A. Mozart, No. 13, K. 525, first movement, mm. 1-55, Breitkopf & Hartel, Leipzig, 1883) and their intended conducting movements to deliver these. For their interpretations of music, participants were asked to provide at least five annotations in the musical score, in which they were free to select musical time-points, specifying the musical features they would aim to highlight in their own conducting at those moments. Depending on the annotations provided by the conductors, follow-up questions were asked about their intended conducting movement at these particular musical time-points. They were prompted to describe features of their gestures using adjectives, and to explain how the ensemble would be expected to respond.

Apparatus

Participants' conducting movements were recorded in a 12 m × 12 m × 5 m biomechanical laboratory at the University of Edinburgh. A nine-camera optical motion capture system (Qualisys, Pro-Reflex, Sweden) was used to record conductors' movement at a sample frequency of 120 Hz. All cameras were adjusted to optimal positions to capture all markers with at least two cameras. The captured area was calibrated using the Qualisys 300

mm wand kit with all cameras' average residuals being lower than 2 mm. An audio recorder (Zoom H6) connected to one pair of Neumann KM184 microphones was set 1 metre behind the conductor to collect audio recordings. In order to synchronise movement and audio recordings, the audio recorder was connected to the motion capture system to receive the time code generated by Qualisys. Three additional video cameras (Panasonic HC-V100) were set facing the conductor from front, side, and rear viewpoints respectively to record the conductors in digital video format.

Motion capture

After the interview, each conductor had thirty minutes to rehearse with an ensemble of five string musicians. After the rehearsal, twenty-five 12mm reflective markers were attached to the conductor's upper body based on the upper body model of Visual 3D documentation, and two additional markers were placed on the baton. Some previous studies stripped down a selection of markers as a proxy for more complex movements (e.g., Burger et al., 2013; Toiviainen et al., 2010), and the baton tip marker was selected for conducting movement analysis (Luck & Nte, 2007; Luck & Toiviainen, 2006). The current study reported here is concerned with the baton tip marker data only. The conductor stood approximately two metres away from five musicians and conducted three repeat performances of the music. Therefore, eighteen conducting sessions were recorded in total (3 trials × 6 conductors).

Data analysis

Music score and interview transcript

Musical features in structural, melodic, rhythmic, and dynamic aspects were extracted according to music analysis theories (Aldwell, Schachter, & Cadwallader, 2003; Bent, 1994; Bent & Drabkin, 1987). Conductors' self-reported interpretational intentions were collected through score annotation and interview. These were coded and analysed thematically (Strauss & Corbin, 1997).

Motion capture data

Pre-processing

Collected data were exported from Qualisys Tracker Manager (version 2.7, Pro-Reflex, Sweden) in C3D format and imported into Visual 3D (standard version 4.93, C-motion, USA). The original signals of the baton tip were smoothed using a 4th-order lowpass Butterworth filter with a cutoff frequency of 10 Hz. Linear kinematic measurements including speed, acceleration, and jerk of the conductor's hands has been identified as key parameters influencing the perceived musical expressiveness in previous research (Luck et al., 2010). In the current study, those three parameters were computed using Visual 3D pipeline commands and were defined as: *speed* ($m.s^{-1}$): the scalar value of the first derivative of baton tip position multiplied by the sample frequency (120 Hz); *acceleration* ($m.s^{-2}$): the scalar value of the first derivative of baton tip velocity; *jerk* ($m.s^{-3}$): the scalar value of the second derivative of baton tip velocity. Scalar measurements were variables of interest because they contain values of measurements without directional information.

For comparison across different trials, all data were time-warped using the following method to equate tempi across 18 trials: The timing of metrical beats were estimated using Visual 3D as the time when the lowest position of the baton tip occurred within the beat.

Movement data were then resampled by interpolation as 1000 data points per musical measure using Matlab (version 8.5, Mathworks, USA).

Cross-correlation

Previous studies have used cross-correlation to examine the time lag between the movement and subjects' response (e.g., Luck & Toiviainen, 2006; Wöllner & Auhagen, 2008). Cross-correlation is a procedure to investigate the correspondence of two sets of time-series data (Stergiou, 2004), and it was used in the present study to reveal the similarity between kinematics across trials of the same and different conductors.

To examine similarities of kinematic patterns, cross-correlations were performed on speed, acceleration and jerk time-warped data of within-conductor and between-conductor trial pairs. This procedure produced 459 coefficients in total (153 pairs × 3 measurements= 459) with greater cross-correlation coefficients indicating higher correspondence between pairs of trials.

To examine whether conductors' kinematic patterns were more consistent with their own conducting as compared to other conductors' conducting, three inferential comparative tests were conducted on the correlation coefficients for speed, acceleration and jerk. If the cross-correlation data were normal (tested with a Shapiro-Wilk test of normality with α-level set at 0.05), then a *t*-test for independent groups (within-conductor coefficients and between-conductor coefficients) were performed on coefficients of trial pairs by the same conductor (n=18), and coefficients of trial pairs by different conductors (n=135). Where Shapiro-Wilk's test of normality failed, a non-parametric Mann-Whitney U test was conducted instead of a *t*-test. As only three inferential tests were carried out (speed, acceleration and jerk), the α-level

was set at 0.05 for the *t*-test or Mann-Whitney U test. Effect sizes were calculated according to Cohen (1988).

Deviation Point Analysis (DPA)

Existing literature regarding musical movement has mostly investigated the overall profile of movement (e.g., Burger et al., 2013). However, the present study aimed to identify specific time-points when the baton tip showed prominent kinematic features, and these points then could be matched to particular compositional elements in the written score. Since no method in previous musical research was suitable to detect such kinematic deviations, a combination of methods examining kinematic variability in other fields (Hamill, Knutzen, & Derrick, 2015; Stergious, 2004) was applied. This was named Deviation Point Analysis (DPA). Since the time-warped data contained local fluctuations of movement, DPA was applied to speed, acceleration, and jerk means per musical measure, with the purpose of exploring kinematic features at musical measure level—which could be better matched with specific musical instances in the score. Prior to DPA, kinematic measurement means per measure were standardised, i.e. transformed in to their *z*-scores using the trial's mean and standard deviation. DPA was used to examine two types of data: 1) each trial, and 2) each conductor's averaged curve (of the three trials by the same conductor).

The curve-averaged standard deviation for each trial was calculated using Equation 1.

$$SD_{avg} = \left[\frac{\sum_{i=1}^{k} SD_i^2}{k} \right]^{\frac{1}{2}}$$ (Equation 1)

where SD_{avg} is the average of standard deviation across all *k* samples, and SD_i is the standard deviation value for the ith sample.

Upper and lower thresholds of the mean±1.96 standard deviations (curve-averaged) were then set, based on the fact that 95% of data points should be included in this range and only 5% of data points would be identified as deviation points if the data were normally distributed. Any data point passing the upper threshold was defined as an upper deviation point, whereas a data point passing the lower threshold was defined as a lower deviation point. This procedure produced 54 analyses (6 conductors × 3 trials × 3 kinematic measurements).

To examine whether those kinematic deviation points identified from each trials were stable across trials, and thus could be considered as typical kinematic features of each conductors' conducting, DPA was also performed on each conductor's mean curve of three trials.

Deviation Point Analysis of between-conductor kinematic variability

In order to examine the kinematic variability between conductors, point-by-point between-conductor standard deviations were calculated using Equations 2 and 3.

$$M_i = \frac{\sum_{j=1}^{n} x_{ij}}{n}$$ (Equation 2)

$$SD_i = \left[\frac{\sum_{j=1}^{n}(x_{ij}-M_i)^2}{n-1} \right]^{\frac{1}{2}}$$ (Equation 3)

where SD_i is the standard deviation value for the ith sample, M_i is the mean for ith sample, x_{ij} is the data value for the ith sample in jth trial, and n is the number of trials.

The continuous kinematic variability was then plotted using the mean curve of all conductors ± 1.96 standard deviations (point-by-point) at each time-point (see Figure 6A as an example). Time-points having high between-conductor variability were identified using the threshold of mean standard deviation (point-by-point) ± 1.96 standard deviations (curve-averaged) of between-conductor standard deviations (point-by-point) (see Figure 6B as an example).

Results

Conductors' interpretational intentions

The analysis of the conductors' interview transcripts is summarised in Table 1. The compositional features highlighted most in conductors' self-reported interpretations involved elements in melodic (e.g., counterpoint melodies), rhythmic (e.g., semiquaver, syncopation), dynamic (e.g., *sforzando*, *crescendo*), and harmonic (e.g., cadence) aspects.

Table 1 Conductors' self-reported interpretational intentions in interviews

Measure	No. of comment	Highlighted compositional feature	Description of movement
1	4	set up the character of piece	breath
		set up the tempo	clear
		set up dynamics	vigorous
			have weight
5	3	semiquaver rhythm	strong downbeat
6	1	underneath melodic line	-
10	2	rest	breath
11	4	dynamic change (*f-p*)	-
15-16	1	rhythmic imitation between instruments	precise
18-19	6	dynamic change (*sf*)	big gesture
			back off quickly
20	2	dynamic change (*crescendo*)	encourage
			hold the attack
21	1	top line melody	-
24	1	syncopation	-
31	4	direction of music	minimum size (R hand)
		counterpoint melodies	pull out gesture (L hand)
		cadence	stress on downbeat
			legato gesture
47	2	counterpoint melodies	-

Similarities of conducting kinematic patterns

The results of the cross-correlations are summarised in Figure 1. It can be seen that trials by the same conductor had higher correlation coefficients than trials by different conductors. In the inferential analysis, the cross-correlation data for the comparison of within-conductor and between-conductor similarities were normal for acceleration and jerk, but not for speed. Therefore, two *t*-tests were carried out for the cross-correlation coefficients (within- and between-conductors) for acceleration and jerk, and a Mann-Whitney U test for those for speed. The results of these tests are presented in Table 2. It was evident that within-

conductor coefficients had significant differences from between-conductor coefficients for all variables, supported by large effect sizes. The results in Figure 1 and Table 2 indicated that conductors' kinematic patterns were significantly more similar to trials conducted by themselves, than trials by the other conductors.

Figure 1 Average of within-conductor and between-conductor maximal cross-correlation coefficients
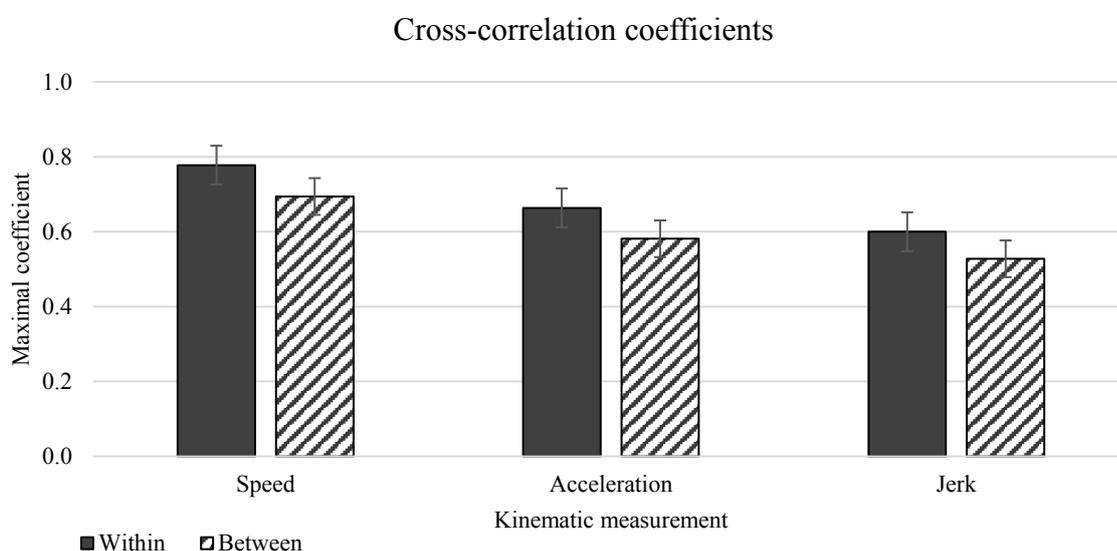

Figure 1 Maximal cross-correlation coefficients of conducting kinematic pairs. Within indicates coefficients of trial pairs by the same conductor; between indicates coefficients of trial pairs by different conductors. Error bars indicate standard error. All comparisons showed significant differences.

Table 2 Results of *t*-tests and Mann-Whitney test (within-conductor maximal coefficient and between-conductor maximal coefficient)

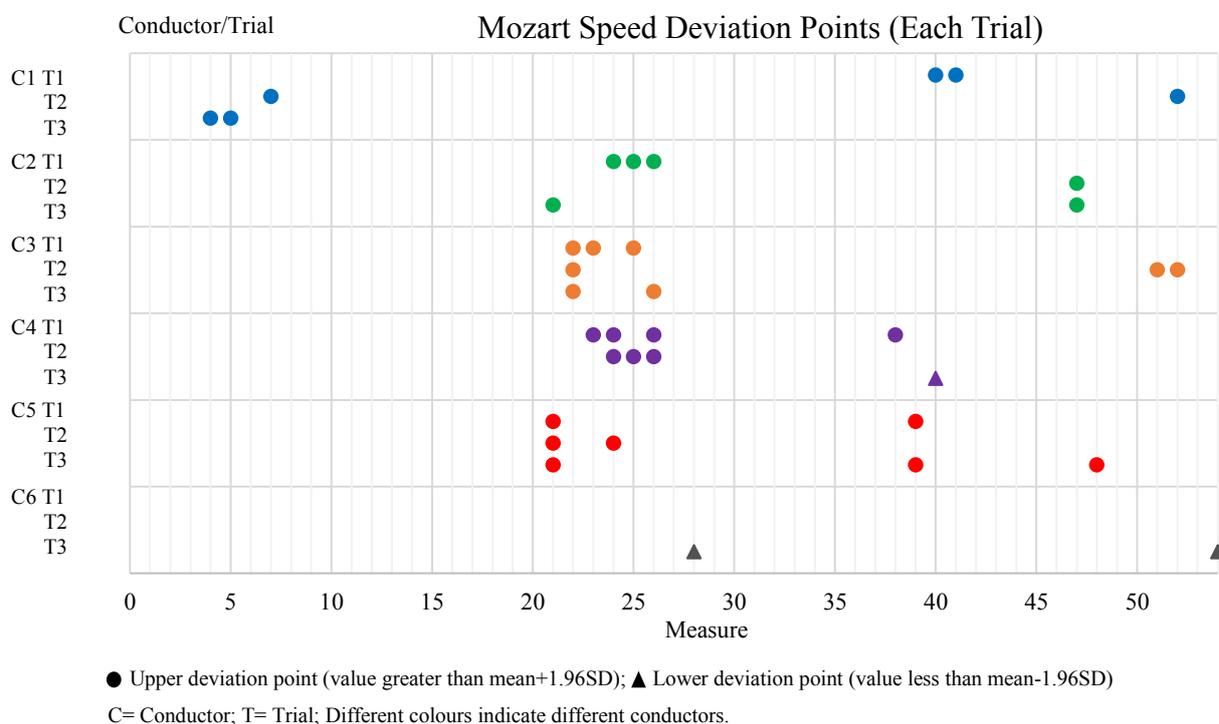| Statistical test	Measurement	Sig.	Effect size
Mann-Whitney test	Speed	$p < .001$	1.6 (large)
T-test	Acceleration	$p = .001$	1.1 (large)
	Jerk	$p = .001$	1.1 (large)

Kinematic deviation in conducting movement
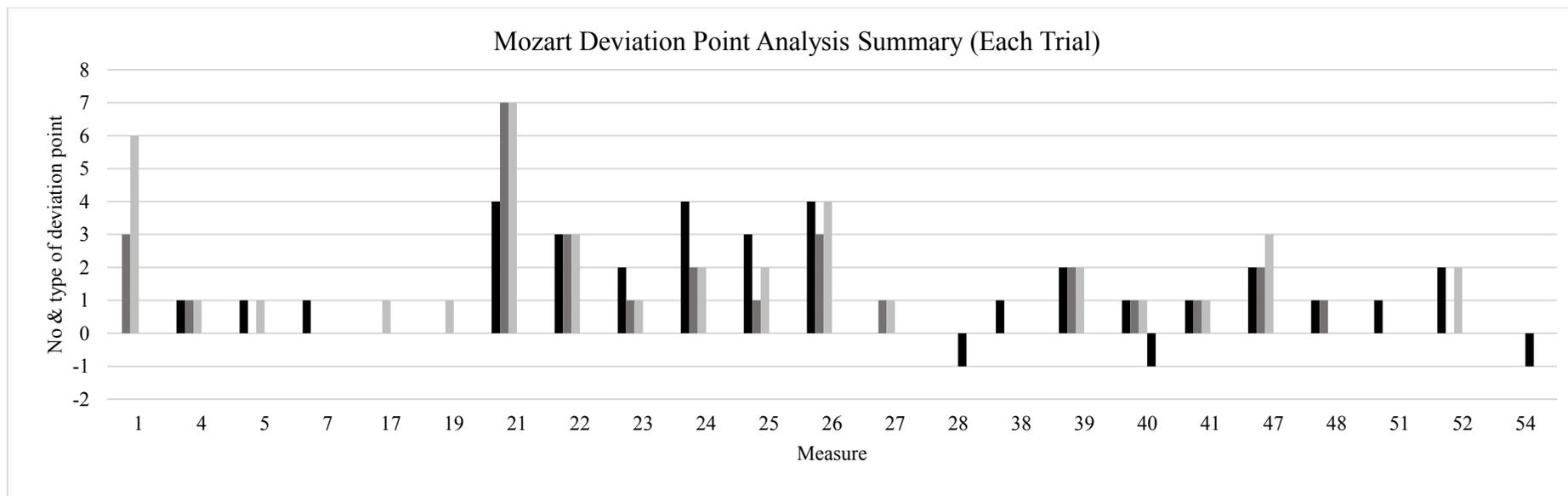
Kinematic deviation in each conducting trial

Deviation points identified from each trial using DPA for three linear kinematic measurements— speed, acceleration and jerk— are summarised (see Figure 2 as an example). The statistics of upper and lower deviation points are arranged by chronological order, together with the summary of music score analysis in Figure 3. Based on conducting principles and conductors' opinions in the interviews, compositional features in music should show in the conducting movements just prior to the time-point when the musical feature occurs, to allow for reaction time of musicians. Therefore, measure numbers listed in the musical feature summary in Figure 3 also include the measure prior to the musical feature.

Figure 2 Example of deviation points identified from each trial

● Upper deviation point (value greater than mean+1.96SD); ▲ Lower deviation point (value less than mean-1.96SD)

C= Conductor; T= Trial; Different colours indicate different conductors.

Figure 3 Kinematic deviation points and the summary of compositional features

Mozart Deviation Point Analysis Summary (Each Trial)

■ Speed   ■ Acceleration   ■ Jerk
+ = Upper deviation point (passing the upper threshold mean + 1.96 SD); − = Lower deviation point (passing the lower threshold mean − 1.96 SD).

Measure	1	4-5	7	17, 19	21-27	28	38-41	47-48	51-52	54
Conductor	1, 3, 5, 6	1, 2	1	4	1, 2, 3, 4, 5, 6	6	1, 2, 4, 5	2, 3, 5	1, 3, 4, 5	6
Music feature	beginning	rhythmic change	accent	(preparation of) *sf*	upward melody melodic climax syncopation *crescendo* dynamic climax	new theme *f→p*	counterpoint melodies *p→f*	counterpoint melodies *p→f*	*trill*	*f→p*

Figure 2 shows that upper deviation points were concentrated between mm. 21-27, and this is confirmed in Figure 3. The concentration of upper deviation points coincided with the combination of melodic, rhythmic and dynamic features in music (Example 1). The upward melodic line from m. 20 leads to the melodic climax in m. 22, companied with *crescendo* from *piano* to *forte*. Syncopation in mm. 24-25 sustains the melodic peak till the melody goes downward in m. 27.

Example 1 Mozart, *Eine Kleine Nachtmusic*, No.13, K. 525, mm. 21-27 (1883, Leipzig: Breitkopf & Hartel).

In general, it can be observed from the summary of Figure 3 that upper deviation points of movement kinematics corresponded with musical features including the introducing of new rhythmic pattern in m. 5, upward melodic line and melodic climax in mm. 21-27, counterpoint melodies by viola and cello in mm. 39-41 and mm. 47-48, particular techniques such as *trill* in mm. 51-52, particular rhythm such as syncopation in mm. 24-25, dynamic change such as *crescendo* in m. 21 and the switch from *piano* to *forte* in m. 39 and m. 47. On the contrary, the dynamic switch from *forte* to *piano* in m. 28 and m. 54 coincided with lower deviation points of kinematics.

Stability of kinematic deviation

Conductors might use different body movements to direct the same composition in different performances. In order to determine that whether the kinematic deviations found in previous DPA were features only emerging from one single trial, or could be considered as stable, typical traits of the conductor's conducting, DPA was applied to examine the mean curve of the three trials conducted by the same conductor (see Figure 4 as an example). Deviation points consistently identified from trial and mean curve analyses could be considered as the most stable ones (squares in Figure 5); deviation points found in mean curves only (solid diamonds in Figure 5) or in trial analyses only (unfilled diamonds in Figure 5) were less stable ones, whereas deviations having opposite deviation types (upper deviation and lower deviation) in two kinds of analyses or between different conductors were regarded as the most unstable ones (crosses in Figure 5).

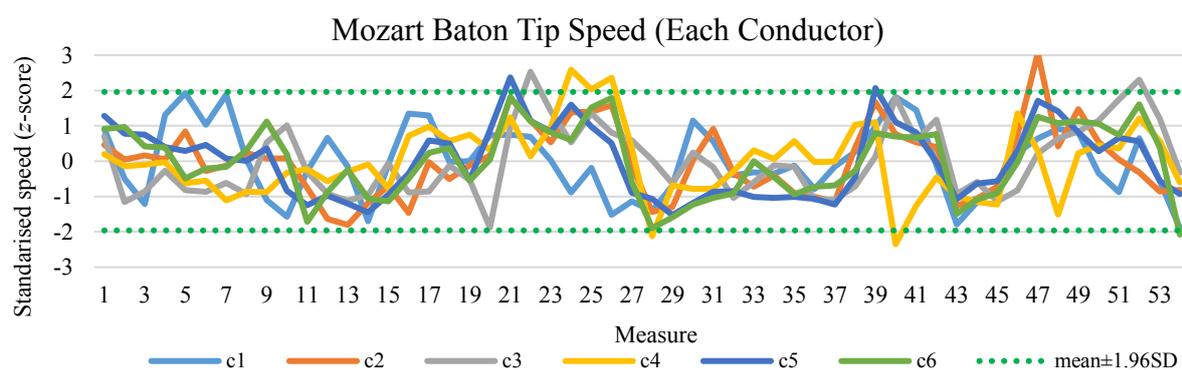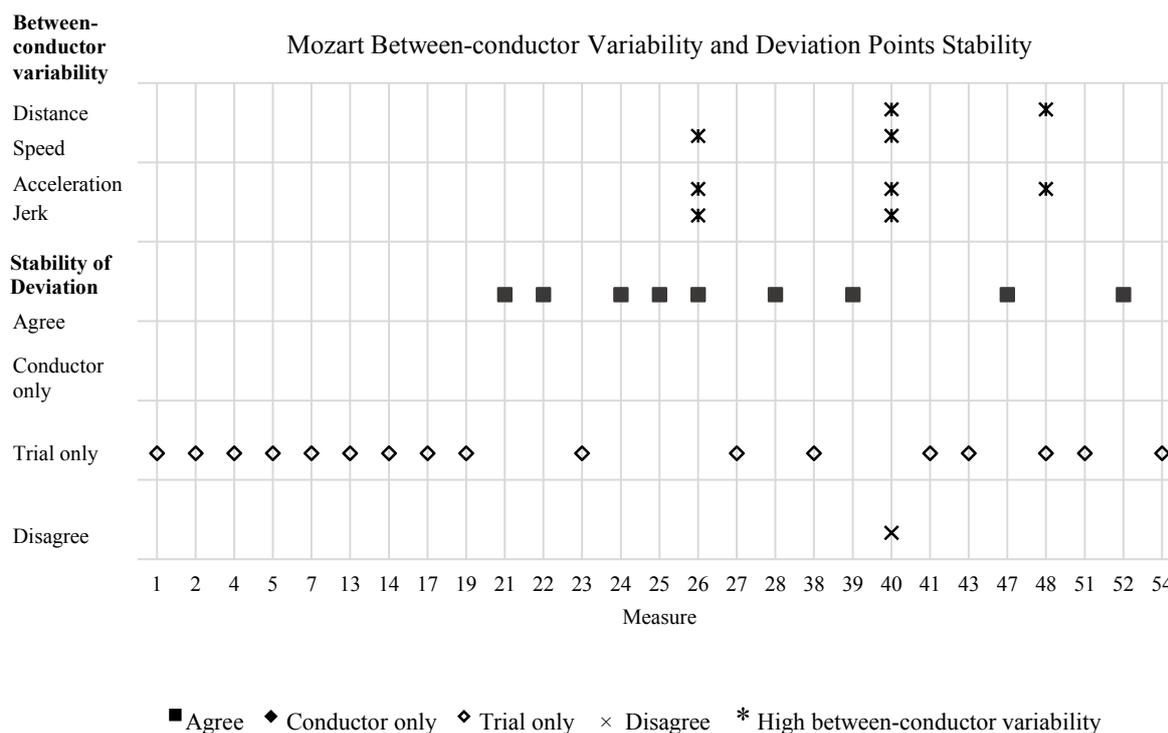Figure 4 Example of Deviation Point Analysis for each conductor's mean curve

Figure 5 The stability of deviation points (in trials and in mean curves) and between-conductor variability

Mozart Between-conductor Variability and Deviation Points Stability

Between-conductor variability

Distance		
Speed		
Acceleration		
Jerk		

Stability of Deviation

Agree

Conductor only

Trial only

Disagree

Measure: 1 2 4 5 7 13 14 17 19 21 22 23 24 25 26 27 28 38 39 40 41 43 47 48 51 52 54

■ Agree ◆ Conductor only ◇ Trial only × Disagree ✻ High between-conductor variability

Kinematic deviation	Description
Between-conductor variability	Deviation point showing high between-conductor kinematic variability
Stability of deviation	Deviation point shown in trial/ conductor's mean curve
Agree	Deviation point shown in both trial analyses and in conductor's mean curve (of 3 trials) analyses
Conductor only	Deviation point shown in conductor's mean curve (of 3 trials) analyses only
Trial only	Deviation point shown in trial analyses only
Disagree	Having opposite types of deviation (upper and lower deviations) in trials and in conductor's mean curves, or in different conductor's analyses

The comparison of deviation points in trial analyses (Figure 2) and deviation points in conductor's mean curve analyses (Figure 4) is summarised in Figure 5. It appeared that the most stable deviation points (squares in Figure 5) matched with the main cluster of deviation points in mm. 21-27 (Figure 2 and Figure 3), and the dynamic contrasts from *piano* to *forte* in m. 39 and m. 47. Less stable deviation points (diamonds in Figure 5) tended to reflect more local musical features including the introduction of new rhythm (e.g., m. 5), musical accent (e.g., m. 19), and *trill* (e.g., m. 51). There was only one unstable point having opposite deviation types in the different conductors' movements (a cross in Figure 5). This case

appeared in m. 40, which is the time-point after conductors delivered the dynamic change from *piano* to *forte*.

Conducting kinematic variability between conductors

Between-conductor variability analysis examined whether each conductor had similar or different kinematic features compared to the other conductors. Analysis of between-conductor kinematic variability is demonstrated in Figure 6A. Time-points with high between-conductor kinematic variability are identified in Figure 6B. Figure 5 summarises time-points having high between-conductor variability together with conductor's kinematic deviation points. It appeared that conductors' movements have higher variability after the highlighted musical events occurred. For instance, in m. 26 (Example 1) after the melodic climax and syncopation, and in m. 40 and m. 48, which are the measures after the music switches from *piano* to *forte*. The high between-conductor variability coincided with the unstable deviation point found in m. 40 in trial and mean curve analyses (the cross in Figure 5, showing opposite deviation types in different conductors).

Figure 6A Example of between-conductor kinematic variability

Figure 6B Example of Deviation Point Analysis of between-conductor kinematic variability

6A

6B
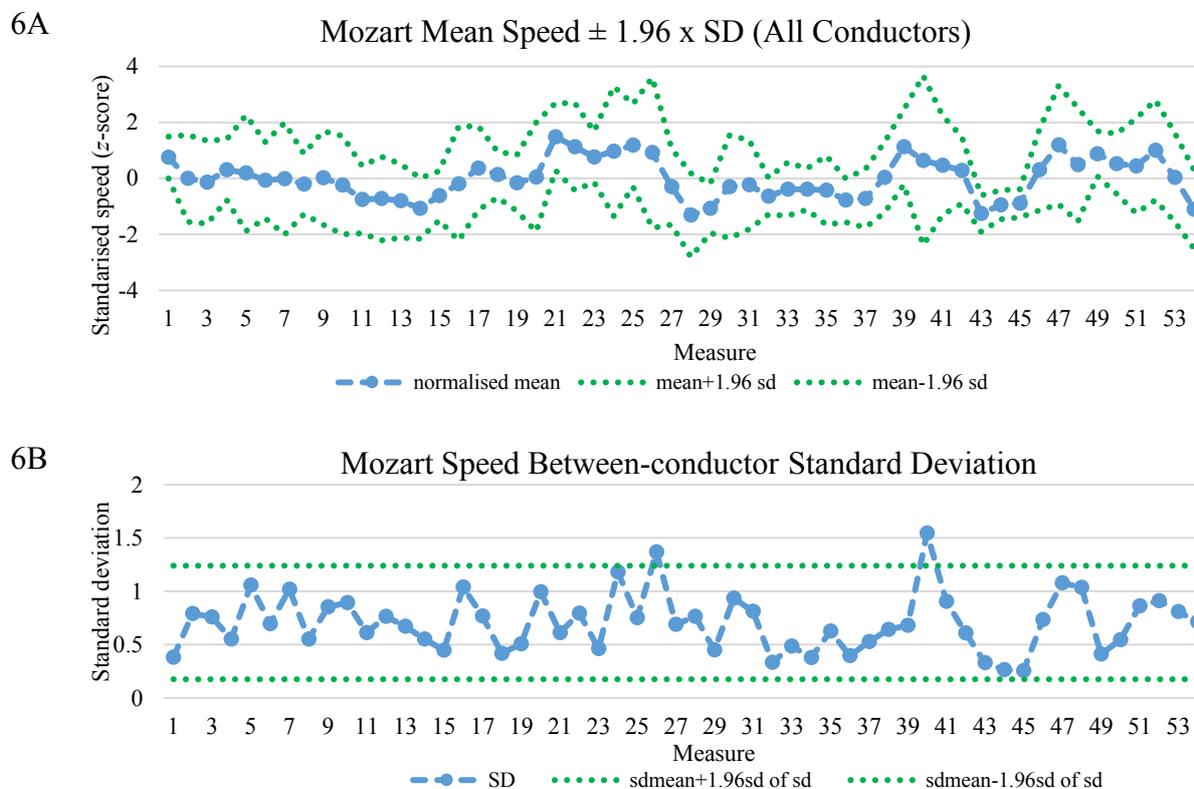
Comparison between interpretational intentions and conducting movement kinematics

The comparison of conductors' self-reported interpretational intentions and kinematic deviations in their conducting movement are summarised in Table 3. It can be seen that the most stable deviation points with high movement variability matched musical passages that conductors intended to highlight in interviews[1]. However, their movement kinematic

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[1] Mm. 38-40 show a similar compositional structure to mm. 47-48. Conductors might be less likely to give comment on mm. 38-40 to avoid repetition in limited time for interviews.

deviations also reflected several instances of local compositional features which they did not highlight in interviews (e.g., melodic contour, rhythmic pattern, *trill*, *staccato*). On the other hand, kinematic deviation of conductors' movement was not observed for some other instances they reported in interviews, including instructing the direction of music, rest, cadence, and rhythmic imitation between instruments.

Table 3 Analysis of music score, interview data, and motion capture data

	Score analysis	Interview data	Motion capture data	
Measure	Compositional feature	No. of comment	Kinematic deviation	Kinematic variability
20-27	melodic climax, syncopation, dynamic change (*crescendo*)	4	conductor & trial	speed, acceleration, jerk
47-48	counterpoint melodies, dynamic change (*p-f*),	2	conductor & trial	acceleration
38-40	counterpoint melodies, dynamic change (*p-f*)	-	conductor & trial	speed, acceleration, jerk
28-30	short rhythmic pattern, *staccato*, dynamic change (*f-p*)	-	conductor & trial	-
51-55	upward melody, *trill*, dynamic change (*f-p*)	-	conductor & trial	-
18-19	dynamic change (*sf*)	6	trial only	-
1	beginning of piece	4	trial only	-
5	semiquaver rhythm	3	trial only	-
11	dynamic change (*f-p*)	4	-	-
31	direction of music, cadence, counterpoint melodies,	4	-	-
10	rest	2	-	-
6	counterpoint melodies	1	-	-
15-16	rhythmic imitation between instruments	1	-	-

Discussion

This study investigated how conducting movement kinematic features communicate compositional elements and conductors' expressive intentions. It was expected that: 1)

within-conductor kinematic patterns would show higher similarity than between-conductor patterns; 2) observed kinematic deviations and high kinematic variability between conductors would reflect prominent compositional elements in melodic, rhythmic, and dynamic aspects, as well as conductors' stated expressive intentions; 3) more frequently observed kinematic deviations in movement would connect with compositional items conductors highlighted in interviews.

Cross-correlation revealed high coefficients in speed, acceleration, and jerk (averages ranging from 0.5 to 0.8), which indicated strong similarities between trials both within- and between-conductors. With such high similarities between trials, *t*-tests and a Mann-Whitney test further confirmed that within-conductor kinematic patterns were significantly more consistent than between-conductor patterns. The similarity of conducting movement patterns is in lines with previous findings that woodwind players' body movements show commonalities between players despite individual differences (Davidson, 2007, 2012). The kinematic similarity across within- and between-conductor performances may suggest that compositional structures were embodied in conducting kinematics, regardless of each conductor's idiosyncratic conducting strategies. This result agreed with previous findings on musicians' body movements (MacRitchie et al., 2013).

DPA further revealed the connections between conducting kinematics and specific compositional elements. It appeared that upper kinematic deviation points reflect compositional elements including melodic features such as upward melodic line, melodic climax, and counterpoint melodies, introduction of new rhythmic pattern, rhythmic pattern of syncopation, special technique of *trill*, as well as dynamic change of *crescendo*, and the switch from *piano* to *forte*. Lower kinematic deviation points tend to coincide with the dynamic switch from *forte* to *piano*. Within these deviations, the most stable kinematic deviations (identified from both trials and conductor's mean curves) were connected to the

combination of melodic climax, *crescendo* and syncopation, as well as dynamic contrasts from *piano* to *forte*. Less stable kinematic deviations (identified from trials only or from conductor's mean curves only) matched local musical features including *sforzando*, *trill*, *staccato* and semiquaver rhythm. These results partly reflect previous findings that musicians' movements connect to salient musical events (MacRitchie et al., 2013; Thompson & Luck, 2011; Vines et al., 2006). However, previous findings were based on the overall profile, whereas in this research, specific movement kinematic deviations were detected and were matched with specific time-points in the composition.

Instances where conductors showed the most unstable deviation points (opposite types of deviation across trials or conductors) coincided with high between-conductor variability. The analysis found that high between-conductor kinematic variability showed after a melodic climax, as well as dynamic switch from *forte* to *piano*, which were both conducting targets conductors had highlighted in interviews. This suggests that conductors use similar movements to deliver targeted musical structures, after which points their movements become flexible. Considering that prior research has found similar movement profiles across musicians (MacRitchie et al., 2013), the stability and variability analyses of deviation point in this study add evidence of exact time-points for the convergence and divergence of conductors' movement.

Comparing conducting movement kinematic deviations with conductors' interpretational intentions, the most stable deviation points matched with musical passages that conductors expressed an explicit intention to highlight, which is consistent with previous findings that musicians' movements bond with their intended musical targets (Davidson, 2007; Desmet et al., 2012). Perceptually, those movement deviations delivering musical targets may also increase musical expressiveness perceived by the audience (Castellano, Mortillaro, Camurri, Volpe, & Scherer, 2008; Luck et al., 2010; Wöllner & Auhagen, 2008).

Sometimes in this study, the comments conductors gave in interviews did not show in their movement, or movement deviations did not match with comments in interviews. One possible explanation for this might be that those compositional features were considered to be of secondary importance during the performance event, thus conductors' comments and movement deviations were connected to those compositional features in a looser manner. Furthermore, perhaps when conductors delivered those compositional features, they intended to employ other movement features or facial expressions, instead of linear kinematic features. Davidson (2007) also showed that sometimes musicians' movements did not match with any expressive targets in the composition. Therefore, it appears that compositional features with higher importance, either in the structural analysis of music score or from the performer's interpretational perspective, tend to have stronger and more stable association with body movement, which is an important agent to communicate such compositional structure in music performance.

The findings of the present study are constrained to one single musical excerpt and its features. Furthermore, due to the amount and complexity of the motion capture data, only linear kinematics of the baton tip were investigated. However, it is recognised that given the complexity of conducting movement, many other factors should be taken into account in due course such as angular features and trajectories (Hove & Keller, 2010; Leman & Naveda, 2010, Naveda & Leman, 2010), movements of different body parts (Davidson, 2007; Thompson & Luck, 2012; Toiviainen et al., 2010), and facial expressions (Davidson, 2012; Wöllner, 2008). These are known to interact together with such linear kinematic features investigated in this study, and to be adapted to different performance contexts (Chaffin, 2011). It is therefore our intention to analyse other body segments from the motion capture data collected in this study for future research.

In spite of the limitations stated above, the present study identified exact time-points with distinctive kinematic features, and connected those features with detailed compositional elements as well as conductors' self-reported intentions. The findings suggested that music compositional structures are embodied in all conductors' movement kinematics, in spite of each conductor's own conducting style. Observable kinematic features also serve as effective cues to accurately communicate the conductor's musical interpretational intentions. The stability of such kinematic features reflects the importance of the featured compositional elements, either from music analysis or from the conductor's interpretational perspectives. Finally, this study developed a new method (Deviation Point Analysis), which holds great potential for future understanding of the body movements of conductors and musicians at particular time-points in musical composition.

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