Special Issue

Investigating Embodiment in Oral Mnemonics within Japanese Music

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An oral mnemonic system known as *shōga* (literally meaning "singing song"), which can be practised without a musical instrument, is an indispensable means for transmitting or representing melodies in Japanese traditional music genres. While it has come to be written as a kind of music notation as well, *shōga* is primarily the bodily experience that begins with imitating the master's voice and movements in a one-on-one teaching scenario. This article aims to approach the nature of *shōga*-performing practices from both quantitative and qualitative angles, dealing especially with the case of a wind instrument in court music (*gagaku*). After discussions on *shōga* and the rhythmic properties of instrumental music in *gagaku*, sound/movement data will be examined and combined with interview results from a participating musician. The investigation reveals that a multi-angled knowledge of *shōga* practices can provide insight into the essence of rhythmic expression in Japanese music genres.

Introduction

An oral mnemonic system known as *shōga* (literally meaning "singing song"), which can be practised without a musical instrument, is an indispensable means for transmitting or representing melodies in Japanese traditional music genres. In learning or recalling an instrumental part, a performer may sing either syllables indicating finger positions or drum strokes, or a set of mnemonics that primarily represent relative pitch. While *shōga* has come to be written as a kind of music notation as well and includes many dimensions, it is, in essence, the bodily experience that begins with imitating the master's voice and movements in a one-on-one teaching scenario. In previous studies, the mechanisms of its transmission and expression have been mainly perceived from written instances of the mnemonics, yet rhythmic expressions such as beat durations and speed fluctuations have been almost entirely absent from these written versions, which are viewed by practitioners as a supplementary tool for facilitating memorisation. The experience of *shōga* performing should not be overlooked as it is a fundamental means of becoming proficient in Japanese music genres.

This article approaches *shōga*-performing practices from a perspective that has not been examined in previous studies: of bodily movement rather than just vocal execution. Specifically, I aim to clarify how *shōga* practices embody the rhythmic expression that should be realised in instrumental performance, dealing especially with the case of a wind instrument in *gagaku* court music. A considerable amount of information, which is not written down and yet is closely related to the aesthetic concepts described later, is transmitted via *shōga*-performing bodies. To approach the nature of *shōga* practices from both quantitative and qualitative angles, sound/movement data from *shōga* and instrumental performances will be examined and combined with interview results from a participating musician.

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Firstly, the importance of *shōga* performance in traditional practices will be highlighted through sections outlining *shōga* and rhythmic properties of instrumental music in *gagaku*. In the analysis section, secondly, the distinctive knee-slapping action will be examined after temporal data from *shōga* and instrumental performances are compared. The subsequent interview section will shed light on the relationship between subjective awareness and praxis. Through these examinations, I will argue for the importance of *shōga*-performing practices in *gagaku* as an essential means of acquiring not only the subtle melodic nuances of individual parts (via voice), but also rhythmic properties typified by fluctuations in beat-duration (via whole-bodily experiences).

Research Perspectives on *Shōga*

Shōga has been explained as "singing/reciting the melody and rhythm of the musical instrument by applying a certain syllable" (Tanabe 1984: 516),[1] and it has often been emphasised as an act symbolic of the orality in Japanese instrumental music and of the abundance of fixed playing patterns. This section outlines previous discussions swirling around *shōga* and raises research issues stemming from them.

It was from the 1970s that attention began to be paid to *shōga* in Japanese musicology, and the central perspective of the pioneering studies was comparison with solmisation. Kikkawa (1974) demonstrated that *shōga* syllables were related to not only pitches but also timbres or the fixed patterns for playing melodies, using *sō*/*koto* zither and *shamisen* plucked lute as examples. Yokomichi and Gamō (1978) considered *shōga* to be "the thing which briefly and successfully transmits information that is difficult to understand from the performance, sheet music, or spoken descriptions" more than a mere syllabic notation system (ibid.: 3), and they expanded the scope to include situations in which *shōga* is sung, such as practice, tutoring processes, and rehearsals.

This was followed by attempts to move beyond the dichotomy of orality and literacy when considering *shōga* practice. Tokumaru (1986) noted that "stylistic memorisation" requires a lengthy process of continual feedback between students and teachers, in contrast to the "the memorisation of individual musical works" that can be written down – this idea provides an interesting space to consider the role that *shōga* plays. Fujita (1986) criticised the fact that *shōga* had been treated "as if it were a 'song' or 'piece' independent of actual performance on the instrument" – and instead depicted it as "the act of singing or utterance which underlies the instrumental music" and "a mnemonic device that is mainly utilized in the process of learning and teaching" (ibid.: 251). The phrase "mnemonic device/system" does not necessarily point merely to a memory aid. Subsequently, it was proved that certain acoustic-phonetic features of vowel and consonant syllables in mnemonics have a symbolic relationship with the tones they represent in many cultures, including those of Japan, Korea, and Uganda (Hughes 2000). These systems do not demand conscious awareness from the music practitioner, but instead rest on subliminal perception. Most traditional teachers, therefore, never explain such logic and are generally unaware of it. The findings, though, have provided theoretical explanation as to how and why *shōga* functions successfully and with impressive consistency.

The focus on the experiential aspect of *shōga* has deepened in the context of its applicability to educational settings since the late 2010s. An educational guide published as part of a collaborative project between musicologists and music teachers stated the purposes of this particular edu-

1 All translations from Japanese are by the author.

cational activity as being "to start from grasping music as a whole" and "to value learning from body to body" (Katō 2018: 12). Video footage of *shōga* practice was appended on a set of DVDs, rather than in audio form on CDs, reflecting the fact that *shōga* is not an upright and immobile form of singing but a physical experience of grasping the music.

Throughout the last half-century, *shōga* has attracted a wider interest not only as a syllabic notation system but as the practical experience utilised in the multiple processes of transmission, learning, playing, and listening. However, despite the current focus on practical aspects, it has been considered from an empirical perspective only a few times, and much less has been stated about dimensions of *shōga* beyond the "singing" act. As the next step for musicological approaches, what I argue in this article is as follows: when discussing *shōga*, we should not be limited to just the act of singing but instead take into account subjective views of the entire performance held by the performers, and quantitative data that support them. Recent empirical research has yielded results by linking timing and movement data with ethnographic considerations (Godøy and Leman 2010; Clayton, Dueck and Leante 2013). As the meanings of performances are subjective and context dependent, it is worth considering not only how *shōga* sounds, but also how it looks when negotiated with a master, as in a one-on-one lesson. As mentioned earlier, a learner first encounters his/her master's *shōga* performance, effectively a two-dimensional visual image. Therefore, the two-dimensional keypoint detection of performance practices, which has not been attempted before, may open up a new area of research.

Rhythmic Properties of Instrumental Music in *Gagaku*

The term *gagaku* (literally "proper music") at present covers three major bodies of classical music and dance: accompanied vocal music and dance of indigenous origin, instrumental music with dance accompaniment deriving from the ancient performing arts of the Asian mainland, and accompanied vocal music originating at the Heian court of the ninth and tenth centuries. This article draws specifically on the current performance practice of instrumental music called *tōgaku*, taking the short double-reed pipe *hichiriki* as an example.

The instruments in *gagaku*, which cover a varied range, can be grouped into three classes: winds, strings, and percussion – traditionally referred to as *fukimono* (blown things), *hikimono* (plucked things), and *uchimono* (struck things), respectively. Unlike the high-ranking nobles at the Heian court who collected notation for these instruments, the tradition of professional music families which became an important basis of the present-day practice has, for centuries, put more emphasis on oral transmission in the learning process. Regardless of whether someone is expected to become familiar with multiple instruments and dances as a professional, their learning begins with *shōga* in one of the *fukimono* instruments; they learn the details and grasp the whole music flow by imitating their teacher's *shōga* performance before playing the instrument. One can see from the very beginning the primary focus of learning falling on stylistic memorisation rather than the memorisation of individual musical works.

In particular, two temporal characteristics are considered important stylistic features in the genre: the gradual acceleration occurring as the piece proceeds, and the distinctive length of a certain beat within the beat-cycle (Nelson 2008: 58; Endō 2013: 152). Regarding the former, a piece begins at a very leisurely pace and gradually speeds up. Regarding the latter, beat extension tends to occur between the last beat of one cycle and the first beat of the next. For example, in the four-beat cycle style called *hayagaku*, the extension of timespan occurs between the fourth beat and the first beat. The existence of careful finger changes in *shō* mouth organ parts and arpeggios in *biwa* lute parts during breaks in the melody can be considered a partial cause of this. These com-

mon phenomena in *gagaku* practices are often mentioned in relation to the structural concept known in contemporary usage as *jo-ha-kyū*, which can be explained as *jo* = slow introduction, *ha* = faster build-up, and *kyū* = fast conclusion.[2] It is used to describe musical development on all formal levels, from the structure of a musical programme, the form of a piece, or the development of a section, to a musical phrase or even an individual note (Tokita and Hughes 2008: 26–7).

Subtleties of rhythmic expression are considered important stylistic features in the genre, yet their details have been almost entirely absent from the notations/written mnemonics that are viewed as a supplementary tool for facilitating memorisation. In other words, a considerable amount of information regarding rhythmic expression is embodied and transmitted primarily via *shōga* practice. In the case of *gagaku* wind instruments, the right-hand action while reciting *shōga* is noteworthy: musicians slap the first and second beats in the *hayagaku* four-beat cycle on the knee and the third and fourth beats on the side of the knee. The existence of two striking positions on the knee reinforces the speculation that the arm movements in-between beat counts also express rhythmic properties, yet this action is not included in the literal meaning of *shōga* ("singing song") and this striking of the knee is generally described as counting. However, I was intrigued by the fact that some *gagaku* musicians explained to me details of music with the knee-slapping action, and their references were not necessarily limited to counting in solo performance – the practical narrative suggested an even more significant role in transmitting musical details than simple counting (personal communications, April 2017).[3] It also underscores the importance that referring to the core meaning of the term *hyōshi* holds – that is, the act of "beating" – and how this term originated from *gagaku* and became widespread in other performing arts and music in Japan (Gamō 2000: 242).

There is undoubtedly great room to analyse Japanese *shōga* practices as bodily experiences; in particular, I hypothesised that the distinction of beats in *gagaku* would be reflected in the knee-slapping actions, just as it is in vocal execution. The next sections will focus on the case study of a *hichiriki* player, and special attention will be drawn to arm movements, which have rarely been described.

Sound and Movement Analysis

The primary focus of my analysis is on locating the actual state of *shōga* performance in both the performed temporal data and the subjective feel of the performing musician. This section provides quantitative data to support the idea of beat fluctuation and gradual acceleration, which is often stated as the characteristic of rhythmic expression in *gagaku*. Having analysed performance footage with Sonic Visualiser (Cannam, Landone, and Sandler 2010) and OpenPose (Cao et al. 2017), the data will be framed with interview results from the participating *hichiriki* player in a later section.

2 *Jo-ha-kyū* is a compound term referring to the three contrasting music styles '*jo*', '*ha*' and '*kyū*', and the way in which different pieces can be combined to create a coherent compositional progression in *gagaku*. It was extended in the context of other performing arts to convey a wider meaning encompassing the progression or gradual increase in speed.

3 For example, the following remarks (April 2017, Tokyo) inspired me for the research. (1) Explaining about ensemble performance with the gesture: "Each instrument plays a different role. (Slowing the slapping action between the fourth and the subsequent first beat) 3, 4, and, 1. If you share these moments [with other parts,] it goes well together." (b) Explaining a specific part of the piece, slapping on the knee relatively lightly: "This is a continuation of the previous [phrase], so let's not get heavy."

Materials

The analysed piece 'Etenraku' is classified as a small piece (*shōkyoku*), one of the three classes of *tōgaku* piece.[4] As a result of the unique transposition method called *watashimono*, the piece exists in *hyōjō* (on E), *ōshikichō* (on A), and *banshikichō* (on B). While based on the same core melody, these three versions are quite different in melodic terms, following types of melodic movement and embellishment favoured in each mode. The order in which each was made is uncertain; the relationship between *banshikichō* and *ōshikichō* can be interpreted with reference to the standard *watashimono* transcription way, yet the melody of *hyōjō* has plenty of peculiarities and the mutual relationships with *banshikichō* are not completely verifiable. The *banshikichō* (on B) version was selected for analysis based on my consultation with the musician.[5]

Figure 1 transcribes the *hichiriki* part and *shōga* syllables from the piece 'Etenraku' in *banshikichō* mode. The melodic structure of this piece can be labelled as consisting of three phrases, each of which includes eight four-beat cycles (interpreted as eight bars of 4/4 in the notation). The performance analysed arranges the phrases in the most simplistic style, ABCAB, which is one of several ways possible.[6] From the middle of Phrase B on its second hearing, the ensemble shifts to the coda phrase where only the principal player in each part performs, now playing in a sort of free rhythm. Phrase C is a transitional section that triggers a return to the previous phrases.

4 *Tōgaku* pieces are classified according to size: *taikyoku* (large pieces); *chūkyoku* (middle-sized pieces); and *shōkyoku* (small pieces).

5 One theory holds that the current *hyōjō* version is a transposition of the *banshikichō* version. In the opinion of the *hichiriki* player Miura Motonori (the musician interviewed later in this article), this transposition had to be heavily modified partly because of the narrow range of *hichiriki*, and as a result, the *hyōjō* version is almost a different piece from the other two. The *hyōjō* version is nonetheless the most familiar piece in *gagaku* partly because it has been chosen as music teaching material for listening exercises in junior high school.

6 In the more formal style, each phrase should be repeated twice, i.e. AABBCCAABB.

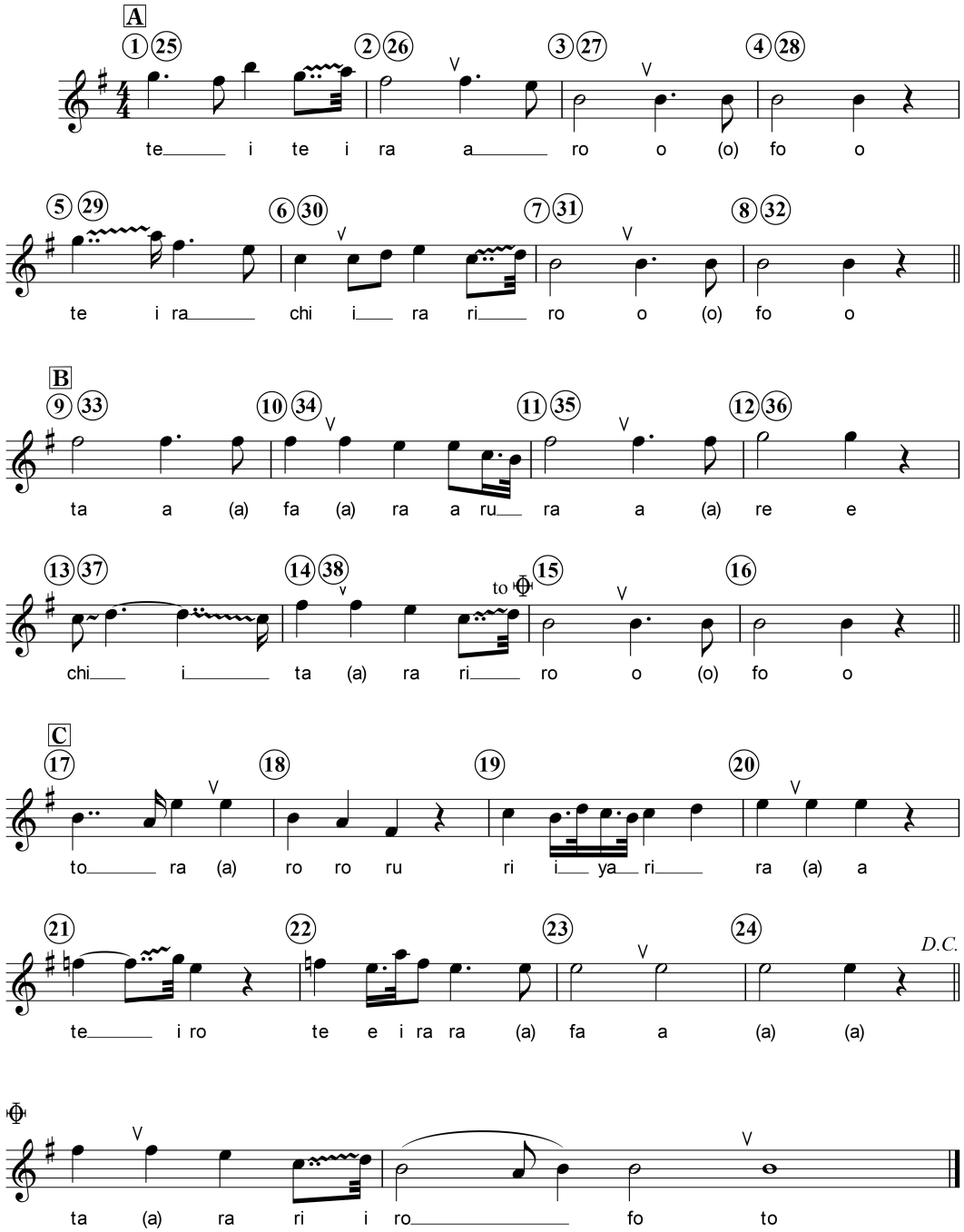

Figure 1. *Hichiriki* passages from the *tōgaku* piece 'Etenraku' in *banshikichō* mode, with *shōga* syllables below. The pitch notation is based on the instrument, while it is adjusted to the musician's range for the *shōga* syllables. Boxed symbols (A, B, C) indicate the beginnings of phrases. Circled numbers correspond to cycle numbers, which will be analysed below. Syllables in parentheses might be omitted depending on the musician.

The data for this analysis were drawn from performances by the *hichiriki* player Miura Motonori playing *banshikichō* 'Etenraku'.[7] He is active in domestic and overseas performances as a member of the professional ensembles Tokyo Gakuso and Pro Musica Nipponia, and he serves as a lecturer on *gagaku* at Tokyo University of the Arts. The recording took place at a small recording

studio in Tokyo during March 2020. Miura, in Western clothes, performed both *shōga* and instrumental performances characterised by an ABCAB form twice, with a total of four examples recorded.[8] These will be referred to by the abbreviations S1, S2, I1, and I2 below. A video excerpt 3.1 (click here) from S2 is published with the permission of the musician.

Figure 2A. *Hichiriki* player Miura Motonori performing *shōga.*

7 I follow the Japanese convention for writing names throughout this article, i.e. the family name comes first followed by the given name.

8 In my paper at the ESEM conference in September 2019, existing recordings including both *shōga* and instrumental performances for three wind instruments were utilised as a test case to compare the *shōga* and instrumental performances. While the approach was able to show the characteristics of bodily movements to some extent, the musician's traditional outfitted sleeves prevented accurate observation of the musician's hand – hence my decision to ask him to wear Western clothes for my videos.

Figure 2B. *Hichiriki* player Miura Motonori playing the instrument.

Methods

In the analysis, the temporal progression of *shōga* and instrumental performances were compared to data from S1, S2, I1, and I2. And by contrasting temporal data and knee-slapping movement data in S2 as an example, the role of this arm motion was considered empirically. The quantitative data were extracted as follows.

I. Manual annotation and calculation of the length of beat

Regarding the 38 cycles from all performances (S1, S2, I1, I2), the onset time (starting timing) of each beat was manually marked on the sound waveform using Sonic Visualiser (https://www.sonicvisualiser.org/). Based on the time value series exported as CSV files, numerical values for the length of each beat were obtained.

II. Detection of knee-slapping motion

To verify how the musician's hand was moving during the repetition of the four-beat cycle, two-dimensional keypoint detection from the S2 footage was carried out with OpenPose (https://github.com/CMU-Perceptual-Computing-Lab/openpose). Based on the 1.5.1 version of the library, the following OpenPose Demo commands were executed on the Powershell, resulting in the output of the eighteen coordinates on the body as a frame-by-frame JSON file.

bin\OpenPoseDemo.exe --video examples\media\video.mp4 --write_json .\output_keypoint

The multiple JSON files were converted to a single CSV file by using Python (https://www.python.org/), from which the right-wrist coordinates (x, y) were extracted. Based on this, the following two factors were estimated for each frame.

i. Distance from the starting position: how far the right-wrist coordinates in each frame were from the starting position (above the knee), estimated at a magnification of approximately 0.21 cm per pixel.

ii. Timescale:[9] the approximate number of seconds in the video recorded at 29.97 fps, estimated by multiplying the frame number by 0.03333667000333667. Each closest frame to the onset timing obtained by manual marking was labelled with the period and the ordinal number of beats so that the movement data could be contrasted with the rhythmic cycle breaks.

Result 1: Beat fluctuation and gradual acceleration

In the following graphs and tables, the temporal progression in *shōga* and instrumental performances are compared through relationships in the beat lengths in the four-beat cycle structure. Each numerical value for the beat length can be found in Appendix 1.

The box plots in Figure 3 visualise the differences in the length depending on the ordinal number of beats within a four-beat cycle. This clearly shows a longer fourth beat than the other beats in the four-beat cycle, which is consistent with the general description of *gagaku*. Comparing the time required for each beat in all performances, one can see that the first beat takes less time and the fourth beat takes noticeably more. Meanwhile, the second and third beats show values closer to the first beat on the whole in both *shōga* and instrumental performances. It is interesting to note that musicians and scholars have not paid much attention to the shortness of the first beat in contrast to the stretched fourth beat, despite the trend being found in all performances. This fact will be reiterated when considering the musician's awareness in a later section.

9 The reason for keeping the timescale to an approximation was because of the limited sampling rate that could be set by the recording device. Rather than forcing the rate down to obtain the exact correspondence with the timing that I manually annotated, I decided to prioritise capturing the trajectory of the movement in as much detail as possible in this first attempt. As there is a distinctly large gap between them, it is possible to capture the correspondence between onset timing and hitting movements even on an approximate timescale. However, this procedure should be improved in the next attempt since it is an important factor in utilising the frame-by-frame detection system.

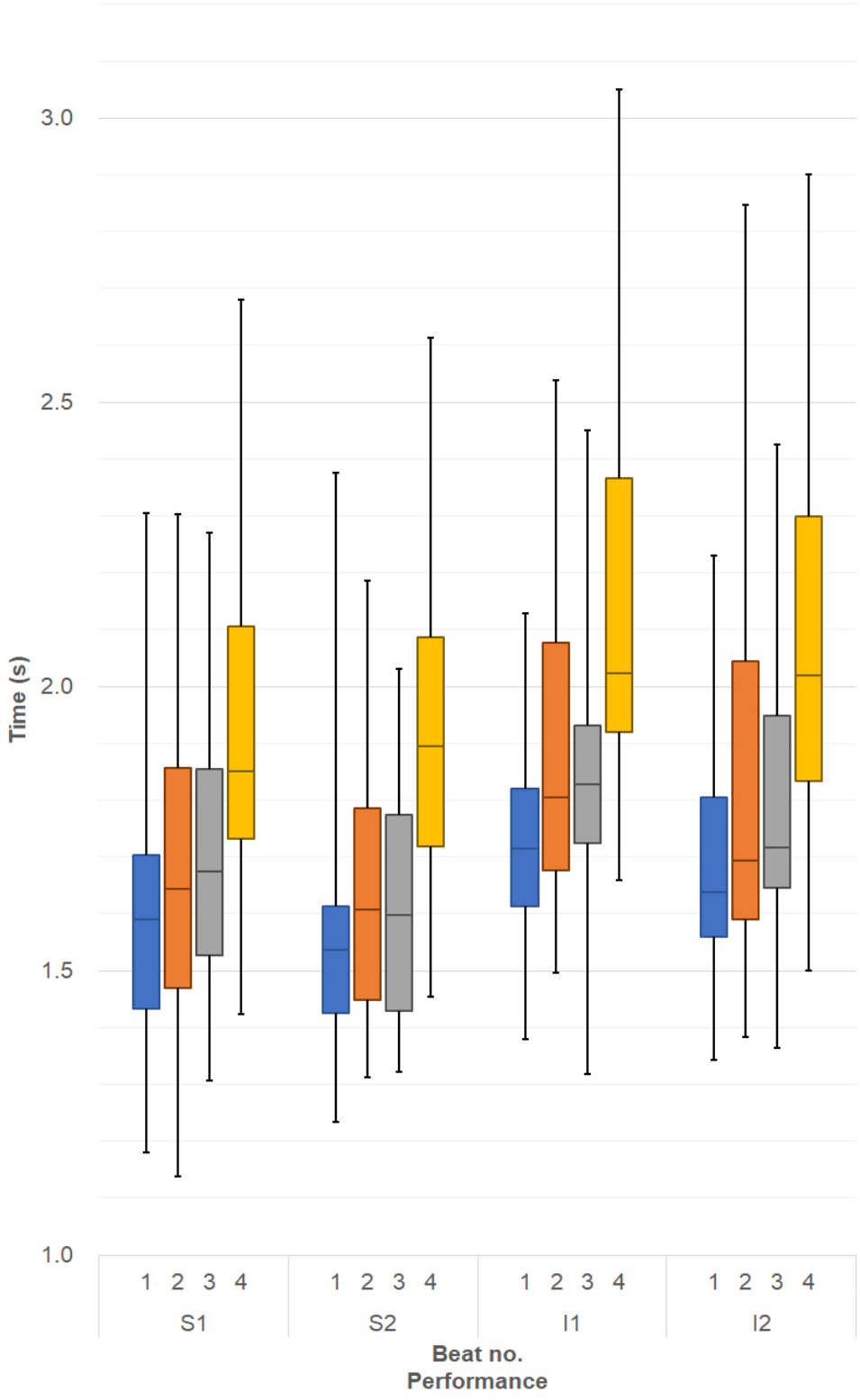

Figure 3. Required time for each beat in four-beat cycle: comparison among ordinal numbers and performances. In each column, the box represents the middle 50% (25–75%) of the score, the line dividing the box into two parts represents the median, and the upper and lower whiskers represent the minimum and maximum.

The width between the maximum and minimum values in Figure 3 indicates the fluctuation in the time required for each beat within a 38-cycle period, leading to the question of how this is realised along with the progression of time. Regarding this issue, the stacked column chart in Figure 4 provides an overview of the changes in beat duration through 38 four-beat cycles in the four examples. All four instances indicate a speeding up as the piece progresses, which is often cited as a reflection of the *jo-ha-kyū* concept. Each beat and each beat-accumulated cycle is not always shortened from the preceding one; for example, the extension often occurs at the cycles in multiples of four that include phrasal breaks (transcribed as quarter rests in Figure 1). Nonetheless, the time required per cycle is steadily reduced from the beginning to the end.

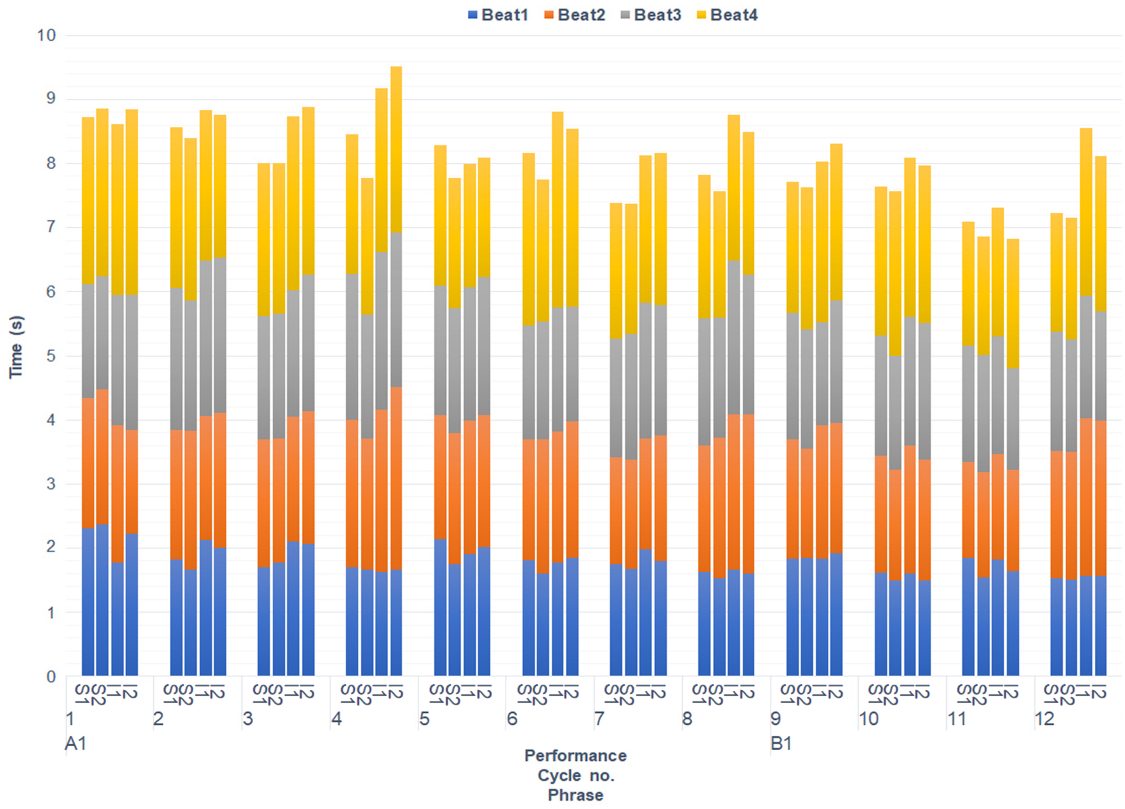

Figure 4. Temporal progression in 'Etenraku' performances. The changes in beat duration through the 38 four-beat cycles (ABCAB form) are shown in three parts: cycles 1-12 (top); cycles 13-25 (middle); and cycles 26-38 (bottom). In each part, the number of seconds for the four colour-coded beats (beat 1, beat 2, beat 3, beat 4) is accumulated on the vertical axis. On the horizontal axis, the corresponding performance code (S1, S2, I1, I2) (on the first line), cycle number (1-38) (on the second line), and the phrase code (A1, B1, C1, A2) (on the third line) are all shown.

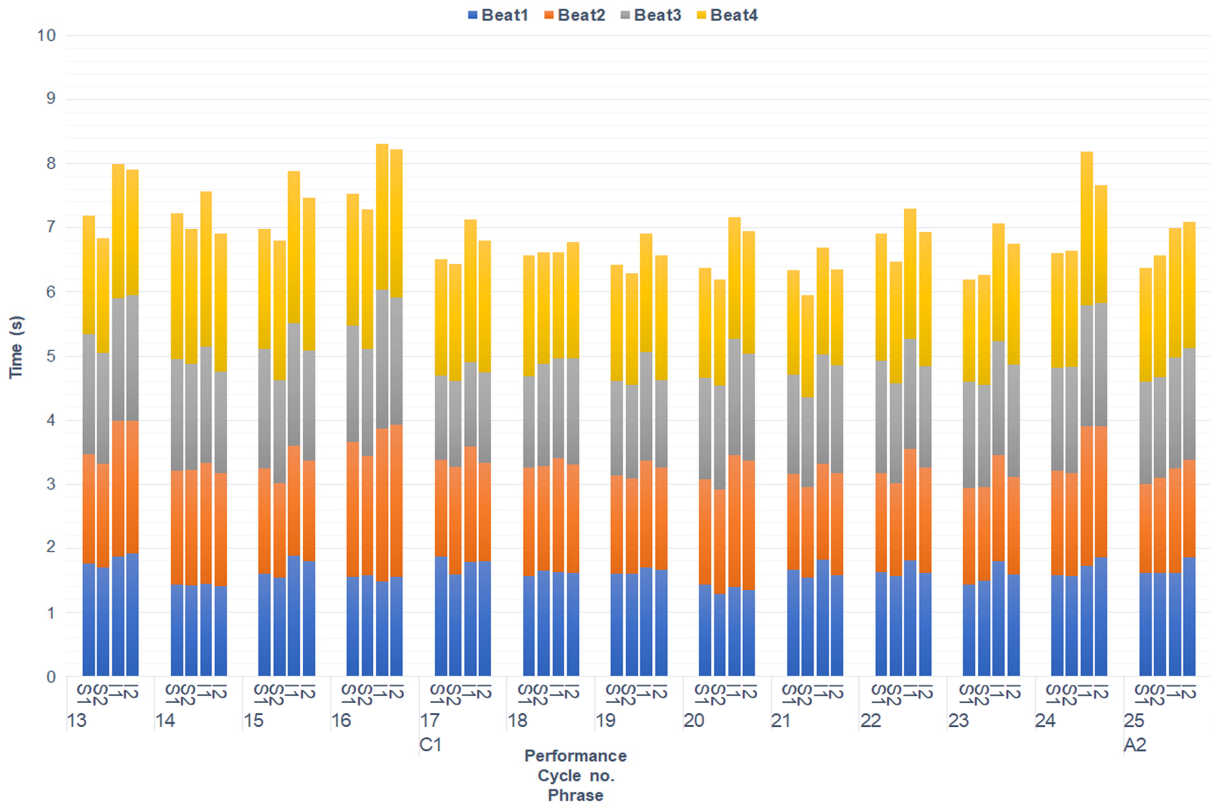

Figure 4. Continued.

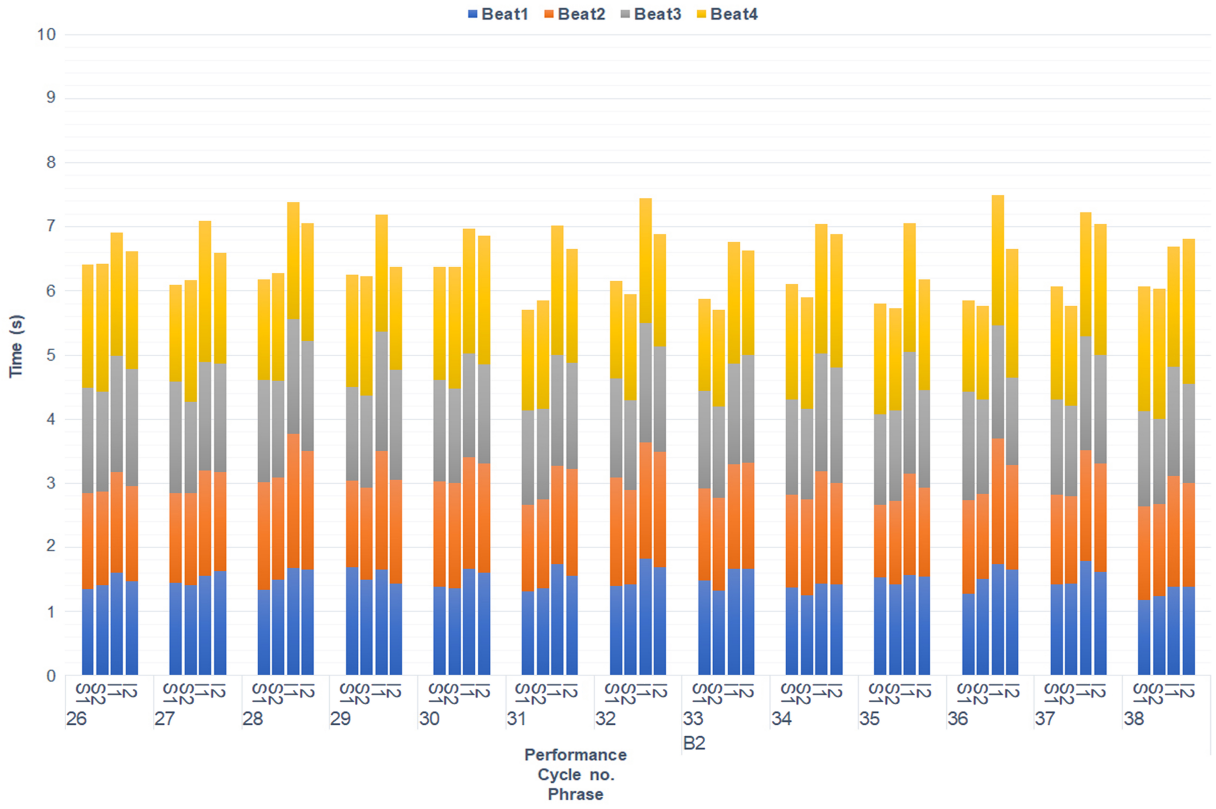

Figure 4. Continued.

Tables 1 and 2 illustrate more specifically the changes in duration occurring through the performance: the former is a comparison of the first and second appearances of the same melodic phrase, while the latter is a comparison of the transitions of the phrase, i.e., successive cycles that straddle the phrasal break. The values in Table 1 show that the length of each beat decreases considerably in the second occurrences of the phrases A and B in comparison with in the first occurrences. In particular, the significant reduction in the fourth beat in both A and B is noteworthy as a commonality between *shōga* and instrumental performances (24–32% decreases). In other words, the duration difference between the fourth beat and the others reduces as the performance progresses, and this can be seen as one of the major factors empowering the acceleration.

Comparing *shōga* and instrumental cases in each repeat, one finds that *shōga* performances take more seconds in A1 (especially on the first and second beats) but catch up with instrumental performances in A2. In Phrase B, there was not much difference between *shōga* and instrumental cases in the first round, but *shōga* performances became faster in the repeat. This could be interpreted as a more pronounced change in speed from the beginning to the end in *shōga* performances. Focusing on the four phrase transitions in Table 2, while not all of the beats in the subsequent cycle are necessarily shortened, the change in beat length that accompanies the B1-C1 transition is commonly noticeable in all performances. The shortening of the second and third beats between consecutive cycles B1-C1 (10–39% decreases) is a close match to the comparisons A1-A2 and B1-B2, 24 cycles apart. That is, when entering Phrase C, which triggers a return to the beginning phrase, there can be a steady acceleration – something in common across *shōga* and instrumental performances. The data above show beat fluctuation and gradual acceleration in both *shōga* and instrumental performances and prove that subtle rhythmic properties have already been internalised in solo *shōga* performance practices.

		Phrase A1 Cycle 1	Phrase A2 Cycle 25	A1-A2 % difference	Phrase B1 Cycle 9	Phrase B2 Cycle 33	B1-B2 % difference
S1	Beat1	2.305	1.618	-30%	1.833	1.484	-19%
	Beat2	2.044	1.392	-32%	1.867	1.433	-23%
	Beat3	1.774	1.585	-11%	1.972	1.521	-23%
	Beat4	2.597	1.785	-31%	2.045	1.437	-30%
S2	Beat1	2.377	1.614	-32%	1.851	1.328	-28%
	Beat2	2.100	1.488	-29%	1.704	1.440	-15%
	Beat3	1.767	1.576	-11%	1.861	1.427	-23%
	Beat4	2.613	1.896	-27%	2.213	1.516	-31%
I1	Beat1	1.773	1.620	-9%	1.835	1.668	-9%
	Beat2	2.144	1.626	-24%	2.085	1.632	-22%
	Beat3	2.032	1.734	-15%	1.605	1.566	-2%
	Beat4	2.661	2.017	-24%	2.507	1.902	-24%
I2	Beat1	2.230	1.860	-17%	1.919	1.660	-13%
	Beat2	1.609	1.516	-6%	2.036	1.660	-18%
	Beat3	2.109	1.752	-17%	1.916	1.684	-12%
	Beat4	2.901	1.969	-32%	2.437	1.628	-33%

Table 1. Duration changes in seconds of the four-beat cycle comparing repetitions of phrases (A1-A2, B1-B2). For the beginning of the A and B phrases performed twice, each duration of the beat is extracted from the four examples and percentage differences between them are calculated. Percentage differences are rounded to integers.

		Phrase A1 Cycle 8	Phrase B1 Cycle 9	A1-B1 % difference	Phrase B1 Cycle 16	Phrase C1 Cycle 17	B1-C1 % difference	Phrase C1 Cycle 24	Phrase A2 Cycle 25	C1-A2 % difference	Phrase A2 Cycle 32	Phrase B2 Cycle 33	A2-B2 % difference
S1	Beat1	1.633	1.833	12%	1.560	1.869	20%	1.577	1.618	3%	1.395	1.484	6%
	Beat2	1.970	1.867	-5%	2.107	1.517	-28%	1.638	1.392	-15%	1.700	1.433	-16%
	Beat3	1.983	1.972	-1%	1.809	1.307	-28%	1.604	1.585	-1%	1.543	1.521	-1%
	Beat4	2.240	2.045	-9%	2.051	1.815	-11%	1.788	1.785	0%	1.521	1.437	-6%
S2	Beat1	1.533	1.851	21%	1.575	1.589	1%	1.574	1.614	3%	1.427	1.328	-7%
	Beat2	2.187	1.704	-22%	1.864	1.683	-10%	1.600	1.488	-7%	1.469	1.440	-2%
	Beat3	1.872	1.861	-1%	1.668	1.333	-20%	1.654	1.576	-5%	1.404	1.427	2%
	Beat4	1.977	2.213	12%	2.180	1.837	-16%	1.814	1.896	5%	1.644	1.516	-8%
I1	Beat1	1.664	1.835	10%	1.482	1.793	21%	1.723	1.620	-6%	1.824	1.668	-9%
	Beat2	2.421	2.085	-14%	2.389	1.797	-25%	2.182	1.626	-25%	1.812	1.632	-10%
	Beat3	2.395	1.605	-33%	2.165	1.317	-39%	1.889	1.734	-8%	1.860	1.566	-16%
	Beat4	2.283	2.507	10%	2.273	2.224	-2%	2.401	2.017	-16%	1.950	1.902	-2%
I2	Beat1	1.600	1.919	20%	1.552	1.804	16%	1.856	1.860	0%	1.694	1.660	-2%
	Beat2	2.485	2.036	-18%	2.372	1.528	-36%	2.048	1.516	-26%	1.797	1.660	-8%
	Beat3	2.186	1.916	-12%	1.990	1.416	-29%	1.928	1.752	-9%	1.646	1.684	2%
	Beat4	2.219	2.437	10%	2.310	2.052	-11%	1.832	1.969	7%	1.745	1.628	-7%

Table 2. Duration changes in seconds of the four-beat cycle during the transition of phrases (A1-B1, B1-C1, C1-A2, A2-B2). For the four phrase transitions, the duration of the preceding ending cycle and that of the subsequent beginning cycle are extracted and percentage differences between them are calculated. Percentage differences are rounded to integers.

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Result 2: Distinction of beats observed in the knee-slapping movements

Figures 5A–5C contrast the extent to which the musician's arm moves in the knee-slapping motion, based on the coordinate positions of the right wrist detected in the video image. Figures 5A and 5B focus on excerpts from the first half of Phrase A, which appears twice, and Figure 5C includes the transition from the last cycle of Phrase B1 to the first cycle of Phrase C1. Details of how musicians' bodies specifically perform *shōga* can be referenced in the video footage. Appendix 2 lists the values of the frames estimated as the starting point of the knee strike and the vertex farthest from the knee in the range taken up in the figures.

As already mentioned, two locations of the knee are slapped during *shōga* performance in *gagaku*: the upper side on the first and second beats, and the right side on the third and fourth beats. Focusing on the coordinates of the starting point, the value difference between these two positions is consistently detected throughout the performance. Specifically, the latter coordinates are located about 4–5 cm lower to the right in a straight line from the former ones. However, much more differentiated than the arrival position of the beats is the course of movement between the beat-hits. In the process of reaching the odd-numbered beats, large up-down movements are seen with positional changes of the hand in relation to the knee – from the right side to the upper part for the first beat, and from the upper part to the right side for the third beat. In the video example, one can see that the performer stretches out his arm laterally between the second and third beat-hits (average distance of the starting point/apex is approx. 21.5 cm) and raises his right hand high between the fourth and first beat-hits (average distance of the starting point/apex is approx. 34.7 cm). It is hard to imagine that this largest amount of movement is irrelevant to the significance of the fourth beat length of the music. Conversely, a fairly small trajectory is drawn on a course that reaches the even-numbered beats without changing the hitting position. Another feature of this course is the fact that the apex of the parabola is closer to the subsequent strike than it is in the case when reaching the odd-numbered beats. This means that the musician keeps his hand close to the knee for a little while, rather than immediately raising the hand as in the preceding motion.

Of particular interest is that the distinction between the beats of each cycle is consistently maintained for the knee-slapping movement and does not appear to change as the piece progresses. To put it another way, the degree of arm extension does not decrease conspicuously as the performance gradually becomes more accelerated. This is demonstrated explicitly when contrasting Figures 5A and 5B – while the required seconds for one cycle become shortened in its second appearance, the characteristics of the trajectory are preserved depending on the distinction of beat-hits within each cycle. This also applies to the phrase transition of B1–C1 between cycles 16 and 17 (Figure 5C), the part where the shortening of the beat is relatively noticeable: a -20% difference on Beat 3 and a -16% difference on Beat 4 (Table 2). These results reveal that this knee-slapping execution, in which the speed is increased while maintaining the beat differentiation, is not merely a byproduct of the singing act but is a part of the expressive act. Little has been mentioned about it before except regarding differences in the place the knee is slapped, yet the hitting process in-between the beats appears to be differentiated quite systematically, if not always consciously; therefore, the trajectory between the beat-hits provides a considerable amount of information. It is an interesting possibility that the bodily movement represents the elasticity of the rhythm, including even in moments of silence, which cannot appear in the singing.

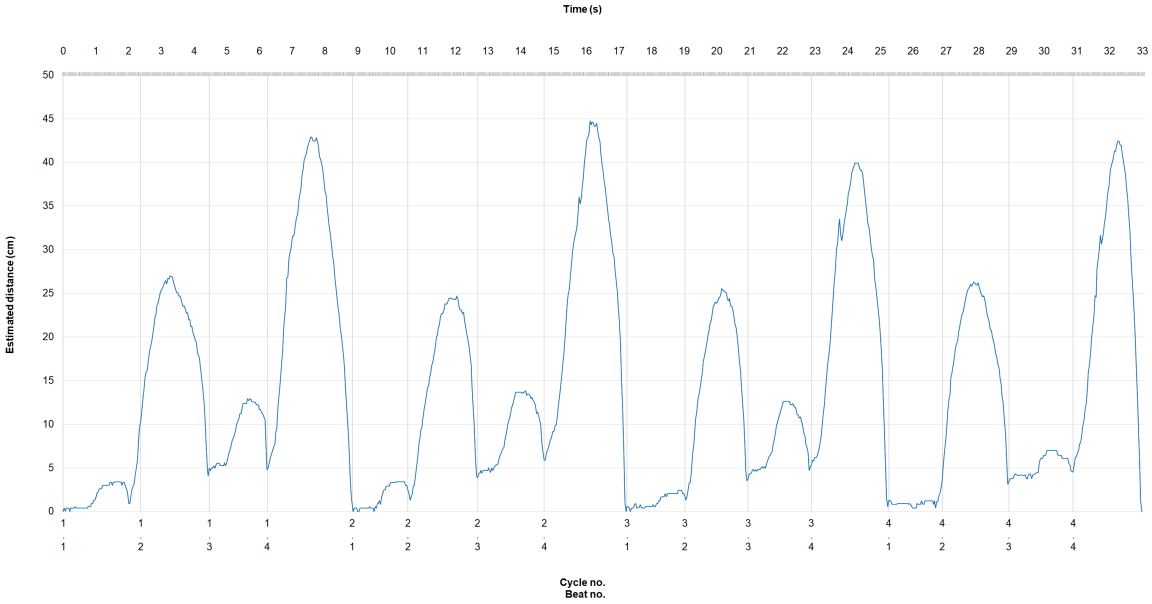

Figure 5A. Estimated distance of the right-wrist coordinates (1) – cycles 1–4 from Phrase A1.

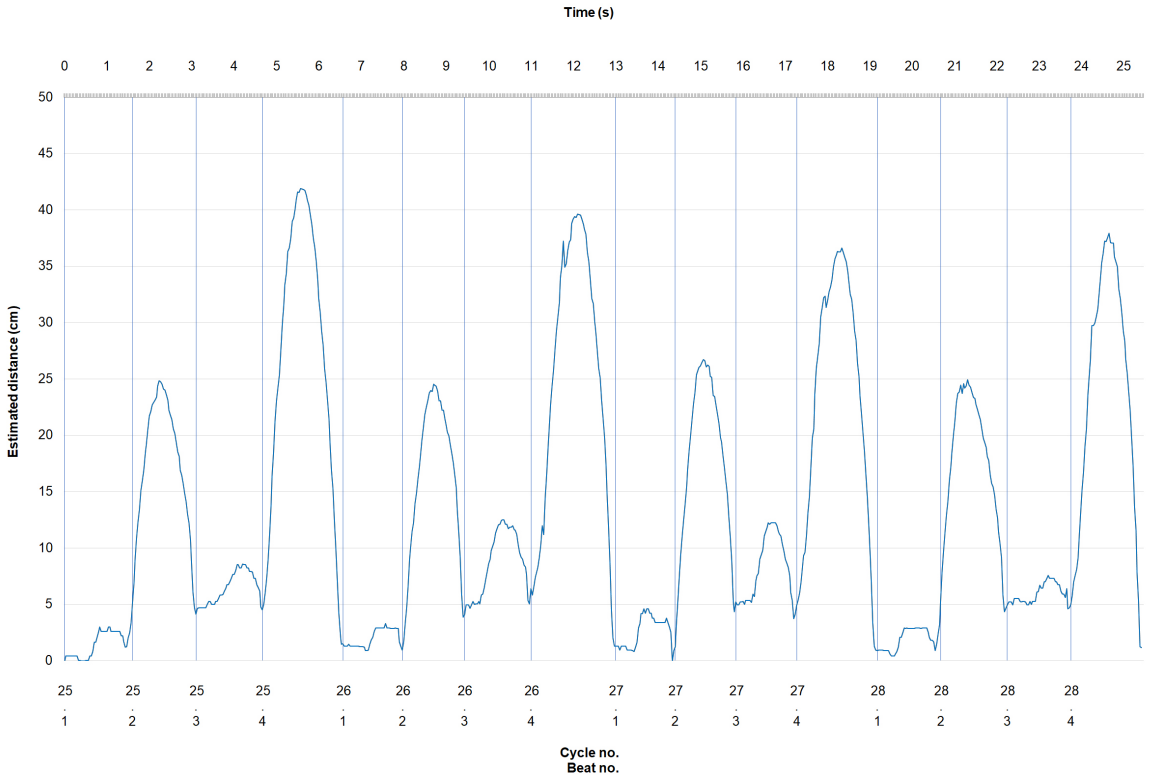

Figure 5B. Estimated distance of the right-wrist coordinates (2) – cycles 25–28 from Phrase A2.

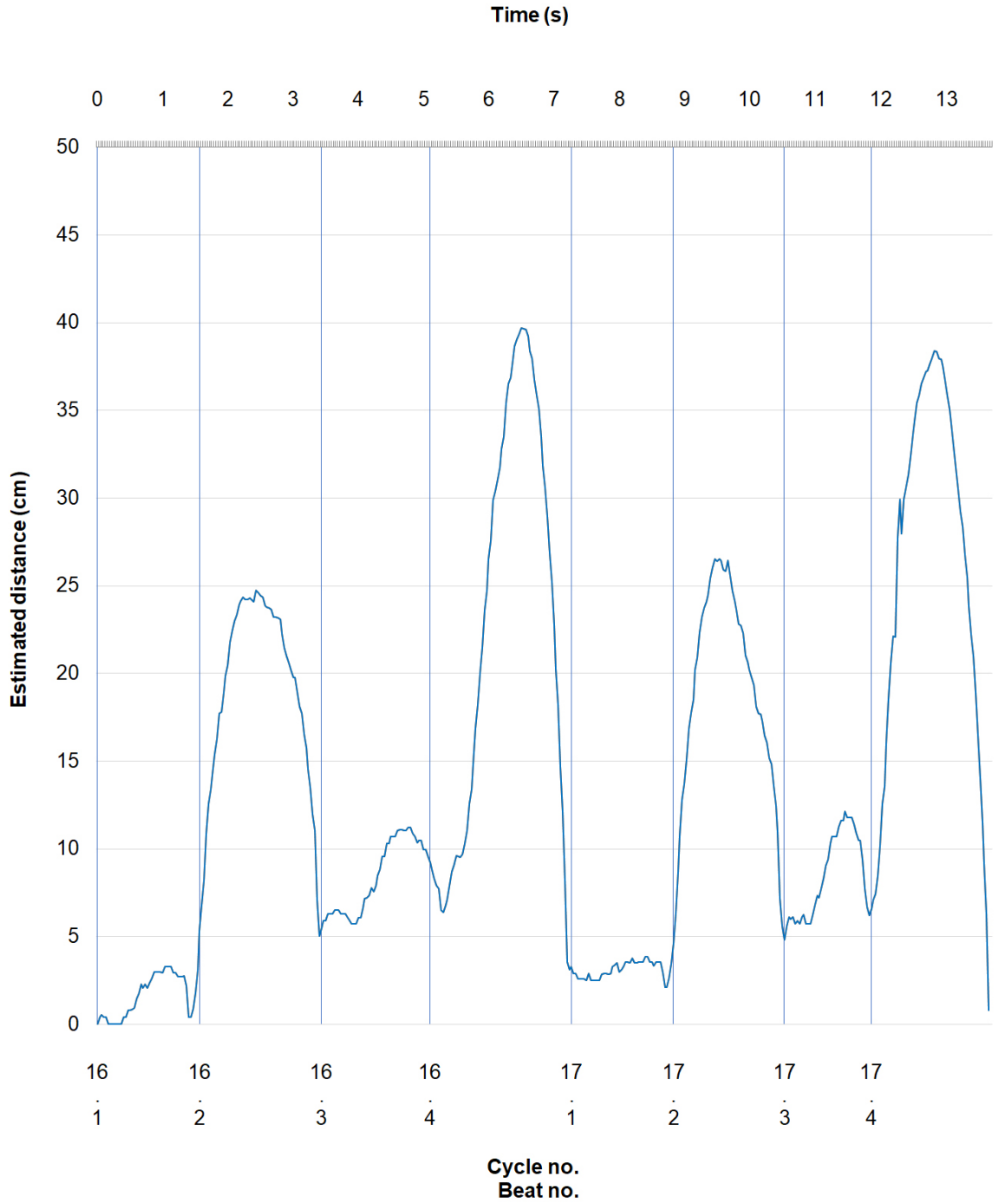

Figure 5C. Estimated distance of the right-wrist coordinates (3) – cycles 16–17 from Phrases B1–C1. The estimated distance between the first position of the video image (above the knee) and each coordinate is shown. Vertical lines dividing the graph area are beat-point guides imported from the manual detection utilising Sonic Visualiser.

The sound and movement analyses show a close relationship between *shōga* performance and the stylistic features in this genre; however, these results alone cannot be used to conclude whether the *shōga* as bodily experience reflects the musicians' awareness and has an impact on their learning process. The next section will explore the musician's subjective awareness of the *shōga* experience, based on his own statements.

How the Musician Experiences *Shōga*

The interview with Miura Motonori, the performer recorded above, was conducted in the form of a semi-structured conversation immediately after the recording – in other words, before the detailed numerical values of the data were calculated. Two themes, in particular, occupied these interviews with Miura about *shōga*. The first was how he finds value in *shōga* through his experience. The second involved his awareness while performing *shōga* in 'Etenraku', a topic which could be related to the data just discussed in the analysis section. All quotations below were translated from Japanese to English.

Shōga as "the basis of all"

Miura took his first lesson when he was around ten years old and, similar to many musicians, it began with a *shōga*-imitating experience. It was not surprising that he had to repeat his teacher's *shōga* with almost no theoretical explanation of where the musical elements, such as the segmenting of phrases or the number of beats, corresponded. The *shōga* of *hichiriki*, an example of mnemonic singing that primarily represents relative pitch, was described as "lyric-less song [*kashi no nai uta*]" or "the way of singing like onomatopoeic words [*gion-go mitaina utaikata*]" in the interview. Looking back on his personal experience, this *hichiriki* player explained how it took time from beginning the practice to arriving at an essential understanding:

> When I was little, first of all, it was imitation [of what the teacher was doing] … The imitation [at that time] was quite basic … such things as being able to sing, or having skills, or sustaining breath for a long time … Gradually as you come to understand these things it slowly becomes more and more fun over time … Even up until middle school, possibly into high school, I couldn't grasp the concepts of a semitone or an even smaller [flatter] semitone interval or complex intonation [*fushimawashi*] … It wasn't until later that nuance of this music practice became clear to me. When I was in the third year of high school, I felt that I was more able to do these musical expressions more naturally. I'm not sure, but somehow I seemed to be able to do it more naturally.

This remark indicates an example of the process by which learners acquire *shōga* as a basis of expression through their training over many years. From the very beginning, *shōga* is presented directly as sounds that include a subtle sense of musical expressions such as breathing and intonation, rather than as an organised form of partial elements such as beats and pitches. With a few years of straightforward imitation without knowing the melodic and rhythmic elements, the basic skills to sing it are put in place. He also recalled *shōga* in his childhood as an "obedient and rough" practice.[10] According to the remark, it was about the third year of high school (around eighteen years old) when he came to understand *shōga* at the level of the delicate pitches and intonation that should be realised. This shows that he deepened his understanding of all that *shōga* holds over the course of eight years. It can be considered a process by which it takes some years to arrive at the song showing all of the details demonstrated by the teacher. In other words, largely based on the orality of the *shōga* practice, stylistic memory and performance skills that make full use of a performer's body are gradually acquired. The ambiguous description of "doing something naturally" is also explained as "to recognise and materialise 'the song'" in another context of free dialogue.[11]

10 From the interview on 17 March 2020: "Looking back, I have the impression that *shōga* by children is a more obedient but also rougher practice than [that by] adults."

11 From the interview on 17 March 2020: "It took me quite some time to recognise and materialise 'the song' in such a [musical] style."

The comments above reveal that *shōga* plays a significant role for *gagaku* musicians as a means of learning prior to instrumental performance; however, it does not mean that the role of *shōga* is limited to mere preparation. In the following explanation, *shōga* in the context of *gagaku* is described as "all" and emphasised as a foundation that should often be revisited even after one becomes a professional musician:

> [There is] everything in *shōga* … especially in the case of *hichiriki*, it is possible to say everything through the *shōga* because the *shōga* is directly transferred into the sound [of the instrument]. [The important thing is] how much [the musician] can sing with *shōga*, and also, how much [the musician] can replicate the musical expressions found within *shōga* when performing on the instruments. Always, even now … for example, when I am unsure of the sound [expression] … I go back and sing the *shōga*. When learning a new piece, I always memorise it through the *shōga*. If I just keep doing that, I will for sure [never make a mistake] … If I remember the *shōga*, I will make almost no mistakes during my performance on the instrument. In this way, the importance of *shōga* is at the basis [of each performance] … [we] have it as the basis, [we] have *shōga*.

This remark about it being the "basis" (*kihon*) to which even professional musicians should often return indicates a clear consciousness of *shōga* being an essence that should always be maintained in the genre. The degree of this emphasis might be strengthened by the characteristics of *hichiriki*, whose melodies can be directly copied into *shōga*, and Miura carefully limits the scope of his comment. The largest difference between *shōga* and instrumental performance is found in *shō* mouth organ parts, since their harmonies cannot be sung by a voice. The *ryūteki* transverse flute plays monophonic melodies similar to *hichiriki*, yet its sound range encompasses a high tone that is difficult to imitate with the human voice, so the difference between *shōga* and instrumental performance is inevitably larger than that for the *hichiriki*. The similarity between *shōga* and instrument melodies gives him the impression that "*how* the musicians imagine *shōga*" is reflected considerably, especially in *hichiriki* playing.[12]

Another notable point in the context of "having *shōga*" is that the musician also refers to the praxis of hand copying a sample of written *shōga*, as ordered by his teacher, from the beginning of taking lessons.

> My teacher often told me the importance of hand copying or memorising the *shōga* by myself. At that time, I was just doing what I was told, but that experience has now proven very useful.

This example highlights the experience of hand copying the written *shōga*, perhaps something more likely to be missed off the list of *shōga* praxis than memorisation via imitation of performing. The juxtaposition of the two approaches, memorising and hand copying, indicates that he recognises *shōga* praxis to be a whole experience that is more complex than the oral/literate distinction.

"Beat it into my body"

In the course of the interview, I asked the musician directly about his consciousness during the *shōga* performance I had just recorded. His responses indicate how the musician intentionally differentiates each beat as a basis of rhythmic expression and how it relates to performing movements.

12 From the interview on 17 March 2020: "Especially *hichiriki* [playing] is greatly based on the musician's image of *shōga*, so if there are some mistakes in the *shōga*, like on pitch and various other things, it will be reflected in the performance of the instrument. Therefore, [the player] cannot correct the mistake unless they return to the *shōga*. Of course, there are mistakes caused by instrumental techniques such as the position of fingers or mouth, but if the issue lies in something different like the image or impression of the music, [the musician] should return to the *shōga* [for correction]."

He accompanied his words with hand movements while referring to the four-beat cycle in 'Etenraku':

> Basically, it is important to emphasise the first and third beats [hits] and grasp them firmly. [This is] where you need to firmly match the other instruments and strike a balance. The second and fourth beats have auxiliary roles, so I hit them lightly. The first and third are strong beats; the second and fourth … the even-numbered beats are weak beats. Somehow, I have the image that [odd-numbered beats] have some sort of weight or decisive feeling. This existence of "*ma-ai*" [the proper timing and distance] results in four beats with considerable fluctuation, rather than an equal four beats … Since there is a "*ma-ai*," the amount of time one needs to wait from the fourth to the first beat, especially when the *taiko* drum joins, should be long. Even after speeding up, a relatively slow, long "*ma-ai*" occurs [within the four-beat cycle], I suppose …

This depiction illustrates how to achieve a unique *"ma-ai"* by emphasising specific beats in the cycle. This is a compound word composed of the aesthetic term *ma* (literally interval or space) and *ai* (matching).[13] While the significant length of the fourth beat is often stated and appears to be emphasised in the analytical data, the beat itself is considered to play a supplementary role here, being "weak" and "light." No contradiction exists if we realise that the ordinal numbers mentioned in the remark reflect the musician's consciousness of hitting movements. The very moment of hitting is considered the endpoint rather than the starting point; therefore, what he refers to as the "first beat" in the description is related to the sequence but actually counted as the fourth beat in the data. To realise the first beat-hit with heavy resistance, the player's right hand should slowly draw a large trajectory, and this is counted as the fourth beat. In other words, the considerable length of the fourth beat is due to the emphasis on the first beat-hit as a "heavy" adjusting point within the cycle.

Miura continued that the suppression of speed is gradually removed as the four-beat cycle repeats during the course of the performance:

> Rather than suddenly becoming faster as if gearing up to go somewhere, one should keep pace [with other instruments], and then [the speed of the music] naturally increases. At first, it's fairly restrained … we hit our knees heavily, the beat is heavily suppressed as we count it carefully … From there, the faster the beat gets, the more comfortable we may feel with it.

This example indicates the possibility of examining *jo-ha-kyū* from an empirical perspective. His consciousness of removing the "weight" through the repetition of the four-beat cycle is associated with the gradual increase in speed as the piece progresses. Interestingly, much attention in the performing process seems to be paid to retaining the balance of beats within each cycle, rather than the speeding up itself, which is described as "comfortable." In other words, while removing the overall "weight," the internal balance between the "weight" of odd-numbered hits and "light" even-numbered hits should be maintained. Miura cites two Japanese verbs to describe undesired states of rhythm: *korobu* (fall forward) and *nobiru* (stretch out). The former refers to cases where the odd-numbered hits arrive too early, resulting in insufficient durations of even-numbered beats (the second and fourth ones in the four-beat cycle). The latter refers to cases where even-numbered hits arrive too late, resulting in excessive durations of odd-numbered beats (the first and third ones).

13 In the context of music, *ma* (lit. space or interval) can refer to various meanings related to temporal/rhythmical/interrelational matters, while none of these completely correspond. Some studies have outlined its multiple usages related to musical expressions (Pilgrim 1986; Tokita and Hughes 2008: 26–7). A recent case study provides usage examples of *ma* from musicians in a specific genre, *rōkyoku* (Kitagawa 2010). This problematic term should be examined in detail, along with *jo-ha-kyū*; however, I will save my opinions on the matter for another occasion.

The remark above suggests that the right-hand movement in *shōga* embodies and strengthens rhythmic expression over a wide range of aspects. Intriguingly, in the latter half of the interview referring to the whole act of *shōga* performance, he contrasts "beating" actions with the flow of singing:

> In creating a "*ma-ai*" or something like that … I am not sure what to say, but … tapping out the beat helps our body understand the music … or at least that is the image I have. I have the sense that I beat it into my body. Even if you can sing the melody with certainty, if you hit your knee lightly, you will not gain the sense of "weight." You have to hit it firmly … while adding resistance to the right-hand's downward movement, striking the first or third beat with weight. This sense of resistance is very similar to how to play instruments. In the case of drums, you need to play with resistance. It's the same for *taiko* and *shōko* … and the same is true for *biwa*; they are played in one movement with some resistance … Striking the beat is an important part of sharing an ensemble with others, but if only the beats are emphasised, one might say the music will be stiff … the sense of weight is important, but that alone is not what makes it musically interesting. After all, there is the melody. There is also the flow. While having a good sense of beats or "*ma-ai*," at the same time, it is also essential to independently sing as the *hichiriki*, a *ryūteki*, and a *shō* … as a wind instrument.

Here, the consciousness associated with striking the beat is regarded as what is to be shared in the ensemble. Despite the author not yet having been told the theme of this journal issue, he also reworded this as "bodily understanding" in the interview and explained that sharing this understanding with all ensemble members is the key to connecting the feeling of each beat to a large progression in speed. It is felt to be linked with not only the realisation of beats but also the playing methods for the percussion and string instruments. The right-hand movement of hitting the knee plays a major role in driving this understanding into each player's body. It is symbolic that his depiction of "beat into" could be literally translated from the Japanese *uchikomu* – a compound verb of *utsu* (beat or hit) and *komu* (put in) – which holds multiple meanings, such as "devote all energy to" and "practice over time."

Concluding Remarks

I began this article with two sections laying out how *shōga* and *gagaku* have been described in the research literature. *Shōga* practices amongst Japanese music genres are increasingly finding interest from the fields of musicology and music education, but research from the perspective of empirical science has not been sufficient. The subsequent analysis and interview sections, forming the central contribution of this article, explored how *shōga* practice embodies the rhythmic expression that should be realised in instrumental performance. The comparison between *shōga* and instrumental performances demonstrates that gradual speed changes in *shōga* are closely linked to those in the instrumental performance. The knee-slapping movement which accompanies the singing is often described as subordinate beat counting, yet it can be understood as a more subjective act which results in a synergistic effect with the voice expression – that is, as an action that strengthens beat differentiation in the rhythmic cycle and supports the acquisition of the beat fluctuations that are valued in this genre.

Also mentioned by the musician in interview is that *shōga* enables the learning of both the independent expressions of each instrument and a consciousness towards the shared beat within the ensemble. The fact that Miura's remarks on *shōga* frequently include aesthetic terms such as *jo-ha-kyū* and *ma-ai* suggests that the exploration of *shōga* praxis can also be a great help to deepening our understanding of those concepts.

Although both written and performed aspects of *shōga* have not yet been sufficiently examined, it has been suggested in this article that oral mnemonics, as performance, already internalise dynamic musical flow and correlations with other parts. It is impossible to master the sense of the rhythm only with written mnemonics. However, it should be noted that the two are not necessarily distinct in the consciousness of musicians, as symbolised by the fact that this interviewee emphasised the experience of hand copying written *shōga*. Interview results also suggest that it is not until the learner continues to experience instrumental playing in solo and ensemble occasions that the individual realises the essence contained in the *shōga*.

While *shōga* has been treated as one of the major characteristics of Japanese traditional music, rhythmic expression has been almost entirely absent from written mnemonics and less attention has been paid to it in previous studies than for pitch representations. However, by examining *shōga* embodiment in the case of solo *gagaku* performance, this article reveals the rich possibilities of examining *shōga*, enabling deep consideration of rhythmic aspects that might have been overlooked or underappreciated. There are still many issues to be addressed, such as melodic expression in the "singing song" (the literal meaning of *shōga*), comparisons among instruments in the ensemble, and detailed observation of the learning process. Further longitudinal studies, taking into account other genres of Japanese music such as *noh* and *kabuki*, are also required. I argue that accumulating multi-angled knowledge of *shōga* is an effective means that can provide insight into the essence of rhythmic expression in traditional Japanese music genres and provide a new basis for analysis to capture the tradition.

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Appendix 1. Beat lengths in performances S1, S2, I1, I2.

		Duration(s)															
		S1				S2				I1				I2			
Phrase	Cycle	Beat 1	Beat 2	Beat 3	Beat 4	Beat 1	Beat 2	Beat 3	Beat 4	Beat 1	Beat 2	Beat 3	Beat 4	Beat 1	Beat 2	Beat 3	Beat 4
A1	1	2.305	2.044	1.774	2.597	2.377	2.100	1.767	2.020	1.773	2.144	2.032	2.661	2.230	1.609	2.109	2.901
	2	1.830	2.010	2.223	2.500	1.671	2.160	2.031	2.064	2.128	1.936	2.416	2.357	2.007	2.100	2.425	2.229
	3	1.705	1.991	1.925	2.389	1.781	1.927	1.950	1.981	2.107	1.947	1.968	2.720	2.064	2.075	2.123	2.626
	4	1.700	2.303	2.270	2.180	1.662	2.046	1.938	1.926	1.627	2.539	2.451	2.557	1.667	2.847	2.414	2.593
	5	2.138	1.939	2.023	2.190	1.755	2.040	1.945	1.904	1.909	2.085	2.075	1.920	2.019	2.061	2.149	1.861
	6	1.807	1.893	1.780	2.680	1.609	2.092	1.834	1.954	1.776	2.048	1.936	3.051	1.843	2.133	1.789	2.781
	7	1.750	1.670	1.847	2.123	1.683	1.695	1.966	1.865	1.984	1.728	2.117	2.304	1.805	1.960	2.024	2.373
	8	1.633	1.970	1.983	2.240	1.533	2.187	1.872	1.976	1.664	2.421	2.395	2.283	1.600	2.485	2.186	2.219
B1	9	1.833	1.867	1.972	2.045	1.851	1.704	1.861	1.813	1.835	2.085	1.605	2.507	1.919	2.036	1.916	2.437
	10	1.620	1.827	1.870	2.330	1.500	1.728	1.777	2.563	1.611	1.989	2.004	2.487	1.491	1.892	2.132	2.457
	11	1.847	1.497	1.813	1.943	1.540	1.652	1.816	1.857	1.829	1.632	1.840	2.011	1.647	1.572	1.588	2.025
	12	1.527	1.990	1.856	1.854	1.511	1.991	1.754	1.900	1.563	2.464	1.915	2.608	1.575	2.420	1.697	2.423
	13	1.758	1.705	1.880	1.847	1.703	1.615	1.731	1.789	1.872	2.117	1.915	2.091	1.924	2.072	1.956	1.960
	14	1.440	1.767	1.740	2.283	1.425	1.805	1.652	2.105	1.451	1.877	1.819	2.421	1.408	1.764	1.584	2.156
	15	1.603	1.640	1.863	1.884	1.546	1.469	1.609	2.178	1.888	1.712	1.914	2.369	1.800	1.568	1.716	2.388
	16	1.560	2.107	1.809	2.051	1.575	1.864	1.668	2.180	1.482	2.389	2.165	2.273	1.552	2.372	1.990	2.310
C1	17	1.869	1.517	1.307	1.815	1.589	1.683	1.333	1.837	1.793	1.797	1.317	2.224	1.804	1.528	1.416	2.052
	18	1.566	1.689	1.433	1.881	1.651	1.637	1.595	1.739	1.632	1.771	1.557	1.659	1.612	1.700	1.648	1.816
	19	1.610	1.531	1.475	1.815	1.611	1.480	1.464	1.736	1.707	1.664	1.691	1.845	1.668	1.587	1.373	1.940

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		Duration(s)															
	20	1.433	1.647	1.585	1.714	1.293	1.629	1.618	1.651	1.399	2.052	1.819	1.893	1.344	2.032	1.664	1.904
	21	1.661	1.498	1.552	1.626	1.541	1.416	1.400	1.594	1.826	1.497	1.707	1.668	1.576	1.596	1.683	1.501
	22	1.629	1.545	1.754	1.989	1.566	1.446	1.566	1.896	1.813	1.739	1.722	2.028	1.613	1.647	1.580	2.100
	23	1.437	1.512	1.651	1.597	1.496	1.458	1.600	1.712	1.797	1.653	1.784	1.841	1.588	1.524	1.754	1.890
	24	1.577	1.638	1.604	1.788	1.574	1.600	1.654	1.814	1.723	2.182	1.889	2.401	1.856	2.048	1.928	1.832
A2	25	1.618	1.392	1.585	1.785	1.614	1.488	1.576	1.896	1.620	1.626	1.734	2.017	1.860	1.516	1.752	1.969
	26	1.349	1.503	1.643	1.918	1.408	1.468	1.551	1.997	1.607	1.566	1.818	1.920	1.475	1.484	1.828	1.832
	27	1.451	1.395	1.740	1.513	1.408	1.440	1.428	1.896	1.560	1.644	1.684	2.204	1.631	1.545	1.688	1.736
	28	1.333	1.682	1.596	1.573	1.500	1.592	1.510	1.682	1.675	2.099	1.782	1.836	1.649	1.855	1.721	1.835
	29	1.694	1.353	1.457	1.749	1.492	1.444	1.430	1.858	1.650	1.848	1.873	1.817	1.440	1.616	1.716	1.600
	30	1.381	1.647	1.578	1.773	1.367	1.637	1.476	1.896	1.662	1.746	1.620	1.944	1.610	1.693	1.549	2.012
	31	1.311	1.349	1.479	1.573	1.364	1.388	1.412	1.688	1.743	1.527	1.736	2.015	1.555	1.673	1.652	1.779
	32	1.395	1.700	1.543	1.521	1.427	1.469	1.404	1.644	1.824	1.812	1.860	1.950	1.694	1.797	1.646	1.745
B2	33	1.484	1.433	1.521	1.437	1.328	1.440	1.427	1.516	1.668	1.632	1.566	1.902	1.660	1.660	1.684	1.628
	34	1.377	1.451	1.475	1.809	1.255	1.488	1.419	1.743	1.440	1.752	1.836	2.016	1.420	1.588	1.796	2.080
	35	1.528	1.139	1.405	1.727	1.417	1.312	1.408	1.598	1.572	1.578	1.896	2.010	1.545	1.383	1.520	1.732
	36	1.274	1.461	1.699	1.423	1.502	1.335	1.473	1.455	1.734	1.968	1.758	2.040	1.654	1.630	1.364	2.008
	37	1.428	1.389	1.491	1.764	1.435	1.367	1.409	1.554	1.782	1.728	1.783	1.931	1.612	1.692	1.700	2.044
	38	1.181	1.456	1.489	1.951	1.235	1.445	1.323	2.027	1.380	1.734	1.710	1.866	1.388	1.612	1.548	2.264

Appendix 2. Values of estimated distance of the right-wrist coordinates.

		The estimated starting point of the knee strike				The vertex of the parabola			
Cycle	Beat	Timescale	Frame no.	(x, y)	Distance (cm)	Timescale	Frame no.	(x, y)	Distance (cm)
1	1	2.569	77	(586.292, 400.127)	0.000	4.238	127	(582.338, 384.516)	3.382
1	2	4.938	148	(552.913, 364.83)	10.202	5.839	175	(458.932, 382.538)	26.999
1	3	7.040	211	(570.536, 417.746)	4.964	8.208	246	(533.399, 431.456)	12.910
1	4	8.809	264	(564.778, 408.019)	4.812	10.143	304	(568.632, 196.481)	42.926
2	1	11.411	342	(584.298, 402.158)	0.598	12.846	385	(582.379, 384.455)	3.392
2	2	13.113	393	(584.295, 388.392)	2.500	14.381	431	(470.693, 386.429)	24.446
2	3	15.249	457	(570.597, 409.989)	3.893	16.717	501	(525.562, 425.579)	13.828
2	4	17.284	518	(558.921, 406.012)	5.879	18.685	560	(560.861, 188.595)	44.742
3	1	19.820	594	(588.281, 398.163)	0.587	21.455	643	(586.266, 388.41)	2.461
3	2	21.588	647	(588.275, 392.273)	1.701	22.723	681	(468.772, 368.884)	25.536
3	3	23.524	705	(570.617, 408.029)	3.686	24.791	743	(529.508, 419.807)	12.621
3	4	25.459	763	(560.803, 404.12)	5.418	26.793	803	(576.465, 210.191)	39.940
4	1	27.828	834	(592.142, 398.23)	1.291	29.029	870	(586.271, 394.272)	1.230
4	2	29.463	883	(582.41, 384.469)	3.388	30.564	916	(470.743, 353.135)	26.195
4	3	31.498	944	(570.623, 404.051)	3.392	32.766	982	(556.877, 415.831)	7.002
4	4	33.467	1003	(564.684, 400.174)	4.538	34.835	1044	(574.52, 198.38)	42.439
5	1	35.569	1066	(586.249, 400.181)	0.014				
16	1	115.916	3474	(588.209, 396.185)	0.000	117.017	3507	(580.365, 382.547)	3.304
16	2	117.484	3521	(578.392, 372.798)	5.326	118.352	3547	(474.603, 364.953)	24.742
16	3	119.353	3577	(564.76, 407.958)	5.510	120.721	3618	(539.325, 417.775)	11.222
16	4	121.021	3627	(549.048, 415.8)	9.198	122.422	3669	(568.682, 208.198)	39.690

		The estimated starting point of the knee strike				The vertex of the parabola			
17	1	123.190	3692	(572.59, 398.177)	3.307	124.124	3720	(574.597, 384.541)	3.762
17	2	124.758	3739	(572.556, 380.523)	4.650	125.459	3760	(466.829, 360.945)	26.542
17	3	126.460	3790	(566.627, 404.077)	4.826	127.394	3818	(535.388, 419.712)	12.143
17	4	127.794	3830	(556.931, 398.195)	6.582	128.762	3859	(572.539, 214.082)	38.383
18	1	129.596	3884	(588.232, 392.323)	0.811				
25	1	174.074	5217	(578.419, 398.201)	0.000	174.908	5242	(574.592, 384.539)	2.979
25	2	175.676	5265	(570.579, 374.698)	5.203	176.310	5284	(462.889, 372.724)	24.844
25	3	177.177	5310	(562.798, 409.967)	4.107	178.178	5340	(545.187, 421.694)	8.546
25	4	178.745	5357	(556.879, 398.235)	4.523	179.646	5384	(552.983, 200.332)	41.894
26	1	180.647	5414	(584.366, 402.071)	1.490	181.648	5444	(580.394, 382.58)	3.307
26	2	182.049	5456	(580.355, 394.248)	0.924	182.783	5478	(462.905, 380.564)	24.539
26	3	183.517	5500	(564.757, 411.913)	4.065	184.418	5527	(521.662, 415.848)	12.482
26	4	185.085	5547	(554.98, 417.762)	6.411	186.253	5582	(566.729, 210.184)	39.560
27	1	187.087	5607	(584.359, 400.145)	1.313	187.855	5630	(574.506, 376.682)	4.593
27	2	188.488	5649	(578.403, 392.276)	1.244	189.156	5669	(455.054, 366.902)	26.727
27	3	189.923	5692	(560.857, 415.834)	5.226	190.791	5718	(523.577, 417.772)	12.228
27	4	191.358	5735	(554.95, 398.171)	4.928	192.426	5767	(572.59, 223.831)	36.638
28	1	193.260	5792	(582.339, 400.177)	0.922	194.228	5821	(576.522, 384.464)	2.912
28	2	194.761	5837	(560.761, 380.523)	5.247	195.395	5856	(462.896, 370.756)	24.935
28	3	196.330	5884	(560.845, 413.863)	4.943	197.297	5913	(551.032, 421.723)	7.581
28	4	197.831	5929	(554.908, 400.143)	4.954	198.732	5956	(566.729, 218.013)	37.919
29	1	199.499	5979	(574.529, 402.081)	1.154				

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