Studying Rhythmical Structures in Norwegian Folk Music and Dance Using Motion Capture Technology: A Case Study of Norwegian Telespringar

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Abstract

Norwegian telespringar is often referred to as being in so-called *asymmetrical triple meter*—that is, the three beats in the measure are of uneven duration. Previous studies report that a systematic *long–medium–short* beat duration pattern seems to be a prominent feature of telespringar. This paper investigates how motion data can be incorporated into studies of rhythmical structures in Norwegian telespringar using motion capture technology. It is reported from two motion capture studies: first, a fiddler playing telespringar on a Hardanger fiddle; second, a couple dancing telespringar. Participants' movements were recorded using an advanced optical infrared motion capture system. Motion analysis of the fiddler's foot stamping confirms the *long–medium–short* beat-duration hypothesis. In addition, the fiddler's upper-body movements seem to be in synchrony with the bar level of the music. Motion analysis of the up/down movement of the body's center of gravity in telespringar dancing shows a consistent *libration pattern*. These results appear to suggest that prominent rhythmical features of telespringar are represented in both the fiddler's and the dancers' body motion. They also indicate that motion capture technology is an effective means of investigating music-related movements in telespringar.

1. Introduction

Music is not only a sonic phenomenon but also a multimodal phenomenon that encompasses both mind and body. A theoretical starting point for a so-called *ecological perspective on perception* is that we obtain knowledge about the world by constantly interacting with it. Hence, the mind must be understood as inseparable from the physical body that interacts with the world (Gibson 1986; Wilson 2002; Clarke 2005). Within this theoretical framework, music perception likewise implies an understanding of body motion, and it has been suggested that an experienced rhythm is in fact an imagined motion (Shove & Repp 1995; Iyer 2002). This correspondence between music and body motion seems to be reflected in rhythmical structures in music that derives from oral tradition, and that has an intimate relationship to dance, as in the traditional dance music of Sweden and Norway (see, e.g., Aksdal & Nyhus 1993; Ramsten 2003). In his studies of Norwegian folk music and dance, Blom (1981) takes as his point of departure the conviction that musical rhythm is intimately related to our bodily experiences, and that our concepts of rhythm are mirrored in the way in which we move our bodies in synchrony with music. In the earlier article "On notation of time, signature and rhythm in Swedish polskas", Bengtsson (1974) suggests that the specific rhythm patterns in the polska are probably conditioned by particular ways of dancing as well.

A considerable part of the traditional dance music of Sweden and Norway are in so-called *asymmetrical triple meter*—that is, the three beats in a measure are of uneven duration. In attempts to both interpret and notate this phenomenon, the intimate relationship between the music and the corresponding dancing is often emphasized. Also, in accordance with the view that musical rhythm is intrinsically related to body motion, it has been suggested that performers' body motion should be incorporated in investigations of rhythm structures in music featuring asymmetrical meter (see, e.g., Blom 1981; Bengtsson 1987; Kvifte 2004). Using motion capture technology, we can track these music-related motions with great precision, and the present study discusses the use of this technology in studies of rhythm structures in Norwegian folk music and dance.

An advanced optical motion capture system, preferred when very precise positional data are required (Skogstad et al. 2011), was used for the study. When one works with quantitative data, one must consider carefully what is actually measured and why, in order to avoid dwelling upon aspects of the music that are not relevant to the experience of it. A qualitative analysis of the music of interest can determine which musical features are experienced as significant, and quantitative data from measurements can then enable the investigation of these features in more detail—this study, for example, measured musical sound and performers' body motion. Also, a visualization based on quantitative data (the vertical movement of a fiddler's foot, for example) can be analyzed qualitatively. Hence, qualitative and quantitative methods complement one another and together produce the best results.

2. Earlier research

From 1892 to 1904 the Swedish folk music collector and schoolteacher Einar Övergaard (1871–1936) travelled through Western Sweden and also Valdres, Gudbrandsdalen, and Østerdalen in Norway, transcribing both vocal and instrumental music. In addition to his transcriptions, Övergaard's field notes also include reflections about the notation asymmetrical rhythms of pols/springar tunes from this area. Regarding the tunes, called *springleik*, from Elverum in Østerdalen, he describes how he first transcribed them in 2½/4 meter, then changed it to ½ +2/4 meter, but ended up using the normal 3/4 meter (Ramsten 1982).

The Norwegian fiddler, composer, and music researcher Eivind Groven (1901–1977) undertook a relatively early study (Groven 1971) of rhythm in Norwegian folk music styles characterized by asymmetrical triple meter. He began by noting that since the three beats in a measure are uneven in duration, a transcription cannot supply an accurate sense of a tune's rhythmical pattern. As an alternative, then, he made use of an old Morse instrument constructed for punching Morse code into a paper slip moving at a regular speed of 30 millimeters per second. While listening to music recordings, Groven tapped the beat on the Morse instrument, producing a paper slip with dots representing the beats in time. By measuring the distance between the dots, Groven derived a measure of the beat duration pattern in the tunes. He then calculated the percentage duration of each beat in a measure to generate an average beat duration pattern, represented by ratio numbers. For telespringar, his pattern indicated a *long–medium–short* pattern. Based on the measurement of tunes in various local styles played by different fiddlers, Groven concluded that these ratio numbers seemed to be a feature of the tune itself, related to the local tradition from whence it derived, rather than a result of a fiddler's personal style.

The Swedish musicologist Ingmar Bengtsson developed methods for analyzing musical rhythm as performed and perceived (see, e.g., Bengtsson et al. 1969; Bengtsson & Gabrielsson 1980; Bengtsson 1987) and introduced the concept of *systematic variations* (SYVAR) to describe the phenomenon of consistent/regular deviations from an isochronous norm (Bengtsson & Gabrielsson 1980). He identified and measured these systematic deviations in musical rhythm using analog sound analysis devices to register features like changes in pitch and amplitude from audio recordings (Bengtsson et al. 1969). Based on these data, musical rhythm could be analyzed and described in terms of estimated measure and beat durations.

In an article on polska, the Swedish musician, music researcher, and teacher Sven Ahlbäck (2003) states that the rhythmical asymmetry in polska tunes can be schematized as a short beat, then a beat that is at most twice as long, then a beat that falls between the two and occupies about a third of the measure. He also shows how the same tune can be played according to different metrical interpretations—starting the measure with the longest beat rather than the shortest, for example. Ahlbäck emphasizes that what is interpreted as the first beat in a measure depends on not only the metrical accents but also the fiddler's foot stamping, and he goes on to argue that there might be a relationship between the accents in the sound and the performer's body motion. He divides these accents into two main types: "grave," which can be characterized as heavy, sustained, and round, and "acute," which can be characterized as light, short, and sharp. The deep accent might be experienced as a downward body movement, and the acute as an upward body movement, he argues. He also notes that the pattern is more important than the individual strength of each accent.

In another article dealing with the phenomenon of asymmetrical meter, Kvifte (1999) notes that Groven and Bengtsson are actually measuring two different things. Groven measures his own beat tapping, or his subjective experience of a beat pattern. Bengtsson's measurements, on the other hand, derive solely from a visualization of physical events extracted from the sound signal; they do not take into account the ways in which these points in time are perceived. Kvifte then suggests a method that he describes as a "Groven approach" with a "Bengtsson modification". He records the music of interest into a sequencer program, then plays it back and, like Groven, records what he experiences as the beat in the music by tapping on a MIDI keyboard. He then plays back his recorded beats simultaneously with the music and modifies them until they appear to be in sync with the music. This method of measurement requires that the researcher is familiar with the musical code, and Kvifte points out that one way to determine the result's source of error is to compare the researcher's measurements with the performers' (both musicians' and dancers') measurements, performing the same tapping task.

In his work on asymmetrical grooves in Norwegian folk music, Mats Johansson (2009) also refers to Groven and Bengtsson's research. In addition to noting that Groven's measurements mainly represent Groven's interpretation of the beats, Johansson also points out that the correspondence between Groven's measurements and the attack points in the music is not discussed as such. Johansson also questions the methods used by Bengtsson with regard to attack points and the onsets derived from Bengtsson's visual graphs. Unlike Kvifte (1999) and Groven (1971), that is, Johansson seeks a picture of the duration pattern based on measurements of the positions of the actual sound events in the audio signal; unlike Bengtsson, Johansson favors a measuring method for sound analysis that incorporates both visual and audible clues. He records the music of interest into a computer program that shows the music's waveform and plays the sound back at the same time. By moving the cursor back and fourth, starting the playback from different positions, Johansson tries to determine where one unit seems to stop and where the following starts. Subsequently, Johansson picked the manually measured onsets representing beat positions. In this way, beat positions not represented by a sound event are not included in the analysis. The result of Johansson's analysis of telespringar indicates a *long–long–short* average beat duration pattern that differs from Groven's *long–medium–short* pattern. However, these two patterns may not be incompatible, because Groven's measurements represent an underlying perceptual beat pattern, and Johansson's measurements represent the physical positions of actual played sound events, which can be two different things.

The importance of body motion in rhythm studies is emphasized in both Bengtsson's and Kvifte's research (see, e.g., Bengtsson 1987; Kvifte 2004, 2007). The Norwegian anthropologist and ethnomusicologist Jan-Petter Blom also emphasizes that one should understand the rhythmical pattern of telespringar in relation to the dance. Blom's (1981) point of departure is that perception and expression of musical rhythm is intimately linked to experiences of body motion, and he illustrates how the alternating stretching and bending movements in the joints in hips, knees, and ankles in the dance results in a *patterned libration of the body's center of gravity*. This pattern can be represented as up/down movements in the form of straight lines. The capital letter A (Greek: *arsis*) can represent rising movements, and the capital letter T (Greek: *thesis*) can represent falling movements, so that a full libration can be notated TA. In telespringar, Blom proposes a TA:T:A libration pattern in relation to the triple musical meter (beats are separated by colons). Although Blom does not refer to methods for measurement, his theories are well grounded based on both his close observations and his own experience as dancer and fiddler.

Scholars have also seen a correspondence between bowing and the dance meter. Kvifte (1987) investigated bowing patterns in terms of dance meter in springar tunes from Valdres and Telemark, based on transcriptions with bowing indications. He starts with the up/down movement of the bow (up when the frog moves toward the strings, down when the frog moves away from the strings). Kvifte finds no direct link between the bowing pattern and the dancing's libration patterns, but he does allow for the possibility of a more general analogy between them—one that should be investigated via studies of performances, not only transcriptions. Blom (2006) points out that while motifs, bow phrases, and form in Hardanger fiddle music seem to be shared across local communities, the relationships between beat duration, fiddlers' regular foot stamping, and speed of bowing may be specific of a particular local style. Based on his own practical experience and close observation, Blom presents a model indicating a relation between bowing speed and dance meter that evokes the model mentioned above—that is, rising movements in the dance (A) correspond to greater bowing speed, and falling movements in the dance (T) correspond to lesser bowing speed.

Motion capture technology appears in a study carried out by Turid Mårds (1999) to investigate correspondences between libration curves and force used in different styles of Norwegian folk dancing. A professional fiddler and three professional dancers participated in the telespringar study, which used a motion capture system consisting of four cameras and passive reflective markers. To produce a visual representation of the dancers' libration pattern, reflective markers were placed on the dancers' heads. In addition, the dancers were dancing on rectangular force plates that registered counterforces, in order to measure the kinetic power of their steps. Four force plates (one 50cm*50cm and three 120m*60cm) were placed one after the other. Due to the force plates' shapes and placements the dancers had to dance in a straight line. The force measurements were used to place the dance steps in time. To produce a further representation of the fiddler's foot stamping, a plate with an accelerometer attached to it was placed under the musician's feet, and the signal from the accelerometer was used to calculate the fiddler's foot stamping in time. Those measurements confirmed the *long–medium–short* telespringar pattern hypothesis. The motion curves of the dancers' heads, on the other hand, showed that the duration of the first TA movement was approximately one half of the "measure", while the remaining beats 2 and 3 of the measure lasted approximately a quarter of the measure each. There are, however, some issues regarding these results. First, the libration curves are based on motion capture of the dancers' heads, not the movement of what Blom referred to as the body's center of gravity. Second, as mentioned above, the rectangular force plates forced the dancers to dance in a straight line, and not in a circle, as they would normally do. One might wonder whether the use of rectangular force plates might have restrained the execution of the dance and skewed the motion-capture results.

3. A case study of Norwegian telespringar

Although many rhythm studies of traditional dance music in asymmetrical triple meter are based on audio recordings, the importance of incorporating performer's body motion is frequently mentioned. For example, Kvifte (2004) and Bengtsson (1974) highlight the dancers' movements and Ählback (2003) the fiddler's foot stamping. As noted, Norwegian telespringar is often referred to as being in asymmetrical triple meter, and the present study will investigate how the motion capture technology available today can be used in studies of rhythmical structures in telespringar performance.

3.1 Motion capture

The term *motion capture* typically describes the technology used for tracking motion and storing motion data (Nymoen 2013). The present study used a passive optical infrared motion capture system from Qualisys.[1] It consists of reflective markers and nine cameras that both emit infrared light and record the light reflected from the markers. During the recording process, each marker must be captured by at least three cameras simultaneously to enable triangulation and generate a three-dimensional (3D) representation of the marker's movement. The software Qualisys Track Manager (QTM) calculates the position of the reflective markers to produce this representation.

In terms of down side, studies incorporating optical infrared motion capture systems are often carried out in a motion capture lab, and the attachment of reflective markers to one's body can exacerbate the awkwardness of being in an artificial environment even more. Fortunately, some previous studies have concluded that the participant's professional experience can compensate for this problem (Naveda & Leman 2008; Haugen 2011).

If a marker becomes occluded or is moved outside the capture space, it will disappear from the motion capture recording for that period, resulting

1. See http://www.qualisys.com.

in so-called *dropouts*. Hence markers must be positioned on participants where they are least likely to be occluded, and participants must be encouraged to move within the capture space. If there are a large number of markers on participants who are moving a lot, some dropouts are to be expected. Dropouts cause gaps in the data. If a gap is quite short, it can be *gap-filled* during post-processing, but the missing trajectories of longer gaps are often impossible to estimate (Nymoen 2013). Recordings containing a lot of long gaps often have to be discarded.

As described above, when a marker is seen by at least three cameras simultaneously, the system can calculate its 3D position, represented as a dot in a virtual 3D space (see Figures 1a and 1b). Next, the dots are identified and labeled manually. After the dots have been identified, they can be connected by "bones" to create an animated stick figure (see Figure 1c). In addition to facilitating the interpretation of the dots, these bones also make the figure more stable.

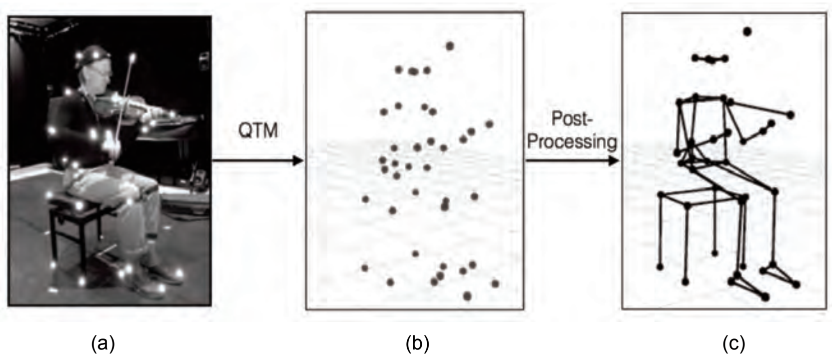

Figure 1: An illustration of the processing: (a) a picture from the recording, (b) the dots in a 3D environment representing the markers as recognized by QTM, and (c) the representation of the markers after they have been manually identified and connected by "bones".

The processed motion data from QTM can be converted into a so-called .tsv file, a text file that contains all of the information from the motion capture, and this file can be read into the MoCap Toolbox for MatLab (Burger

& Toiviainen 2013) for further analysis (Figure 2). The MoCap Toolbox contains a set of functions for analyzing motion capture data and was developed for studies of music-related movements.

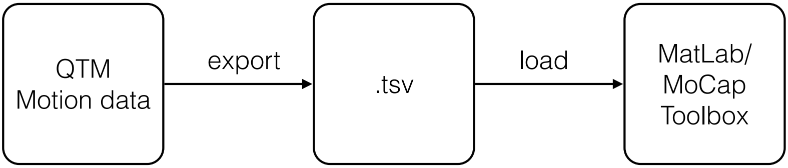

Figure 2: The motion data from the Qualisys Track Manager (QTM) are converted into a .tsv file that can be read into the MoCap Toolbox for MatLab for further analysis.

3.2 Set-up

The recordings were carried out in the fourMs Motion Lab[2] at the Department of Musicology at the University of Oslo using a nine-camera motion capture system from Qualisys. The system tracked the movements of reflective markers at the frame rate of 100 Hz. Video recordings were also created for reference purposes.

There were two separate recordings. The first featured a fiddler playing telespringar via a total of 27 reflective markers attached to the fiddler's body. In addition, two markers were attached to the fiddle (at either end of the instrument), one at the end of the bow, and eight on the chair, for reference (see Figures 1a and 1c). The second featured a couple dancing telespringar via markers placed mainly on the dancers' joints but incorporating some variation in order to both identify and separate the two participants. In addition, a number of control markers were placed on the dancers in an asymmetrical manner between some of the joints. The placements of the markers on dancer 1 and dancer 2 are presented in Table 1 and Figure 3.

2. See http://www.uio.no/english/research/groups/fourms/about/labs/.

Marker Number	**Dancer 1**	**Dancer 2**
1	RF head	RF head
2	LF head	LF head
3	RB head	RB head
4	LB head	LB head
5	neck	neck
6	R shoulder	R shoulder
7	R elbow	R elbow
8	R wrist	R wrist
9	R hand	L shoulder
10	L shoulder	L elbow
11	L elbow	L wrist
12	L wrist	lower back
13	L hand	RF hip
14	lower back	LF hip
15	RF hip	R knee
16	RB hip	R ankle
17	LF hip	R heel
18	LB hip	R toe
19	R knee	L knee
20	R ankle	L ankle
21	R heel	L heel
22	R toe	L toe
23	L knee	CTR R shoulder
24	L ankle	CTR R arm
25	L heel	CTR L arm
26	L toe	CTR R thigh
27	CTR R shoulder	CTR L thigh
28	CTR L arm	CTR R lower leg
29	CTR R thigh	-
30	CTR L thigh	-
31	CTR R lower leg	-

Table 1: Placement of the markers on dancer 1 and dancer 2 (L = left, R = right, F = front, B = back, CTR = control).

Since the recording of the fiddler and the recording of the dancers did not take place on the same day, the dancers were dancing to the sound that had been recorded in the fiddler's session. Consequently, no direct interaction between the musician and the dancers could be analyzed for this study. However, since the dancers were dancing to the sound from the actual fiddler's recording, the motion data from the dance recording can be precisely synchronized with the sound and motion data from the fiddler's session.

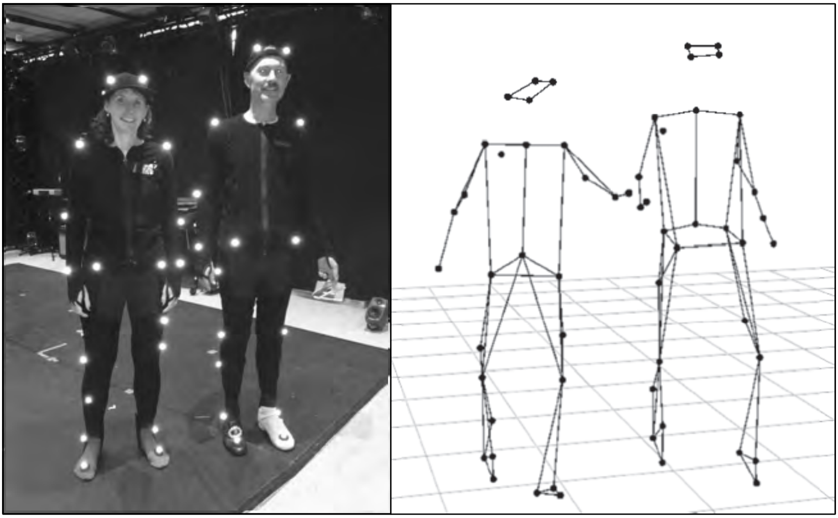

Figure 3: Placement of the markers. Dancer 1 is on the right, and dancer 2 is on the left. The markers are placed slightly differently from one person to the other in order to distinguish them.

4. Sound analysis

The MIRtoolbox for Matlab (Lartillot & Toiviainen 2007) was developed to extract musical features like timbre, tonality, and rhythm from audio files. One way to visualize sound is by looking at its waveform (signal strength over time). A sudden increase in signal energy, for example, can indicate a new sound event (Collins 2010), and an *onset detection* function can then perform peak detection on the audio signal in order to estimate the positions of the notes. However, the sound of Hardanger fiddle is complex, and the peaks in the fiddler performance's waveform seem neither unambiguous nor likely to represent the beginning of notes, so the waveform may not be the best point of departure for estimating the position of sound events in telespringar playing (Figure 4).

The temporal positions of sound events may also be determined in terms of changes in pitch. This can be done manually—Johansson (2009), for example, suggests moving a marker back and forth, starting playback from different positions in order to locate the start of a sound unit (Figure 4).

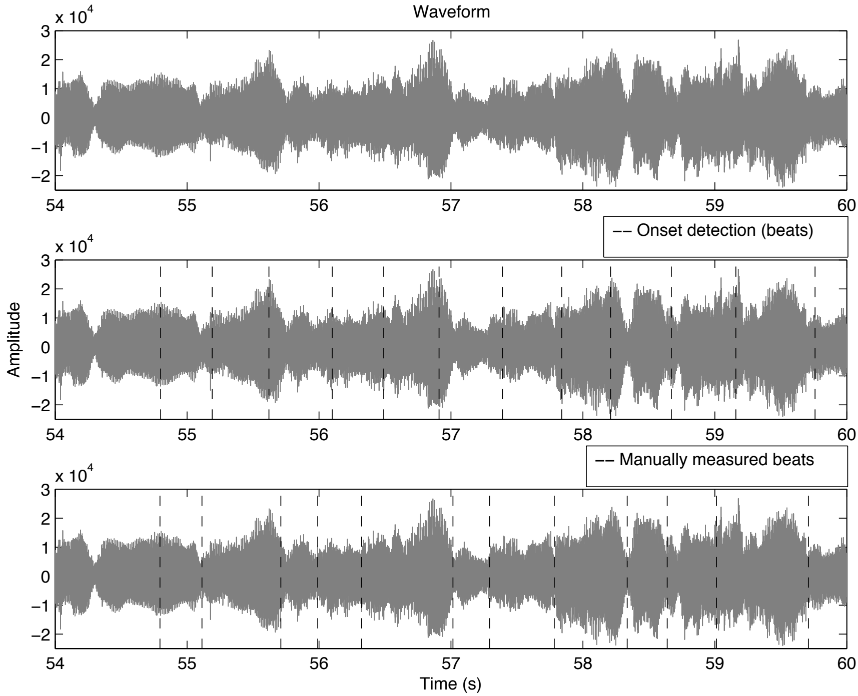

Figure 4: Visualizations of the sound of four measures of telespringar playing. The audio waveform (top), the waveform with beat positions estimated using the onset detection function in the MIRtoolbox (middle), and the waveform with manually measured beat positions (bottom).

However, there are some fundamental problems with investigating meter based on the locations of physical sound events in time (Kvifte 2004; Johansson 2009). For example, the physical onset of syncopated notes is located "off" the experienced beat. Sometimes the duration of a tone extends the duration of a given beat, so that the beats in an underlying experienced pulse may not be present in the sound signal. In the end, when investigating the asymmetrical meter in telespringar, such determinations of sound events may not be sufficient. As previously mentioned, studies have therefore suggested that the body motions of performers and dancers should be incorporated into rhythm studies (see, e.g., Blom 1981; Baily 1985; Kubik 1990), and that will be the case in what follows.

5. Motion analysis

According to previous studies (Kvifte 1999, Blom 2006) the fiddler's foot stamping, bowing movements and the up/down movements of dancers' center of gravity are of particular interest in rhythm studies of telespringar.

5.1 The fiddler's foot stamping

Foot stamping appears to be an integral part of telespringar playing, although the style and pattern of the motion differ among fiddlers (Kvifte 1999, Ahlbäck 2003, Johansson 2009). The fiddler in the present study seems to stamp both feet in a regular pattern while playing. There are two reflective markers attached to each of the fiddler's feet, one on the toe and one on the heel. Because the feet primarily move up and down, we plotted the vertical movements of the foot markers (Figure 5). The plots show that the right heel stamps on every beat of the measure, the left heel stamps on every first beat of a measure, and the left toe stamps on every second beat of a measure.

Motion capture data representing the right heel's vertical movement on each beat provide measurable intervals between stamps, which are represented as unambiguous downward "spikes." The beat duration pattern was estimated by calculating the intervals between foot beats, the durations of

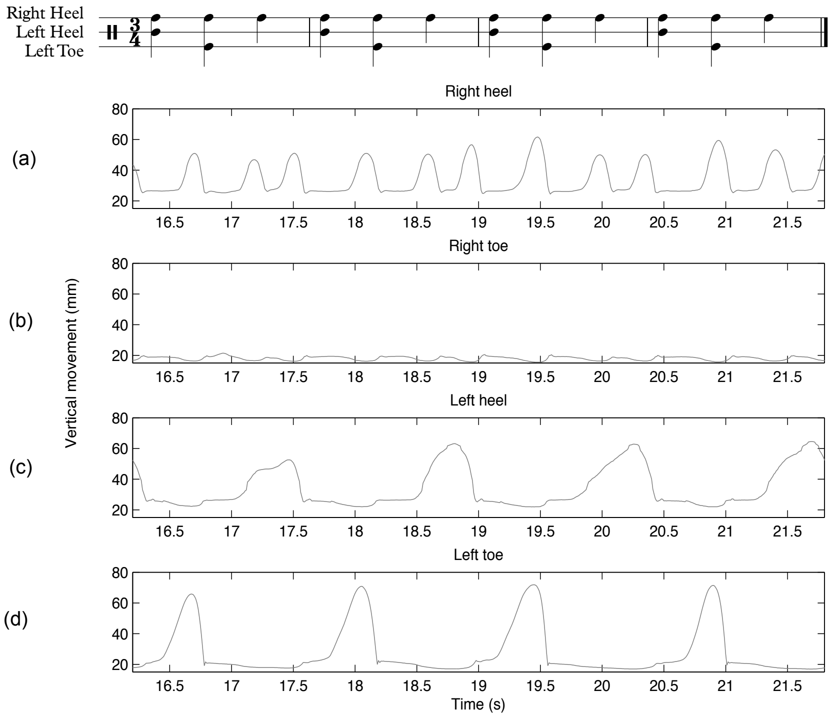

Figure 5: Plot of the vertical movements of the markers placed on (a) right heel, (b) right toe, (c) left heel, and (d) left toe over time in seconds. The left heel movement seems to synchronize with the first beat in a measure, the left toe movement seems to synchronize with the second beat in a measure, and the right heel movement seems to synchronize with all three beats in a measure. The right toe does not move.

which were measured in seconds to four decimal places. The calculated beat durations were then converted into percentages of the measure over the course of the first 40 measures, or a total of 120 beat durations. The results confirm the *long–medium–short* pattern in telespringar with a ratio of 41:34:25 (Table 2).

Beats	**Mean duration (in %)**	**SD**
First beat	40.83	0.02
Second beat	33.80	0.02
Third beat	25.36	0.02

Table 2: Mean duration with standard deviations (SD) for the first, second, and third beast in a measure (N=120), based on the fiddler's foot stamping.

Analysis of variance showed significant differences between beat durations (p<0.001), and Bonferroni-corrected post-hoc tests showed significant differences between the duration of first, second, and third beat (all p<0.001). A boxplot of the beat durations based on foot movements (Figure 6) and the standard deviations (SD) in Table 2 indicates that the *long–medium–short* pattern in the foot stamping seems to be very regular. Previous studies suggest that fiddlers' regular foot stamping plays an important part in

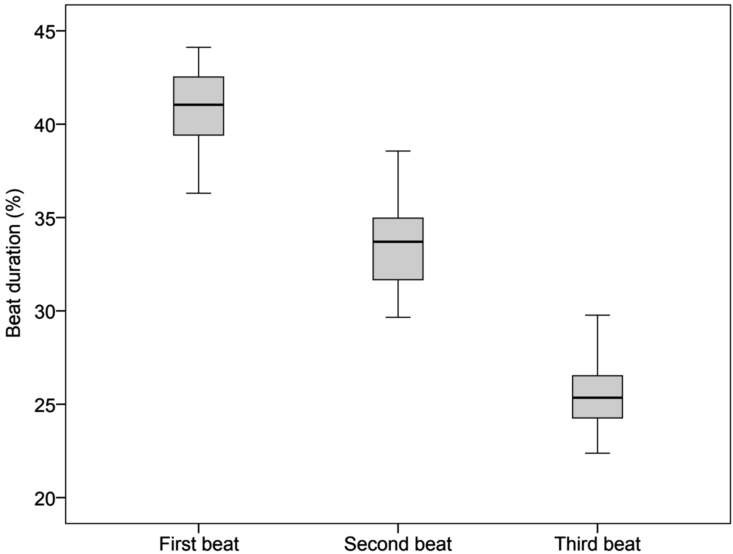

Figure 6: Boxplot showing the distribution of the duration of the first, second, and third beats in a measure, based on the fiddler's foot stamping over the course of 40 measures.

distinguishing a particular local style and in enabling the interpretation of asymmetrical meter (see, e.g., Ahlbäck 2003, Blom 2006). Hence in this study the patterned foot stamping may serve as a structure of reference in rhythm studies of telespringar.

5.2 The fiddler's upper body movement

The fiddler in the present study sways back and forth with his upper body while playing, begging the question of whether this movement was related to the rhythmical pattern in his foot stamping. From a position plot of the horizontal movement of the marker attached to the fiddler's neck, it became clear that this swaying synchronized with the measure level of the telespringar, as previously determined by the vertical movements of the foot stamping (Figure 7).

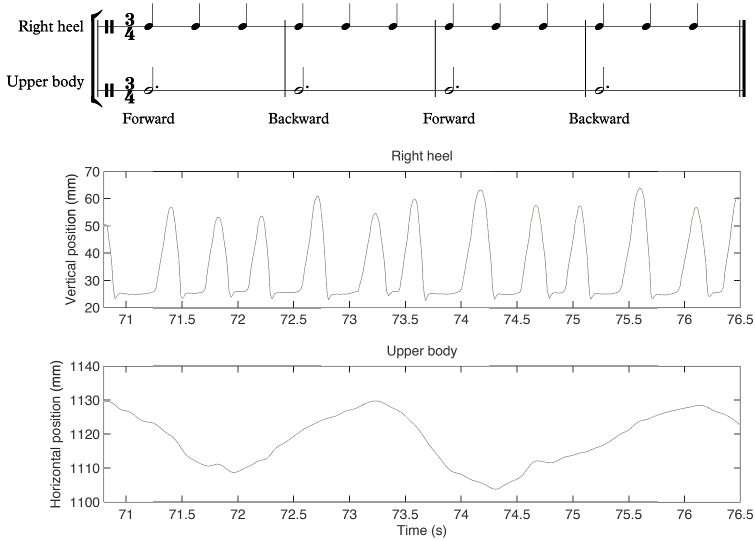

Figure 7: Plot of the vertical movements of the markers placed on the right heel and the horizontal movement of the neck. The movement of the upper body seems to move in synchrony with bar level.

To clarify the relationship between the upper-body swaying and the foot stamping, we measured the points in time when the swaying changed direction, then correlated them with the first beats of the measures, as indicated by the foot stamping. We did so for 21 measures at the beginning of the recording. A scatterplot confirmed that the upper body swayed in synchrony with every first beat in a measure (Figure 8).

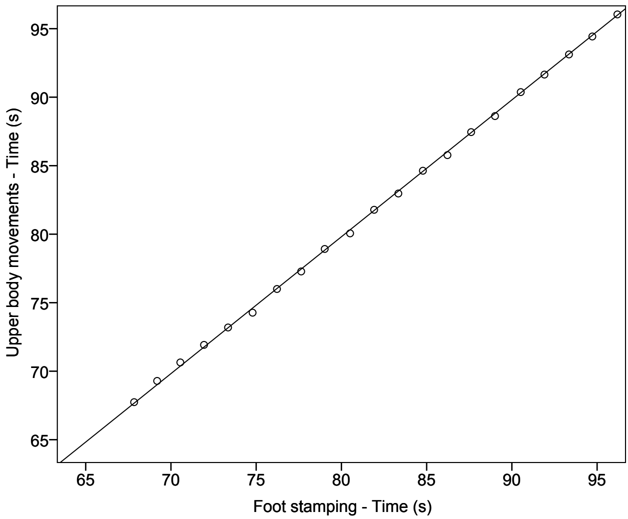

Figure 8: Scatterplot showing the relation between the points in time when the upper-body swaying changed direction and the first beats of the measures, as indicated by the foot stamping, in 21 measures.

5.3 The patterned libration of the body's center of gravity in telespringar dancing

The up/down pattern of telespringar dancing has been referred to as *the patterned libration of the body's center of gravity*, and it has been related to the musical meter in telespringar (Blom 1981). To explore this link further, we analyzed the vertical movements of the markers placed on the dancers' lower backs. A plot of lower-back marker data based on four measures in the middle of the recording was compared to the fiddler's right-heel stamping, and the resultant visualization of the vertical movement of the dancers' lower back seems to confirm Blom's TA:T:A libration pattern hypothesis (Figure 9).

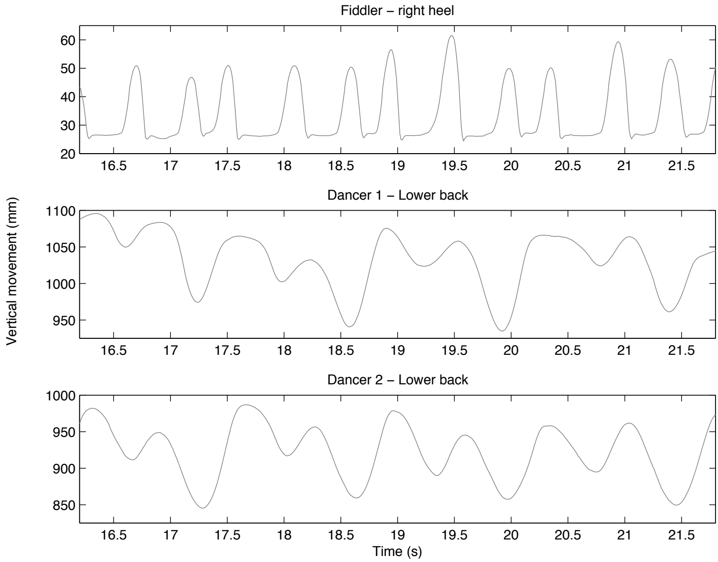

Figure 9: Plot of the vertical movements of the markers placed on the fiddler's right heel and the dancer's lower back for four measures.

In order to investigate the dancers' libration patterns in more detail, we applied a mathematical function for picking the *peaks* and *throughs* in a graph to calculate the movement pattern of the dancers' lower backs. The *throughs* were where the curve changed from downward to upward, and the *peaks* were where the curve changed from upward motion to downward. The plot of the lower back's vertical movement included some "noise" that may have interfered with the determination of peaks and lows, forcing us to smooth the motion capture data using the mcsmoothen function in the MoCap Toolbox (Figure 10).

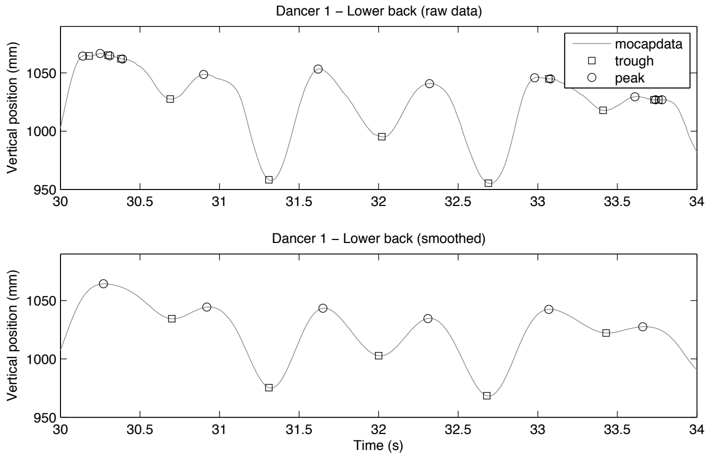

Figure 10: Illustration showing the difference between the plot of the libration curves in telespringar dancing, including calculated peaks and throughs, (a) before and (b) after the data was smoothed.

Next we estimated the beat durations based on the libration curve. In accordance with Blom's libration-pattern hypothesis, we measured the duration between the first two peaks (beat 1), the second peak and the second through (beat 2), and the second through and the third peak (beat 3) of the libration curve. The beat durations were measured in seconds and subsequently converted into percentages of the measure. The result indicated a ratio of 48:27:25 for dancer 1 and 46:27:27 for dancer 2. The mean durations of the beats, as percentages, for both dancer 1 and dancer 2 are presented in Table 3.

An analysis of variance showed significant differences between the beat durations ($p<0.001$), and Bonferroni-corrected post-hoc tests showed significant differences between the durations of the first and second beats and of the first and third beats (both $p<0.001$). However, no significant differences between the second and third beats were found ($p>0.70$ for dancer 1 and $p>0.99$ for dancer 2). This means that the dancers' libration pattern in this study seems to be *long–short–short* rather than *long–medium–short*, which accords with Turid Mårds' (1999) findings.

	Beats	Mean duration (in %)	SD
Dancer 1	First beat	48.2	5.9
	Second beat	26.9	4.1
	Third beat	25.0	4.8
Dancer 2	First beat	45.8	3.2
	Second beat	26.9	2.1
	Third beat	27.3	2.3

Table 3: Mean duration with standard deviations (SD) for the first, second and third beat in a measure in 40 measures for Dancer 1 and Dancer 2 (N=120).

5.4 Dance meter and bowing velocity

As previously mentioned, Blom (2006) suggests a correspondence between dance meter and bow velocity, and Kvifte (1987) defines a bowing movement as *up* when the frog is moved toward the strings and *down* when the frog is moved away from the strings (this is also the ordinary definition of bowing movements). In this study the bow marker was attached to the tip of the bow, so a bowing movement is defined as *up* when the tip of the bow is moved away from the strings and *down* when the tip of the bow is moved toward the strings.

We then estimated the bow velocity by differentiating the previously obtained position data. Blom's (2006) model, which shows a relation between bowing velocity and dance meter, suggests an increase in bowing velocity toward the second beat in a measure, which also corresponds to the "heaviest" beat in the dance meter, in that it contains the longest downward movement. Based on the four measures plotted in Figure 11 (next page), it seems as though the "upward" bow velocity peaks once in every measure, and that this peak is located around the second beat. This confirms Blom's hypothesis, though by looking at the distribution of the bowing velocity over a longer period of time, we found different patterns in different parts of the tune.

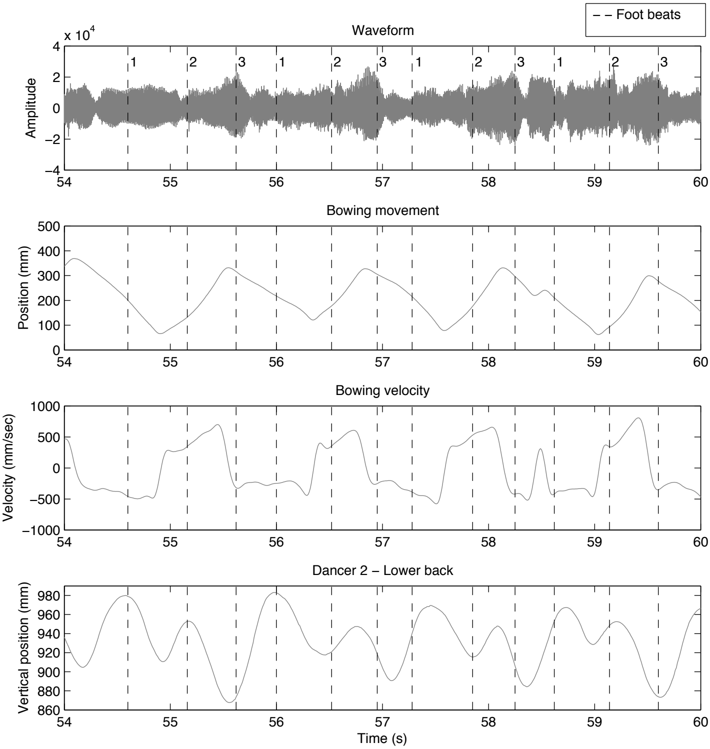

Figure 11: Plots showing the waveform (audio), the bow's movements (where "up" is when the tip of the bow is moving away from the strings and "down" when the tip of the bow is moving toward the strings), the bow's velocity over time in seconds, and the vertical movements of dancer 2's lower back over time for four measures. Beat positions, estimated from the fiddler's foot stamping, are indicated by dotted lines.

6. Discussion and future work

This paper investigates rhythmical structures in telespringar performance, based on motion capture recordings of a fiddler and two dancers. Analysis of the fiddler's foot stamping confirms the *long–medium–short* beat-duration pattern hypothesis, and the stability of the pattern suggests that it constitutes an essential feature of telespringar. The visualization of the vertical movements of the dancers' lower back seems to confirm Blom's TA:T:A libration pattern hypothesis. The estimated beat durations based on the libration curve, revealed a *long–short–short* duration pattern that accords with Mårds' (1999) findings. The results presented in this paper are based on the analysis of one recording of one fiddler and one recording of two dancers and should not be interpreted as indicative of any *overall* rhythmical pattern of telespringar. While we have demonstrated some of the ways in which motion data could be used in rhythm studies, more telespringar performance recordings should be included if more general conclusions are to be drawn. Future studies should also incorporate recordings of dancers and fiddler performing simultaneously, rather then separately.

Lastly, sound data is as important as motion-capture data in the exploration of telespringar rhythms. Previous studies have pointed out that audio analysis, like motion analysis, must confront *what* to measure as well as *whether* measured units represent features experienced by performers and perceivers (Kvifte 2004, Johansson 2009). The audio signal of a Hardanger fiddle is complex, so it is not necessarily obvious what should be measured. However, the technologies and possibilities for audio analysis are progressing fast, and future studies will probably determine methods for audio analysis that are capable of tackling the sound of Hardanger fiddle playing.

7. Conclusions

The results from this study support the view that performers' body motion should be incorporated into the study of rhythmical structures in telespringar. We recorded a fiddler and two dancers using an advanced infrared motion capture system, and our motion analysis of the fiddler's foot stamping confirms the *long–medium–short* hypothesis. In addition, the fiddler's upper-body movements seem to be in synchrony with bar level. An analysis of the dancers' libration pattern showed a consistent TA:T:A pattern, which is in accordance with Blom's (1981) hypothesis. These observations suggest that prominent features of telespringar are represented in *both* the fiddler's and the dancers' motions. It has been suggested that the body motions of performers may offer a more perceptually relevant reference structure for rhythm studies than an abstract time line with isochronous time marks. To get a better understanding of the phenomenon of asymmetrical meter, more motion capture recordings, including both musicians and dancers, should be carried out in the future.

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