Motor control in drumming: Influence of movement pattern on contact force and sound characteristics

S. Dahl and E. Altenmüller

Institute of Music Physiology and Musicians' Medicine, Hanover University of Music and Drama, Hohenzollernstr. 47, 30161 Hannover, Germany
dr.sofia.dahl@gmail.com

In order to investigate how grip and striking gesture influence the sound characteristics of drum strokes we recorded movements, audio, contact duration and contact force during drumming. Different instructions were given with the intention to influence how a player's grip controlled the drumstick. "Normal" strokes were allowed to freely rebound from the drumhead. For "controlled" strokes the player was asked to control the ending position of the drumstick, stopping it as close as possible to the drumhead after the stroke. Compared to the relaxed grip, the controlled grip resulted in higher peak force, shorter contact duration between drumstick and drumhead, and higher difference in stick velocity before and after impact.
In an auditory assessment, eight listeners rated the recorded strokes with respect to timbre and attack. The listeners rated the relaxed strokes as having more full timbre and a softer attack compared to the controlled strokes.

1 Introduction

Musicians typically adjust the physical interaction with the instrument while playing. In order to obtain specific tone qualities a wind instrumentalist may apply a different embouchure, whereas a string player adjusts the bow pressure and velocity. In drumming the grip plays an important role. Normally, the stick is held so that it is free to rotate around a fulcrum point at the contact with thumb and index finger (see e.g.[4]). The player strives to have control over the stick without hindering its movement, letting it freely strike and rebound from the drumhead. Using the appropriate adjustment of grip, a good player is able to utilize the dynamics of the stick and influence the energy transfer to the instrument. Typical for percussion instruments is that this energy transfer is completed in a very short time.

Whereas wind instrumentalists and string players have a continuous control of the acoustic sound parameters during playing, a percussionists' direct contact with the instrument is limited to a few milliseconds. Contact durations lie in the range 5–8 ms for a mezzoforte stroke at the center of a tom-tom [1] or snare drum [6]. During contact, the time course of the contact force between the drumstick and drumhead is the major factor determining the sound. Strokes where the stick is free to rebound away from the drumhead are believed to develop a fuller sound, as compared to strokes when the rebound of the stick is hindered, for instance by a muscular hypertension of the grip. However, on occasion the player may need to restrain a rebound that is too strong for the next stroke.

Percussionists often rely on playing techniques that will help them produce particular sound characteristics and specific dynamic levels at different tempi. Such techniques can involve strategies for which height above the instrument the stick is lifted to in preparation for a stroke and the height at which the stick ends after a stroke [2], [3]. For instance, to play a soft stroke immediately after a loud one, the player may try to restrain the stick from rebounding too high above the drumhead [4]. However, due to the brief contact duration, the adjustment of grip made to halt the stick may begin already before impact. Consequently, such "controlled" strokes should therefore change the perceptual tone qualities, because the timbre, attack characteristics, and sound level are dependent on what happens before the time of contact.

To investigate how different instructions affected grip and sound characteristics, we recorded movement, contact force, and audio for drumming with different end positions of the stick after the stroke.

2 Method

A 14 inch (35.5 cm) rototom was selected as a suitable drum to be used for the experiment. This type of drum has a short, well defined attack and the tuning can be reliably reproduced between sessions. A rototom has no shell but consists of a single head in a threaded metal ring. Unlike most other drums, the rototom can easily be tuned to a (fairly) defined pitch by rotating the head. The rotation raises or lowers the head relative to the rim, which increases or decreases the tension of the head and thus the pitch of the drum. To control for the tension of the head at each tuning peg, a TAMA tension watch was used to establish that the surface tension at each peg was approximately the same.

The rototom used was equipped with a coated Remo Ambassador drumhead (approximate thickness 10 μm). The rototom is normally struck somewhat off-centre and the nominal striking position, 12.5 cm from the rim, was indicated by a circle, (5 cm diameter with the centre a distance of 5 cm to centre of drumhead). In order to measure the contact duration between drumstick and drumhead, the circle was sprayed with a thin layer graphite spray.

Movement. The three-dimensional movement of the drumstick was recorded using a motion detection system (Selcom Selspot) at a rate of 400 Hz. An infrared light emitting LED-marker was placed at the tip of the drumstick, 26 mm from the tip. Five more markers were placed on the players' shoulder, elbow, inner and outer wrist, and the base of the index finger (MPC joint), respectively. In addition to the motion capture, the activity of three muscles were recorded. The analysis of the arm movement and the muscle activity will not be reported here.

Audio. A high-quality omnidirectional condensator microphone (Sennheiser ME 62) was mounted at a distance of 50 cm, angled 45 degrees from the center of the drum head. The microphone was calibrated by playing a 1 kHz note simultaneously into the microphone and a dB-meter, recording the value of the dB-meter.

Contact force and duration. The contact force between drumstick and drumhead was estimated by the bending deformation of the stick. Two strain gauges formed a half-bridge, measuring the deformation in the vertical direction. The sensors were glued 180 degrees from each other and 75 mm from the tip of a Vic Firth American Classic drumstick (type 5B, length 47 mm, thickness 15 mm, weight 60 g). The output signal from the strain gauges was calibrated by observing the step function as known weights were abruptly removed.

In order to measure the contact duration, a thin copper foil was glued to the tip of the drumstick. Upon contact with the conductive graphite layer at the striking position of the drumhead, an electric circuit was closed and the signal showed a step function with a steep edge.

All acoustic measures and a trigger from the motion capture system were simultaneously sampled by a multichannel analog-digital converter (National Instrument PCI-6143) at 160 kHz, 16 bits). The signals were then lowpass filtered at a cut off frequency of 22 kHz, and downsampled to 44.1 kHz for analysis.

2.1 Player and procedure

The player participating in the experiment was a male, 38 year old, right-handed professional jazz drummer. At the time of recording he had 23 years experience and no previous history of movement disorder.

The player played one stroke at a time, with enough time to let the sound decay, instructed to listen to the sound and to play as well as possible. To avoid rotation of the stick the player was asked to pay attention so that the sensors were facing upwards before striking.

The player was first instructed to play "normal" strokes with a usual relaxed grip, letting the stick move freely away from the drumhead. For the "controlled" strokes the player was asked to control the height at which the stick *stopped*. That is, immediately after each stroke the player tried to stop the stick as close to the drum head as possible without making contact. The player was given time to try out and get acquainted with the two types of strokes before several 25-s trials were recorded, alternating the two instructions. After playing another type of task the stroke procedure was then repeated in the reversed order, starting with the controlled strokes. Then followed a short break during which the setup was made ready for recording of the other arm.

After the recording session, the player listened to the recorded series of strokes and was asked to indicate his satisfaction with the each stroke on a scale from 1 (not at all satisfied) to 5 (very satisfied).

3 Analysis

Acoustic analysis. The recording session resulted in 17 recorded trials, each leaving between 7 and 11 strokes for analysis.

Stroke onset and duration were automatically detected from the electrical signal from the contacts between drumstick and drumhead. The output of the algorithm was checked for multiple bounces and unreliable contact signal and two such strokes were removed. A total of 147 strokes (36 normal left, 36 controlled right, 41 normal left, and 34 controlled left) remained for analysis.

Figure 1 shows the output from the strain gauge pair and the measured contact duration. As seen in the figure, the force pulse is well defined.

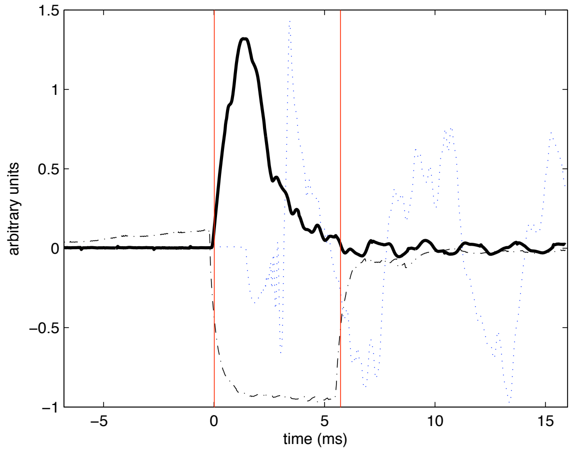

Figure 1: Measurement of contact force and duration. The curves show the output signal for contact force (full, bold line), contact measurement (dot-dashed line), and audio (dotted) in arbitrary units for one normal stroke. The automatically detected on- and offset in contact is indicated by the vertical lines.

In addition to peak force $\hat{F}$ and contact duration (dur), the impulse I was calculated by a summation of force across the measured contact duration.

Motion analysis. The 3D-movement trajectories from the six markers were checked, and outliers and data gaps repaired. The analysis was concentrated on the vertical movement of the stick, as this was assumed to be the one most important for the energy transfer at impact. After some sparse filtering, the vertical velocity of the stick directly before and after impact were detected using an algorithm virtually identical to that used in [2].

4 Listening test

A perceptual rating of the timbre and attack qualities of different strokes played was made. In order to include strokes representing the span of the performance the choice was based on the player's own assessment of the recorded strokes. That is, the "best" and "worst" stroke for each combination hand (left or right) and grip (relaxed or controlled) were identified.

For some combinations of hand and grip no extreme ratings were found. More specifically, the player did not mark an any controlled strokes played with the right hand as 5 ('very satisfied'), and the only strokes marked as 1 ('not at all satisfied') were the controlled strokes played with the right hand. Two of the strokes marked 2, instead of 1 were also included. Table 1 shows the different types of strokes represented in the listening test. In addition to the original strokes, four averaged audio signals were included. The average strokes were generated from the mean signal of strokes the player marked as 3 (intermediate).

In all, seven authentic and four averaged strokes were included as stimuli. Each stroke was repeated once, re-

No.	Player's mark	Instruction		Acoustics			Ratings	
		hand	stroke	dur(ms)	$\hat{F}$(N)	I (Ns)	timbre	attack
1	5	right	norm.	5.53	56.13	.1207	745	753
2	5	left	norm.	5.12	55.58	.1190	896	710
3	5	left	cont.	5.17	89.76	.1719	688	787
4	2	right	norm.	5.53	50.03	.1143	768	733
5	2	left	cont.	5.65	81.17	.1678	495	366
6	1	right	cont.	5.60	67.90	.1415	456	442
7	1	right	cont.	5.51	75.20	.1542	482	431
8	3	9 Right normal strokes					416	416
9	3	17 Right controlled strokes					202	267
10	3	5 Left normal strokes					454	401
11	3	23 Left controlled strokes					456	463

Table 1: Descriptors and data for strokes included in the listening test. For each stroke, the columns from left to right are the player's own mark (from 1:'not at all satisfied' to 5:'very satisfied'); with which hand ('left' or 'right') and instruction ('normal' or 'controlled') the stroke was played; contact duration (ms); Peak force (N); Impulse (Ns); and the average ratings for timbre (from 0:'flat' to 1000:'full') and attack (from 0: 'soft' to 1000:'full'). Strokes 8-11 were generated from averaged audio signals for strokes the player had marked as intermediate.

sulting in a total of 22 stimuli that listeners rated with respect to attack characteristics (soft – hard) and timbre (flat – full).

The eight listeners participating in the rating experiment were tested individually, listening to the strokes in mono using headphones. The rating was done using a sort and rate method [5] where the listener could listen and compare the different strokes, arranging them on the screen until satisfied.

5 Results

The two instructions clearly had an effect on movement of the stick as well as the acoustic measures. As expected the player did not only alter the movements after the impact, but the instructions also had an effect on the stick movement immediately before and and on the interaction drumstick – drumhead.

5.1 Stick motion

Examples of movement trajectories for the two types of strokes can be seen in the two stick figures in Figure 2. The figure shows the displacement for the wrist, MPC joint, and stick markers, interconnected by straight lines. To make the overall pattern clearer, each data point has been slightly translated in relation to the previous one. Tracing the trajectory for the marker at the drumstick, the uplift, downstroke, and rebound is clearly seen. For the controlled stroke (right panel) the player is restraining the stick from rebounding up to its normal height after the stroke. Although the the average striking velocity for the normal strokes was lower compared to that of the controlled, the velocity *after* impact was higher for normal strokes. The absolute difference between velocity before and after impact was greater for controlled compared to normal strokes (two tailed t-test, $t = 19.42$, $df = 69.21$, $p < 0.001$). That is, more of the kinetic energy in the stroke was transmitted to the drumhead for the controlled strokes.

5.2 Listeners' ratings

The consistency in ratings was measured as the correlation between how listeners rated repetitions of individual stroke files. For both timbre and attack consistency was high, with average coefficients of 0.81 and 0.79, respectively. On average, each stimulus was played 16 times.

As expected, the ratings differed depending on the type of stroke a stimulus was based on (see Table 1). Listeners consistently rated the normal strokes as having fuller timbre and harder attack compared to controlled strokes. Figure 3 show the timbre and attack ratings for the averaged and authentic normal and controlled strokes. Two-sample Wilcoxon tests showed the difference to be significant for both timbre ($W = 2677$, $p < 0.001$) and attack ($W = 2327.5$, $p < 0.001$).

In general, the four synthesized stimuli received rat-

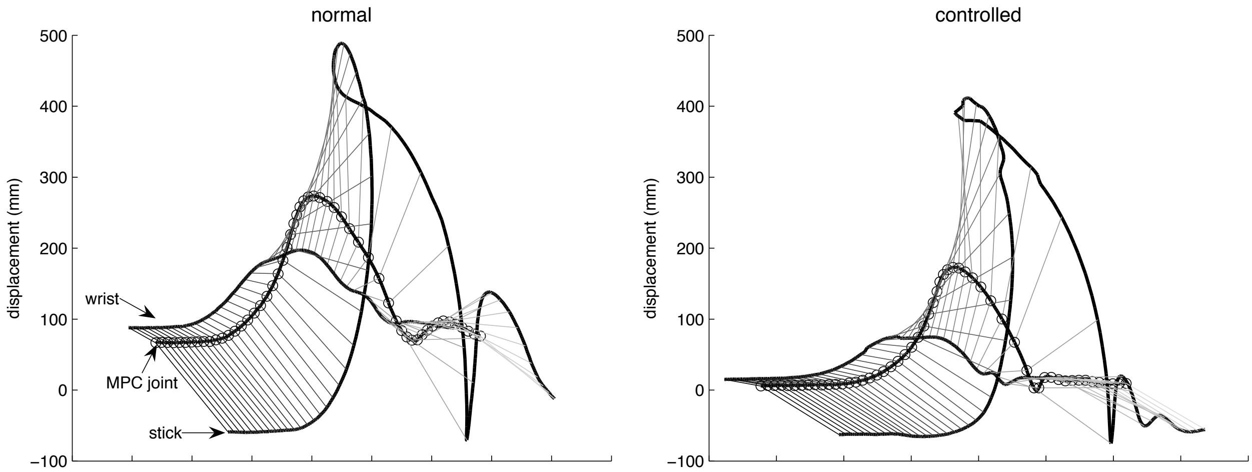

Figure 2: Stick figures for a normal (left) and controlled (right) stroke (strokes No. 2 and 6 in Table 1). The figures show, from left to right, the vertical position of the wrist, finger, and stick marker at different time instances. The time separation between frames is 25 ms and trajectories are translated in the y-direction for clarity. The path of the marker close to the fulcrum point at the index finger knuckle (MPC joint), is indicated by circles. As can be seen from the rightmost trajectory in each plot, the stick rebounds freely for the normal stroke, and is restrained shortly after impact for the controlled stroke.

ings in the lower end of the scale. In particular stroke No. 9, a mean across 17 controlled strokes played with the right hand, was rated as having flat timbre and a soft attack.

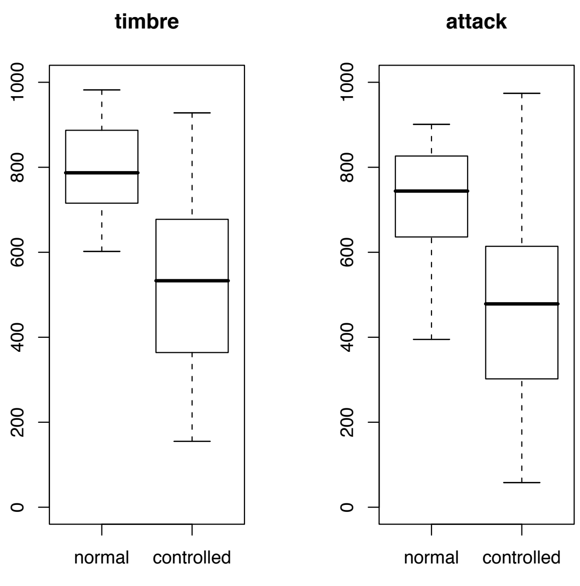

Figure 3: Timbre and attack ratings for normal and controlled strokes (strokes No. 1–7 in Table 1). The main concentration of ratings can be found in each “box”, with the black bars indicating median values. The whiskers indicate the highest/lowest rating to fall within a distance of 1.5 times the box edge.

In informal interviews after the listening test, participants stated that they had, in general, a preference for the strokes they rated as having full timbre. For the attack some listeners preferred hard attacks, whereas others liked the strokes with attack in the middle range.

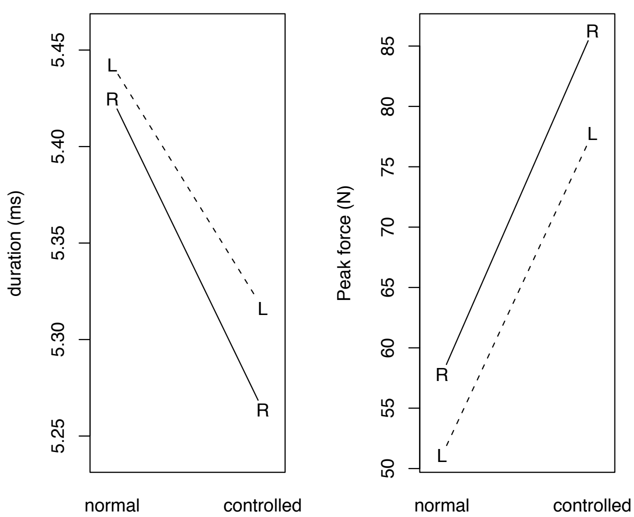

Figure 4: Contact duration (left panel) and Peak force (right panel) for the different arms (right and left) and types of strokes (normal and controlled) measured.

5.3 Acoustic measures

The contact duration, peak force and impulse were clearly influenced by the type of stroke. On average, the controlled strokes displayed shorter contact duration and higher peak force compared to normal strokes. Figure 4 displays the influence of stroke type and hand used on contact duration (left panel) and peak force (right panel). As can be seen in the figure, there was some effect also with the arm used. This is to be expected as performance generally differ slightly between the preferred and non-preferred hand. However, only one arm at a time was recorded and thus this difference is likely to be reduced when left and right arms are playing alternately.

Comparing the measurements and the ratings for attack and timbre one can see that sounds with high peak force and shorter contact durations were not necessarily rated as having hard attack or full timbre. Figure 5 displays the force pulses for the strokes in Figure 2, together with an average across 17 controlled strokes (used for stimulus No. 9). Stimulus stroke No. 2 (bold line) was considered giving rise to a full timbre and hard attack, whereas listeners considered stroke No. 6 (thin, full line) to be more flat and have a softer attack. The averaged force pulse appears to be similar to that of No. 6 in shape and magnitude. The corresponding sound average (stimulus No. 9 in Table 1) was the stimulus rated as most flat and with the softest attack.

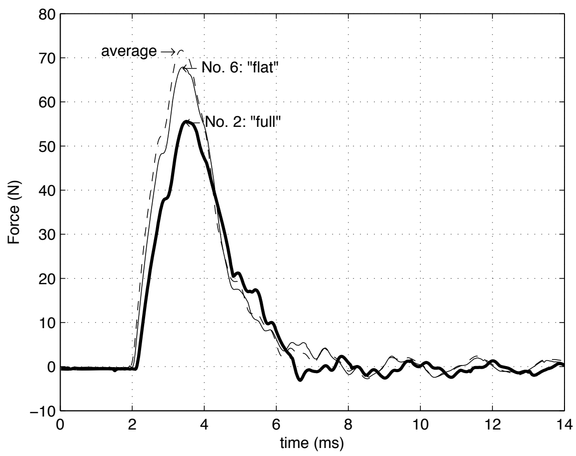

Figure 5: Comparison of force pulses for strokes No. 2 (bold line) and 6 (thin, full line) from the listening test, together with an averaged force pulse (dashed line). The average was calculated as the mean from 17 controlled strokes with the right hand (No. 9 in Table 1).

6 Discussion and conclusion

In this paper we have investigated how the interaction between drumstick and drumhead is influenced by the grip of the player. Our experiment showed that it is possible to influence the grip by giving instructions to what extent the stick is allowed to rebound after the stroke. Such constraints are frequently used in different styles of playing (see e.g. [4]) Ideally, such an adjustment of the stick should be made after the stick has left the drumhead. In practice, however, the player must adjust the grip already during the downstroke.

The changed stick – drumhead interaction altered the sound characteristics of the strokes in our study. In the listening test, the controlled strokes were rated as being more flat or dull compared to the normal strokes. The controlled strokes were also rated as having a softer attack, despite the significantly higher peak force for these strokes.

Compared to the normal strokes, the controlled strokes had shorter contact durations and higher peak force. This result was somewhat surprising. Intuitively, one might expect longer contact durations when the drumstick is not free to rebound away from the drumhead. A longer contact duration could interfere with the vibrations of the drumhead, dampening some modes, and therefore give rise to dull, dampened timbre. However, the altered grip for the controlled strokes appeared to have affected both the effective mass and possibly also the stick modes. Through the tightened grip the stick may have been clamped enough to set other stick modes into vibration compared to a normal stroke.

The results presented here are part of a work in progress. Nevertheless they demonstrate that the grip is, indeed, important for the sound when playing. An extended acoustic analysis using data from more players will be reported in forthcoming studies.

7 Acknowledgments

The authors are indebted to Normann Plass and Dieter Drescher for help with the experimental setup, and Michael Grossbach for help with setup, testing of the experiment equipment, running experiments and helpful suggestions.

This work was supported by the European Commission through a MOBILITY-2.1 Marie Curie Intra-European Fellowship (EIF).

References

[1] S. Dahl. Spectral changes in the tom-tom related to striking force. Speech Music and Hearing Quarterly Progress and Status Report 1, KTH, Dept. of Speech, Music and Hearing, Royal Institute of Technology, Stockholm, 1997.

[2] Sofia Dahl. Playing the accent - comparing striking velocity and timing in an ostinato rhythm performed by four drummers. *Acta Acustica united with Acustica*, 90(4):762–776, 2004.

[3] Sofia Dahl. Movements and analysis of drumming. In Eckart Altenmüller, Mario Wiesendanger, and Jürg Kesselring, editors, *Music, Motor Control and the Brain*, pages 125–138. Oxford University Press, New York, 2006.

[4] Don Famularo. *It's Your Move. Motions and Emotions.* Warner Bros. Publications, 1999.

[5] Svante Granqvist. The visual sort and rate method for perceptual evaluation in listening tests. *Logopedics Phoniatrics Vocology*, 28:109–116, 2003.

[6] Andreas Wagner. Analysis of drumbeats - interaction between drummer, drumstick and instrument. Master's thesis, KTH Computer Science and Communication, Stockholm, Sweden, 2007.