Effect of dynamic level in drumming: Measurements of striking velocity, force, and sound level.

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Summary
Four professional percussionists played single strokes on a single headed drum (rototom) at different tempi and dynamic levels. The movements of the stick and players' arm were recorded using an optical motion capture system. The players used a drumstick equipped with strain gauges, and the bending deformation of the stick provided an estimate of the contact force between drumstick and drumhead. The data shows close relationship between the height to which the drumstick is lifted before a stroke, and its striking velocity. The players' different control strategies and interpretation of the dynamic levels is reflected in both striking velocity and measured peak force.

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1. Introduction

Percussion instruments can produce sounds over a very wide dynamic range. When using an implement, such as a drumstick or mallet, a percussionist is able to excite the instrument even more than when playing with hands only. However, In order to play a sequence of strokes with similar sound characteristics and loudness, a player needs to have detailed control of the stick movement. The drumstick will strike the drumhead with the velocity and effective mass supplied by the player's movement, and then quickly bounce away. The interaction time is very brief, and once a stroke is initiated a player has small possibilities of altering it.

In order to control timing and sound characteristics of individual strokes, percussionists use preparatory movements. A player can ensure sufficient striking force by creating a runway during which the stick increases its velocity before impact. Previous work has shown professional players to adjust the height from which a stroke is initiated to the dynamic level [1, 2]. By adjusting the distance during which the stick is accelerated, louder sound levels can be produced at low physiological cost. In this work, we recorded movement, force, and sound level with the aim to investigate how percussionists control loudness during drumming.

2. Method

Drum. 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, 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 of 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.

Contact force and duration. The contact force between drumstick and drumhead was estimated by the bending deformation of the stick(Vic Firth Americal Classic type 5B, length 47 mm, thickness 15 mm, weight 60 g). Two strain gauges glued to the stick, forming a half-bridge, measured the deformation in the vertical direction. 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.

When using a half-bridge configuration, rotation of the stick could pose a potential problem for reliability. At slow tempi, it was possible for the player to monitor the position of the LED-marker on the stick, and to avoid rotation. Force values will therefore be reported for the slowest tempo only.

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. One exception was the first player recorded, where the microphone was placed closer, 40 cm from the center of the drum head, resulting higher measured peak levels for this player.

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.

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. Players and procedure

The players participating in the experiment were four male, right-handed professional percussionists

After the attachment of LED markers the player was given time to try out the equipment and to adjust the height and the position of the drum throne in relation to the drum (which was centered in the motion capture area). When the player was satisfied and reported that no cables distracted the playing, the recordings started.

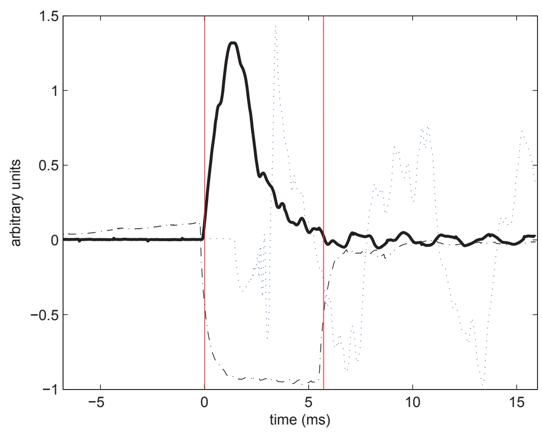

Figure 1. Measurement of contact force and duration. The curves show the output signal for contact force (full, bold line), contact measurement (dot-dashed line), and audio (dotted) in arbitrary units for one normal stroke. The automatically detected on- and offset in contact is indicated by the vertical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

For each arm, combinations of three dynamic levels (p, mf, and f) and tempi (50, 120, and 300 beats per minute), yielding 18 trials (3 tempi x 3 dynamic level x 2 repetitions) were recorded. The order was randomized and to avoid fatigue the trials were separated in three blocks, interleaved with another task (see [3]).

At the start of each trial, the experimenter indicated the dynamic level to be played and started a metronome to which the player synchronized. The player was asked to synchronize each stroke with the metronome, without subdivision, and - if possible - avoid rotating the stick so that the sensors were facing upward. When the nominal tempo was established, typically within 5 s of synchronization, the multichannel recording was started and three seconds later the experimenter turned off the metronome and 25 s of motion capture was recorded.

After recording two repetitions at each dynamic level and tempo, a short break followed during which the setup was made ready for recording of the other arm.

3. Analysis

Motion analysis. The 3D-movement trajectories from the six markers were checked, and outliers and data gaps repaired. After some sparse filtering, the vertical velocity of the stick directly before impact were detected using an algorithm virtually identical to that used in [2]. The *preparatory height* was measured as the maximum vertical position before the stroke.

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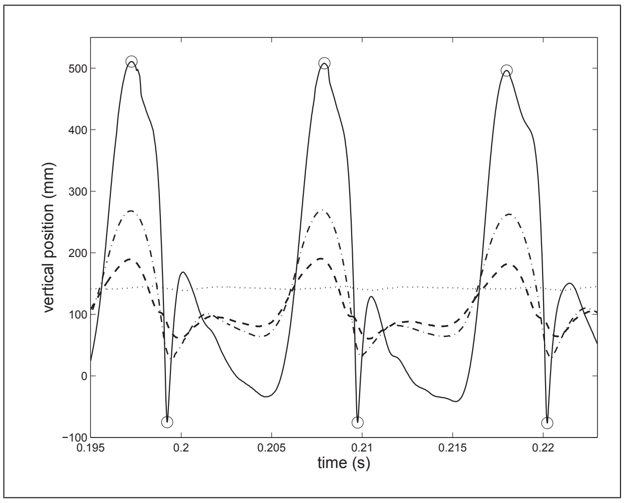

Figure 2. Vertical trajectories of markers at a drummer's elbow (dotted), wrist (dashed), MPC-joint (dot-dashed), and drumstick (full line) during three strokes at slow tempo. Circles mark the hits and the preparatory heights of the stick. It is clearly seen how movement magnitude decreases with distance from the drumstick.

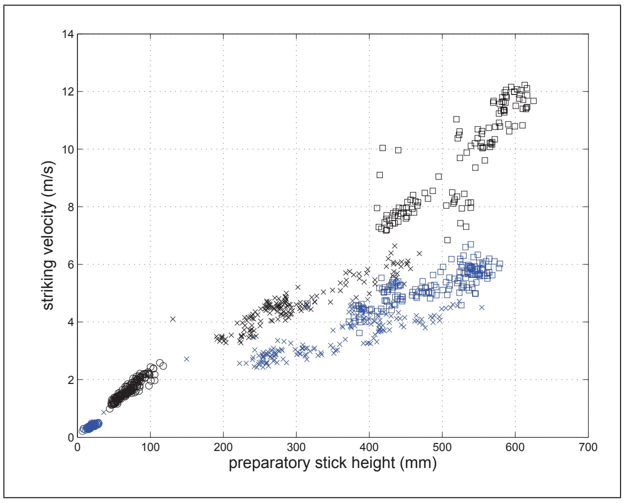

Figure 3. Striking velocity vs preparatory height for strokes at p (circles), mf (crosses), and f (squares) for two players. Strokes in black were played by the same percussionist as in Figure 2, while the strokes in blue were performed by another professional player with a slightly different movement strategy. Both players adjust the preparatory height in response to different dynamic levels. The spread within each dynamic level is partly due to differences between the two arms (which were recorded separately).

Acoustic 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, which were removed.

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. The peak force was measured as the maximum force within the measured contact duration for each stroke. Peak sound level was measured as the maximum, absolute value of the waveform within a window of 17 ms.

4. Results

4.1. Preparatory movements

The movement analysis showed differences between players and also between arms used, an expected result.

Examples of movements for strokes at slow tempo can be seen in Figure 2. The figure displays vertical displacement of markers at the stick, MPC-joint, wrist, and elbow during three strokes at slow tempo for one professional player. The preparatory movements are seen as peaks in the trajectories of the markers on the hand and drumstick. The preparatory movement is initiated from the wrist and hand, which lead the drumstick up to its maximum height before the actual down stroke (marked with circles).

Despite differences in players' movement strategies, all players clearly adjust the preparatory height in response to different dynamic levels. Figure 3 displays the close relationship between preparatory height and striking velocity for two players. The different dynamic levels are indicated by circles (p), crosses (mf), and squares (f). As can be seen in the figure, the relationship is close to linear, but with different slope. The interpretation of the dynamic levels differs between the two players. Strokes at f played by player 1 (in blue) produce striking velocities around 4–6 m/s, in the same range as those player 2 use for stroke at mf. Differences between the two hands (which were recorded separately) can be seen as different "clusters" within each dynamic level .

4.2. Contact force and duration

The differences in movement strategies used was reflected in the dynamic range of the data with measured peak forces ranging from 1.8 to 106.8 N, with a mean of 32.4 N across players.

Figure 4 shows measured contact durations and peak force for all players playing at slow tempo and three different dynamic levels. The inverse relationship between peak force and contact duration is clearly seen. The contact durations are between 4.5-8 ms, in the same range as has been reported for strokes at the center of a tom tom [4] or snare drum [5].

5. Concluding remarks

The data presented in this paper further adds to our understanding on how professional percussionists use

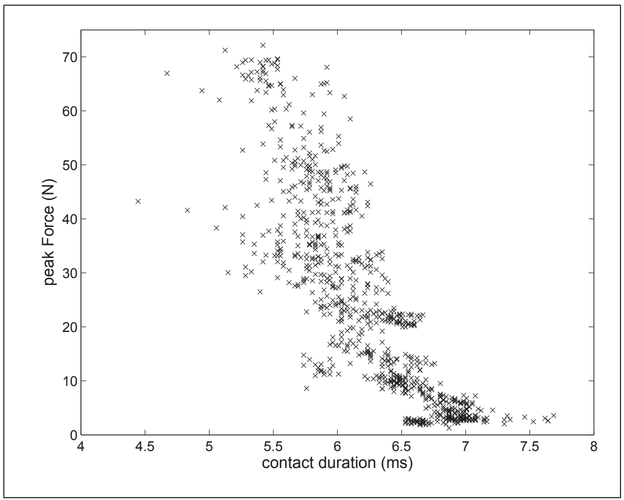

Figure 4. Contact duration and peak force for four players playing at three dynamic levels at 50 beats per minute.

preparatory movements to control playing at different dynamic levels. The data is in line with earlier work reporting changes in preparatory height with dynamic level [2] and observed contact durations between drumstick and drumhead [4, 5]. Ongoing work aims to model the interaction between player and instrument by linking movement and force data to produced sound.

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