Once again: The perception of piano touch and tone. Can touch audibly change piano sound independently of intensity?

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Abstract

This study addresses the old question of whether the timbre of isolated piano tones can be *audibly* varied independently of their hammer velocities — only through the type of touch. A large amount of single piano tones were played with two prototypical types of touch: depressing the keys with the finger initially resting on the key surface (*pressed*), and hitting the keys from a certain distance above (*struck*). Musicians were asked to identify the type of touch of the recorded samples, in a first block with all attack noises before the tone onsets included, in a second block without them. Half of the listeners could correctly identify significantly more tones than chance in the first block (up to 86% accuracy), but no one in block 2. Those who heard no difference tended to give struck ratings for louder tones in both blocks.

1. Introduction

For almost a century, physicists and musicians have been arguing whether it is only the final hammer velocity that determines the sound of a piano tone or whether a pianist can additionally influence the piano timbre by varying the way of touching the keys. Pianists study for many years extremely intensively to advance their technique of touching the keys so that the outcoming sound satisfies their (and their teachers) high artistic demands. They establish and refine various kinds of accelerating the keys in order to obtain finest timbral shades so that it might be hard for them to believe that piano timbre might be expressed by a single physical parameter. The physicist, on the other hand, argues that the pianist loses control over the hammer after the jack is escaped by the let-off button. Therefore, it is only the endmost velocity of the hammer that determines the intensity and thus the timbre of the piano tone.

The two positions are apparently contradictory, but they are not necessarily. A pianist manipulates naturally all expressive parameters simultaneously when playing a piano, so there might be audible differences in sound when two tones are played with different types of touch. However, it is very likely that in such an uncontrolled case, more parameters than only final hammer velocity have been varied. For scientific investigation, we have to reduce the problem to its very essence: Is it possible to produce two isolated piano tones without using the pedal with identical final hammer velocities, but with audibly different sounds?

Apart from 'historic' studies starting from the 1920s [1, 2, 3, 4, 5, 6, 7], the more recent literature found different kinds of noise that emerge when the key is struck in different ways [8, 9, 10]. The most prominent noise emerges when the hammer hits the strings (hammer–string noise, "attack thumb" [8]). This noise characterises the specific sound of the piano, is most prominently audible in the treble strings, but cannot be varied with type of touch independently of hammer velocity.

When a key was hit from a certain distance above, a characteristic finger–key noise was found to occur 20–30 ms before the actual tone ("touch precursor" [8], "early noise" [9]). This noise was clearly visible in audio wave form plots. Although the authors reported that listeners could easily distinguish between tones that were played from above and those played from the keys, no systematic listening test was reported [9].

Although measurement tools improved since the first systematic investigations in the 1920s, no more conclusive results could be obtained as to whether the touch-variant noise components (especially finger–key noise) can be aurally perceived by listeners not simultaneously involved in tone production. This study investigates whether musically trained participants in a controlled experimental situation are able to distinguish between different types of touch, even if the finger–key noises are removed.

2. Method

2.1. Participants

The 22 participants were aged between 23 and 46 years with a mean of 31.2 years. All were practising musicians or musically well trained; 13 of them had piano as main instrument, the others play violin, guitar, violoncello, and clarinet. They had been playing their instruments between 8 and 36 years (mean = 21.7); 18 of them had studied their instrument at a post-secondary level for an average period of 8.8 years (2–18 years).

2.2. Stimuli

The piano tones were samples recorded on a 173-cm Yamaha grand piano (the same recordings as in [11]). The middle C (C4, 261.6 Hz) was played by two pianists (WG, RB) with two different types of touch: one with the finger initially resting on the key surface and pressing it down (*pressed*), and one hitting the key from a certain distance above (touching it already with a certain speed, *struck*).[1] The hammer movement was monitored with one accelerometer mounted at the front end of the hammer shank and another one at the front side of the key. The microphone was placed close to the strings (about 10-cm distance), and the digital recordings were sampled mono at 16 kHz with 16-bit word length (for details, see [11]). Each sample started 250 ms before hammer–string contact (as measured from the hammer accelerometer) and lasted for 750 ms, so all possible noises emerging from hitting the keys were included in the stimuli.

From the recorded samples, we selected 100 isolated tones from the two pianists and for the two touch conditions so that each of the four groups comprised 25 tones and case-wise similar maximum hammer velocities. The hammer velocities ranged from 0.37 to 4.07 m/s with a mean of 1.65 m/s.[2] In Figure 1, we show two typical piano tones. Their hammer velocities are almost equal, but they were played with two types of touch. The pressed tone (Fig. 1a) exhibits a gradual increase of key velocity, whereas the struck tone (Fig. 1b) shows a very sudden jerk. Parallel to this first key impulse, there is a clearly visible (and audible) knock in the audio wave form.

2.3. Procedure

The stimuli were presented to the participants via headphones. A graphical user interface provided play buttons and rating radio buttons for all stimuli of a block at once arranged in random order. The participants had to judge whether a piano key was originally pressed or struck by the pianists in a two-alternative forced choice paradigm. They could listen to each stimulus as often as wanted and in any order they liked until they were sure about all their judgements. In a first block, they listened to all 100 tones. After a short break, they listened to a selection of 48 tones in which the first 250 ms before hammer–string contact were replaced by silence so that all attack noises prior to the sound were removed. The task was then the same as before.[3]

3. Results & Discussion

The participants needed usually 20 to 25 minutes to accomplish the first block and 5 to 7 minutes for the second.

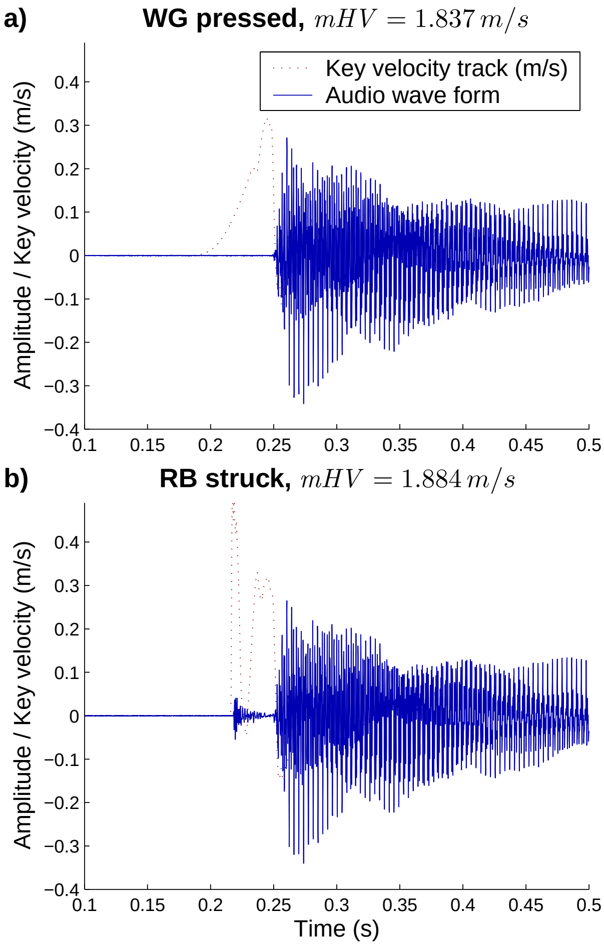

Figure 1: Audio wave form and key velocity pattern (dotted line) of two piano tones with similar hammer velocity. The upper tone was played with the finger initially resting on the key surface (a), the other struck from a certain distance above (b).

They found the test quite difficult throughout. A minor portion of them admitted that they did not hear any differences and that they had to guess. In contrast to the second block, where the overall accuracies were throughout at chance level, the overall recognition rates were much better in the first block: Four of the 22 participants got 80–86% correct, five 70–80%, two 60–70%, and the other 11 rated at chance level.[4] Overall, half of the participants identified significantly more tones correctly than chance, the other half did not.

In Figures 2 and 3, the relative frequencies of correct ratings are plotted separately for touch condition and pianist for the two blocks, respectively. The error bars indicate the range of an insignificantly different accuracy according to the χ^2 statistic with $n = 22 \times 25 = 550$ and $p < 0.05$. In the first block, participants identified around two thirds of the pressed tones correctly on aver-

[1] In previous papers, we used instead of "pressed – struck" "legato – staccato," a terminology introduced by [12]. We changed to the present terminology to avoid confusion with terms referring to articulation.

[2] The standard deviation for each of the 25 hammer-velocity quadruples ranged between 0.005 and 0.237 m/s with a mean at 0.065 m/s.

[3] The entire stimulus material can be accessed at `http://www.oefai.at/~wernerg/pianosound/`.

[4] Accuracies between 59.8% and 40.2% are not significantly different from chance according to the χ^2 statistics with $n = 100$ and $p < 0.05$.

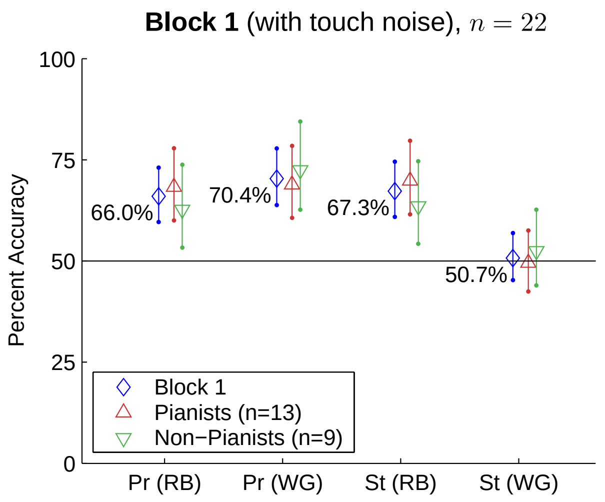

Figure 2: Relative frequency of correct ratings (accuracy) of all participants for block 1 (with touch noise), separately for two touch conditions (struck, "St" and pressed, "Pr") and two pianists ("RB" and "WG"). Error bars denote the range of an insignificant difference according to the χ^2 distribution with $p < 0.05$. Additionally, triangle plots show the accuracy for pianists (upward pointing triangle) and other musicians (downward pointing triangle).

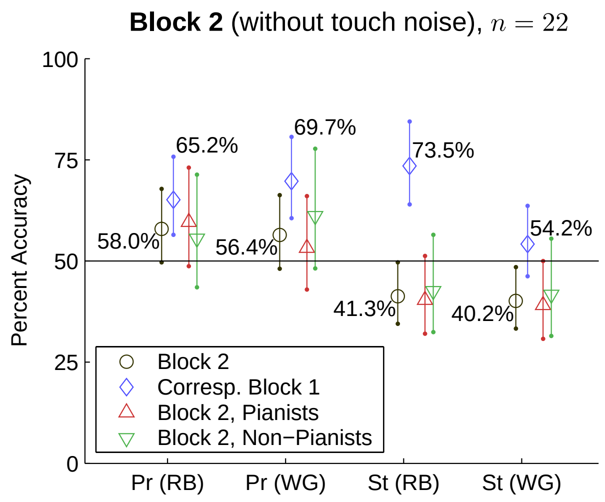

Figure 3: Accuracy of all participants for block 2 (without touch noise, circles with error bars), as in Figure 2. Empty diamonds denote the ratings of the corresponding stimuli from block 1. Triangle plots show ratings for pianists and other musicians, respectively.

age. They had the same accuracy for the struck tones, but only when RB played them; those played by WG were judged randomly. This result is due to differences in the stimuli played by the two pianists. The finger–key noise was clearly more present in RB's struck tones than in those played by WG. It might be that although both pianists hit the key surface from a certain distance above, RB played with a slightly different position of the finger tip that produced a more prominent impact noise.

In block 2, they heard a selection of the first-block stimuli with the touch noises before the actual tone replaced by silence. As Figure 3 shows, the listeners could not correctly identify the type of touch anymore. The ratings for pressed tones were not significantly different from chance. Those for the struck tones had a small but significant tendency to be erroneously perceived as pressed tones. These results confirm that the cue for differentiating the two types of touch were the touch noises before the actual tone.

It might be assumed that pianists perform in this touch identification task better than other musicians, because they are especially familiar with piano sounds and different touch conditions. In Figures 2 and 3, the accuracies are plotted separately for pianists and non-pianists (upward and downward pointing triangles, respectively). The differences are small and insignificant. These results are consistent with the overall accuracies we considered before: From the 11 participants who heard significantly better than chance were 7 pianists and 4 other musicians, whereas among those eleven who identified nothing were 6 pianists and 5 non-pianists. It is evident, that pianists and other musicians were able to judge equally well.

From those 11 participants who did not hear any difference (rated at chance level), 7 rated the stimuli clearly according to their intensity: The louder a tone the more they tended to judge it a struck one. Evidence came from highly significant (positive) correlation coefficients between rating and hammer velocity ($0.27 < r_{pb} < 0.78$, all $p < 0.01$).[5] This tendency was also found with some of the good identifiers. From them, four had significant correlation coefficients between 0.24 and 0.32 ($p < 0.05$). This finding suggests that when participants were unable to identify the actual cue in this listening test (touch noise), they assigned touch by tone intensity. This is both obvious and interesting. On the one hand, louder sounds always involve larger and faster body movements (hands, arms, etc.), while softer tones require smaller, more controlled movements. This applies not only for the piano, but also for other instruments, as e.g. string or percussion instruments. Therefore it is not surprising that some participants connect loud with struck and vice versa. Moreover, a struck touch generates typically loud and loudest tones, while a pressed touch provides more tone control and is typically applied for soft and softest tones (as reported in [13]). On the other hand, this finding provides empirical evidence for a phenomenon that might be essential for synthesis of sounds communicating body movements in general.

The present results are also essential for the conceptual design of computer-controlled reproducing pianos. They rely entirely on the hammer-velocity-only assumption, measuring and reproducing only the final hammer

[5] Using the point-biserial correlation coefficient between rating (dichotomous variable) and hammer velocity (continuous variable).

velocities — up to now with extremely convincing results. However, noises different from the human fingers emerge at machine playback.

We tested an extreme condition: single tones at a 10-cm distance from the strings, a position that even a performer is usually not able to listen from. First, it is interesting that finger–key noises are so salient in the audio signal recorded close to the strings (compare findings reported in [8]). And second, it is remarkable that the different touch conditions were not identified more correctly given how salient those noises were in the stimuli. This might be explained by the absence of other cues, as e.g., visual or hapto-sensorial information. We expect that especially hapto-sensorial feedback to the player influences considerably his/her aural perception of a played tone, since this feedback changes substantially with the type of touch (cf. [14]). However, we expect that the listeners' accuracy in this test would improve considerably, if they were instructed to listen to the touch noises and with training.

4. Conclusion

This study confirms that the difference between two equally loud piano tones due to type of touch lies in the different noise components involved in the keystroke [8, 9]. These noise components (i.e. finger–key noise) are audible when the key is struck, and absent when it is pressed down. This study provides a first systematic perceptual evaluation of whether musicians can aurally identify the type of touch that produced an isolated piano tone, independently of hammer velocity. Our results suggest that only some musicians are able to distinguish between a struck and a pressed touch using the touch noises as cue, especially the finger–key noise that characterises a struck attack, whereas others could not tell any difference. Without those touch noises none of them could tell a difference anymore. When they could not hear the touch differences, they tend to rate louder tones as being struck, and soft tones as being pressed. We can only speculate about how the present findings generalise to a real-world concert situation (including pedals, reverberation, reflections, and the listener at a certain distance away from the piano). In the light of the present results, we consider the pure aural effect of touch noises (excluding visual and other cues) a rather small one.

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