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Technical Note

Assessment of dynamic finger forces in pianists: Effects of training and expertise

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Abstract

Playing a musical instrument requires complex sensorimotor programming of hand and finger movements. During musical training motor programs are optimized to achieve highest accuracy with a minimum of effort. In the lack of handy measurement tools these rational assumptions of piano theorists did not undergo an experimental evaluation up to now. In the present pilot study we used a dynamic pressure measurement system with the pianoforte. Three finger exercises with increasing degrees of difficulty had to be performed by a group of musical amateurs and a group of expert players. From the dynamic force measurements we calculated (a) the mean pulse per touch and (b) the mean touch–duration for each exercise and each subject. To achieve the same tempo and the same loudness, amateurs applied significantly more and longer force to the keys, leading to higher mean pulses per touch. Pulse and duration values increased with higher demands on finger coordination in both, expert pianists and amateurs. The results show that dynamic force measurement systems can support music learners and teachers in training a relaxed piano technique and preventing musicians from overuse injuries.

Keywords: Motor control; Force economy; Expert performance

1. Introduction

An uneconomic use of force in piano playing is recognized as a risk factor for developing overuse injuries, tendinitis, or chronic pain syndromes (Fry, 1989). Due to the fact that no handy measurement facilities were available, until today only few experimental data on forces and durations of piano touches exist. Wagner (1987) recorded the temporal course of the lever-motion and the force applied on a single piano key using strain gauges applied to the key lever. He demonstrated characteristic differences between expert pianists and amateurs with uneconomical expenditure of force in the amateurs. However, since only forces from a single key could be assessed, coordinate tasks, which are more close to the pianist's daily reality could not be investigated.

The present experimental study was designed to surpass these restrictions, using a force measurement method which provides data from five keys simultaneously. The aim of the investigation was to delineate characteristic differences in force-economy due to instrumental expertise. Furthermore, we were interested in whether the degree of difficulty in the coordinate demands affects force control.

2. Methods

2.1. Measurement system

For the experiments, the commercially available f-scan sensor–matrix–foil (tekscan inc. Boston, MA) containing 960 sensors per foil (4 cm^{-2}) was used. The foil that was originally developed to record spatiotemporal pressure distributions in shoes was adopted for a grand piano. It is flexible, extremely thin and can be applied in the key-bed beneath five adjacent white keys (c″–g″, grand piano Steinway B, Fig. 1). The felt under each key was removed and replaced by the sensor foil fixed with a two-sided sticky tape on a sheet of metal. Then the matrix foil was adjusted so that the same count of sensors was touched by each key. Finally, the sensor-unit was

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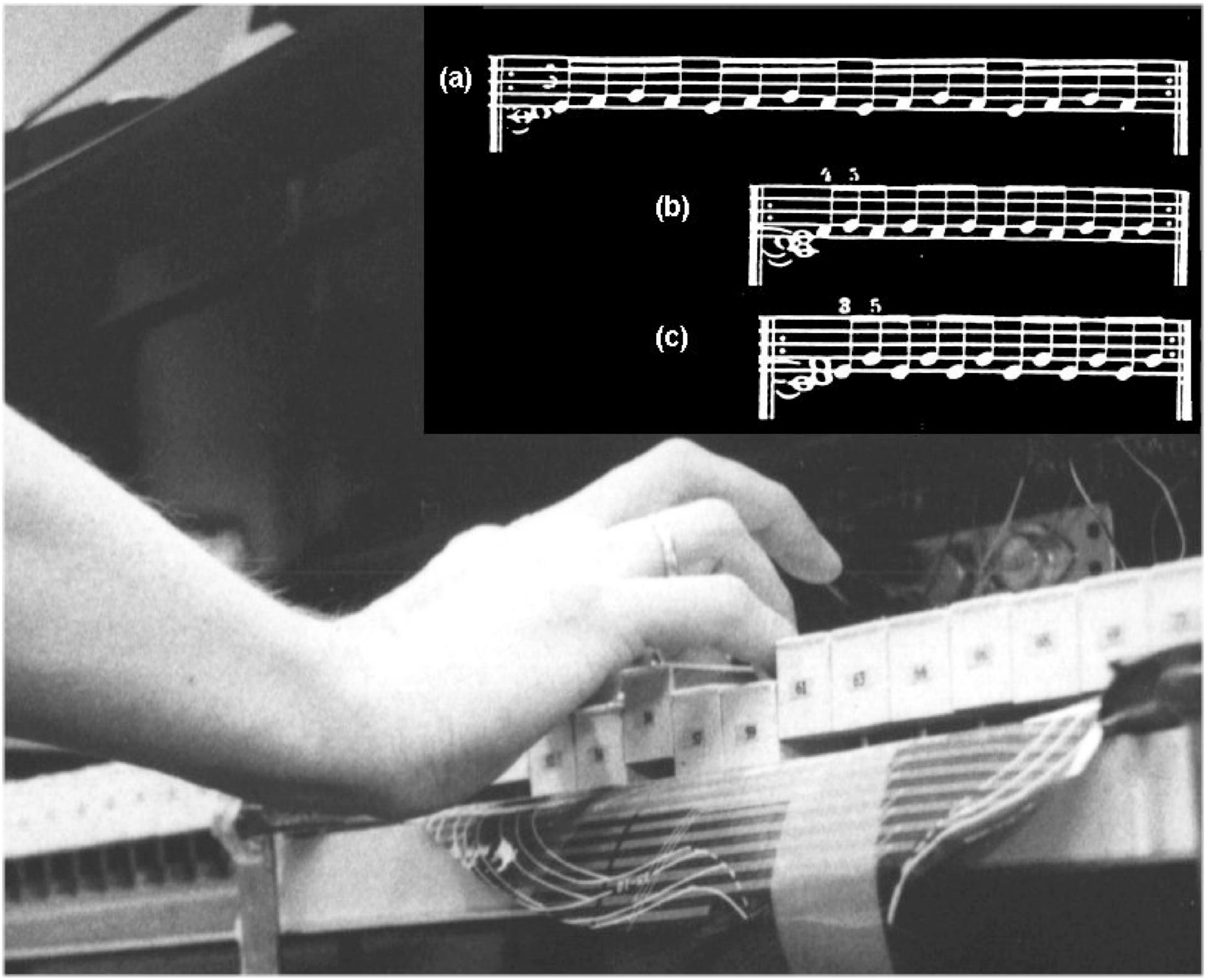

Fig. 1. The F-scan sensor foil was placed beneath 5 adjacent white keys (c″–g″) and all subjects had to play so called 'tied finger exercises'. Three different exercises with increasing difficulty from (a)–(c) were taken from Dohnányi (1929). The photograph shows a subject playing exercise (c), when striking the little finger (5) and lifting the middle finger (3), while thumb, index and ring-finger are tied down.

connected to a special measurement card in an IBM-compatible PC 486.

The F-scan software allows for the definition of four measurement areas that can be analyzed independently. For our experiments, we combined the areas under keys c″ and d″ (1st and 2nd finger) and let the other three key-areas separate. Data were collected at a sample rate of 80 Hz.

2.2. Subjects

Two different groups of healthy and right handed subjects were tested: (a) ten expert players (5 females, 5 males; average age 23; range 20–29), who had started piano-playing at the average age of 6 y and were practicing presently about 4 h a day.

(b) Ten musical amateurs (3 females, 7 males; average age 29; range 17–55), who had started piano-playing between 5 and 20 y of age. The average duration of daily practice was below 1 h.

2.3. Tasks

Subjects had to play the so-called 'tied finger exercises', i.e. some fingers were depressing piano keys and holding them down for the entire exercise, while the remaining fingers executed key-strokes (Fig. 1). The fingers that remained stationary we refer to as 'tied down'. Three exercises at different levels of difficulty were taken from Dohnányi (1929). In exercise (a), the thumb and index finger were tied down, whereas the middle-finger, ring-finger and the little finger strike the keys alternately. In exercise (b), the thumb, the index, and the middle finger were tied down, whereas the ringfinger and the little finger strike the keys alternately. In exercise (c), which is judged generally as more difficult than the previous exercises, the thumb, the index and the ringfinger were tied down, whereas the middle and the little finger press the piano keys alternately. The motion patterns had to be performed at a controlled loudness-level (65 dBA, equivalent to a 'forte' tone) and speed (60 bpm). Each exercise of 30 s duration was repeated 3 times, with 2 min breaks in between. During each break the system was recalibrated statically using 3 kg weights. The experiment was in all subjects started with exercise a, followed by b and c.

2.4. Analysis

Since in pianos the tone generation is finished after the hammer has activated the string, each effort after an initial pulse is wasted. Therefore, as parameters describing the force-economy we calculated (a) the average pulse per touch by integrating the force–time curves and dividing the results by the number of touches per measurement period and (b) the duration of touch, i.e. the time interval between touch onset and the decrease of force below our measurement resolution (< 2 N). Since all tasks had to be performed at a tempo of 60 bpm, the subjects played one touch per second and the maximum touch duration never exceeded 1 s.

3. Results

The main phenomenon can already be seen in the raw-data-plots of single measurements in each group. In Fig. 2 the first force–measurement of exercise (b) is shown for an expert player (age 23, solid lines) and an amateur (age 55, dotted line). Touches of the fourth and fifth finger

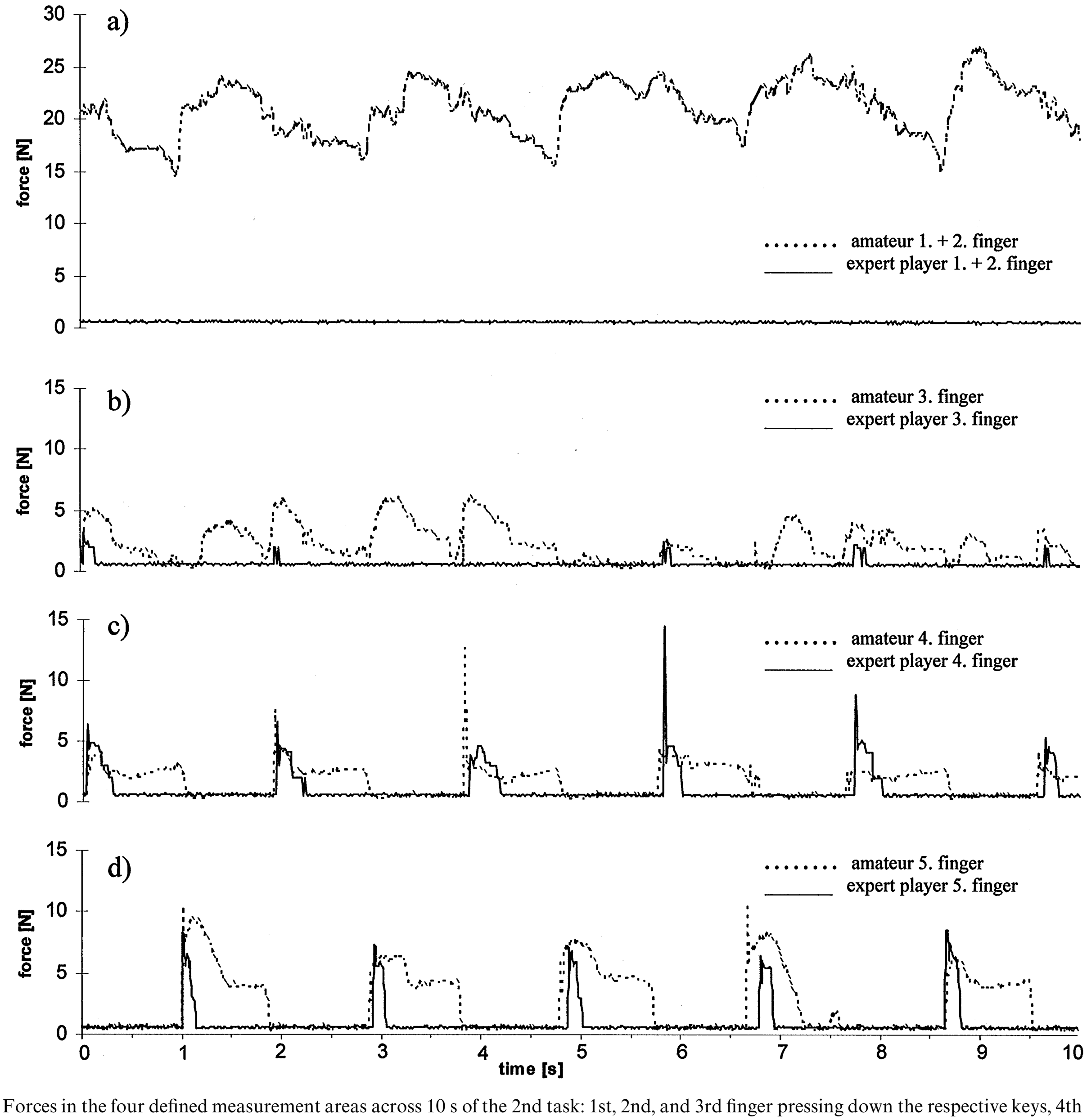

Fig. 2. Forces in the four defined measurement areas across 10 s of the 2nd task: 1st, 2nd, and 3rd finger pressing down the respective keys, 4th and 5th finger playing alternately. The touches of the expert player are short and precise whereas the amateur (dotted line) shows an uncoordinated and uneconomic waste of forces, especially in the non-playing fingers.

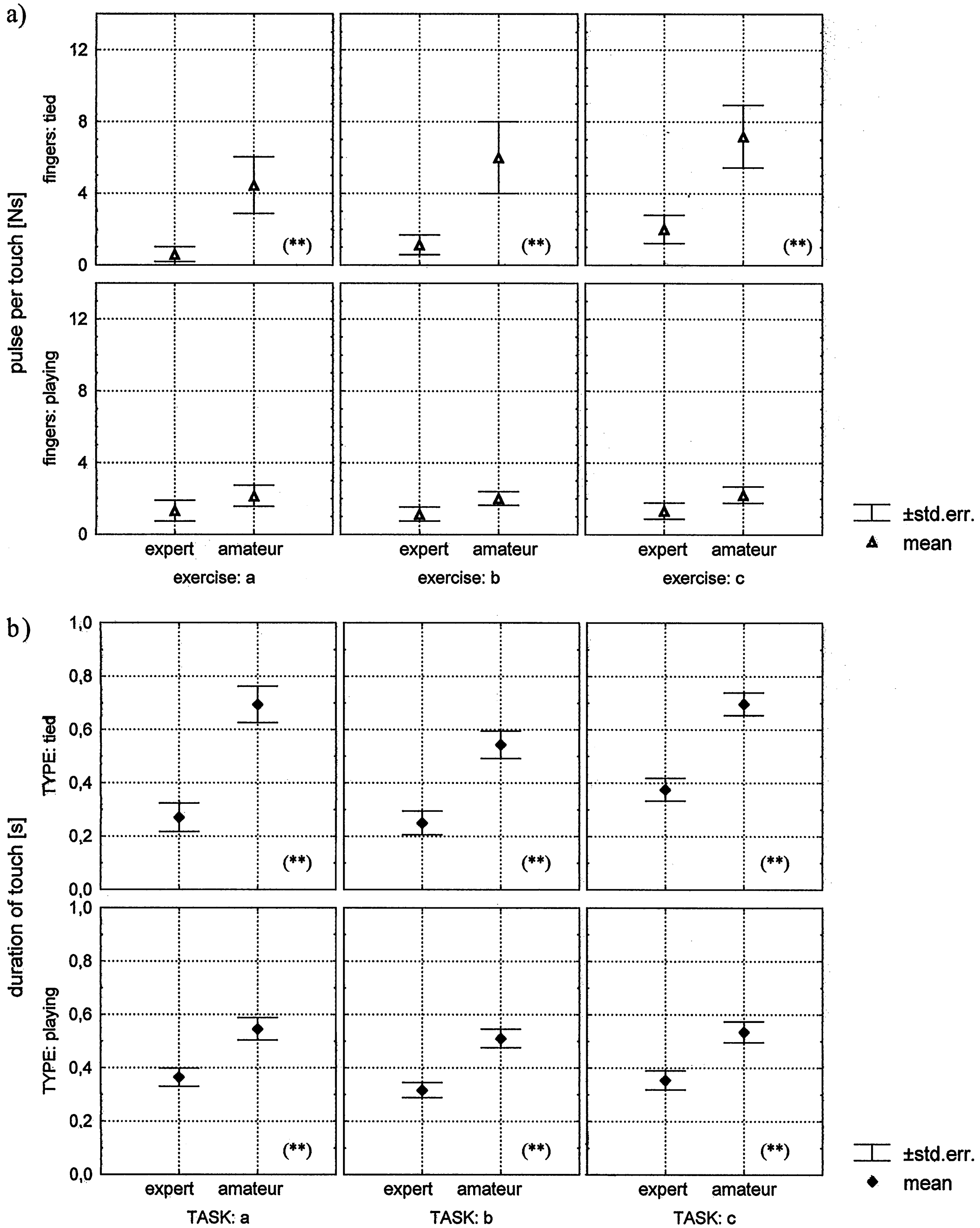

Fig. 3. (a) Mean pulse per touch in both groups (expert vs. amateur) for the three exercises. Data from playing fingers are grouped: exercise a 3rd, 4th and 5th, exercise b 4th and 5th, exercise c 3rd and 5th. (b) Mean duration of touch calculated as the time interval between touch onset and the decrease of force below the measurement threshold of 2 N. Each data point represents the mean of 25 touches in 3 repetitions. Significant mean differences are indicated (*), highly significant (**).

alternate regularly with an initial force of about 6 N. While the expert player relaxes his playing fingers immediately after each touch the amateur remains much longer in a state of tension. Moreover, the forces of the expert's non-playing fingers remain below the resolution of our measurement tool (<2 N) while the amateur shows an enormous expenditure of forces in the first and second finger.

For the following group analysis we calculated the average pulse per touch for playing and non-playing fingers, respectively (Fig. 3a). The expert player performs all exercises with a fraction of the pulse used by the amateur. The statistical analysis of the main effects in an ANOVA design with the factors GROUP [expert | amateur], TASK [a | b | c], and TYPE [playing | tied] confirmed highly significant effects of the factors GROUP ($F = 22{,}63$; $p = 0.000006$) and TYPE ($F = 10{,}47$; $p = 0.0016$) and the interaction term GROUP $\times$ TYPE ($F = 10{,}58$; $p = 0.0015$). Although not significant in the ANOVA there can be seen a tendency of growing expenditure of force from exercise a to exercise c (factor TASK, Fig. 3a).

In each exercise, the expert player group is able to relax much earlier after a keystroke than the amateurs (Fig. 3b). This yields in the playing fingers mean touch durations of about 0.3 s for the experts and about 0.5 s for the amateurs. The analysis of variance (ANOVA) for a GROUP by TASK by TYPE design results in a high significance for the main effect GROUP ($F = 106{,}22$; $p = 0.000000$) and the interaction GROUP $\times$ TYPE ($F = 9{,}72$; $p = 0.0019$). The factor TASK has also a significant effect ($F = 4{,}32$; $p = 0.0136$) indicating a relation between the different coordination demands of the three exercises and the ability to relax after touch.

4. Discussion

As expected the comparison between keystrokes performed by expert players and musical amateurs leads to highly significant differences with respect to the mean pulse per touch or the duration of touch. Years of experience enable the expert player to perform precise and reproducible motion patterns with an independent coordination of playing and non-playing fingers, an immediate relaxation of the playing finger after touch and a sense for the piano's response. Furthermore, it seems that with increasing demands on coordination of both groups, expert players as well as amateurs react with an increasing overall force exerted on the keys. This might be due to the counterproductive attempt to compensate for the difficulty by stabilization of the hand with the 'tied fingers'. Additionally, an increasing general tenseness might be caused by the higher coordinate demands.

In subsequent discussions on the results, most of the subjects in the amateur-group were surprised by the enormous amount of force they had applied to the non-playing fingers. They were not aware of this waste of force and had no conscious sense for the cramping. In consequence, in a pilot study we developed a visual feedback-system which represents force values graphically and in real time on a computer screen. First tests with this facility point to a promising support for the piano education as well as for the medical prevention from wrong training and from overuse.

With respect to the measurement method, the applied technology has the advantage of a 'ready to go' system, with no further necessities to develop self-made hard- and software.

Although the force-sensing resistor technology of the F-scan insole is reported to be error-prone at higher loads of more than 80 N (McPoil and Cornwall, 1995), it provided a fairly good accuracy and reproducibility within the limits of force produced by our pianists which never exceeded 20 N). The sensitivity of the system at the lower range however is limited. The F-Scan system detects a minimum force of 2 N. We therefore asked the pianists, to play at a considerable loudness (forte) requiring at least 5 N. Considering the fact that a minimum normal force of only 0.6 N is sufficient to hold down a key, we have to admit that forces below 2 N exerted on the tied fingers might be missed by this system. We therefore at present are developing a more sophisticated hard- and software-system based on strain-gauge technology in multiple keys, installed in a Steinway-B Grand Piano.

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