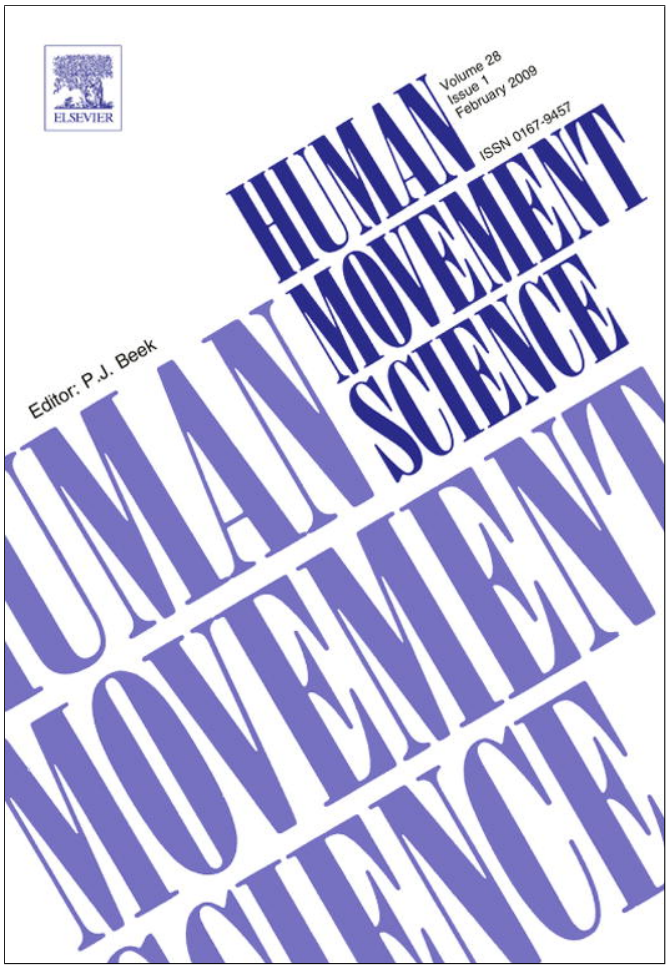

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The influence of practice on the development of motor skills in pianists: A longitudinal study in a selected motor task

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ABSTRACT

A longitudinal study was conducted to investigate the influence of practice on the long-term development of expert pianists' motor skills in a relevant musical context. Temporal evenness in standardized scale playing was assessed twice in 19 pianists within an average time interval of 27 months. Questionnaires were used for retrospective assessment of practice quantity and several qualitative parameters related to practicing of scales. The development of temporal evenness in scale playing over the follow-up period correlated with the practice time accumulated during that period and with the average daily practice time. Expert pianists with an average daily practice time of 3.75 h or more showed an improvement of performance in this selected motor skill. No significant association was observed between motor skill development during the follow-up period and the content of practice. Stepwise linear regression revealed a model predicting 43% of the variance of motor skill development, with practice time accumulated during the follow-up period as the only predictor. It was concluded that, in expert pianists, maintenance of motor skills in the selected motor task was strongly influenced by practice quantity.

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1. Introduction

Performing music at a professional level is arguably among the most intricate of all human accomplishments. Musicians' motor coordination is highly complex and takes place at an extremely high level of spatiotemporal accuracy (Kopiez, 2004). In virtuoso late romantic piano music, as for example in the sixth Paganini-Etude by Franz Liszt, pianists have to bimanually coordinate the production of up to 1800 notes per minute (Münte, Altenmüller, & Jäncke, 2002). Successful strategies for the acquisition and maintenance of motor coordination and musical abilities required for this challenging task are of interest to both music teachers and expertise researchers. Previous research on musical performance achievement has focused on biographic and behavioral factors determining musical development in children, music students, and expert musicians. For this purpose, different measures have been used to assess musical expertise in order to compare musicians with different levels of achievement. Overall musical achievement was, for example, measured by the results of admission tests at music schools (Davidson, Howe, Moore, & Sloboda, 1996; Howe, Davidson, Moore, & Sloboda, 1995; Sloboda & Davidson, 1996), by the rating of instrumental teachers (Sloboda & Howe, 1991), competition results (Sosniak, 1985), or other external rating methods (Ericsson, Krampe, & Tesch-Römer, 1993; O'Neill, 1997; Williamon & Valentine, 2000). Alternatively, musical achievement was measured in the musical sub-skills "performing rehearsed music", "playing from memory", "playing by ear", "improvising" (McPherson, 2005), or "sight-reading" (Kopiez & Lee, 2006; Kopiez, Weihs, Ligges, & Lee, 2006; Lehmann & Ericsson, 1993; McPherson, 2005) or in manual coordination tasks (Ericsson et al., 1993).

Little attention has been paid to the long-term development of motor skills in musicians, in particular, of motor performance in relevant musical tasks. Objective quantification of motor performance in a relevant musical task, as required to investigate its development, was previously carried out in professional pianists while they were playing standardized C major scales (Jabusch, 2006). Scales are basic elements of the musical architecture in classical music as well as in jazz, rock, and pop music. Therefore, scale playing is a fundamental aspect of piano technique. Playing scales requires finger cross-over maneuvers which are considered main difficulties in scale playing (Breithaupt, 1912). Outward scales require thumb-under movements and inward scales require third-over and fourth-over movements (outward is defined as ulnar playing direction, inward as radial). The difficulty of temporal evenness in scale playing is a central aspect in the training of pianistic fluency. Among all scales, C major scales are regarded as most difficult due to the fact that no black keys are involved which might facilitate crossing-over maneuvers of fingers (Neuhaus, 1967). In C major scales played by professional pianists, Jabusch (2006) found a high degree of temporal evenness in the inter-onset intervals using a musical instrument digital interface (MIDI)-based analysis method. This method has been shown to be a valid and reliable tool to investigate temporal evenness in scale playing of pianists (Jabusch, Vauth, & Altenmüller, 2004).

To date, the long-term development of this basic motor skill has not been investigated in pianists, and it is not clear which elements of piano practice have an influence on this development. The present paper addresses these questions. In a longitudinal study, temporal evenness in scale playing was tested in 19 pianists and retested after an average time interval of 27 months. Practice habits were recorded using a questionnaire similar to protocols for retrospective interviews commonly used in music-related expertise research (e.g., Lehmann & Ericsson, 1996). The predictability of the temporal evenness in pianists' scale playing and of its development over time was analyzed using practice habits as independent variables.

2. Methods

2.1. Participants

Nineteen pianists (12 men, 7 women) were recruited for participation in the study. Thirteen pianists were piano students at the Hanover University of Music and Drama, (Hanover, Germany), and six pianists were already graduated. Eighteen pianists were performing in public. At the beginning of the study, the pianists were aged between 19 and 39 (mean: 28 years; standard deviation: ±6 years). They had started to play the piano between the age of 3 and 9 years (6 ± 2 years). Seventeen

pianists were right-handed and two were left-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971).

2.2. MIDI-based scale analysis and retrospective analysis of practice habits

The procedure of scale playing and analysis of temporal evenness was performed according to a previously published protocol (Jabusch et al., 2004). Scales were performed on a digital piano (KAWAI MP 9000) which was connected to a computer. For recording and generating MIDI-files, commercially available music editing software was used (*Musicator Win, V. 2.12*; Music Interactive Technology; Bergen, Norway). Before the test, participants had the opportunity to warm up for 5 min according to their own warm-up habits and to get used to the keyboard. For the test, sequences of 10–15 C major scales were played over two octaves (range: C3–C5) in both directions, inward and outward, with each hand separately. Participants were asked to play in legato-style (notes were played in a smooth, connected manner). Fingering was according to the regular C major fingering (1–2–3–1–2–3–4–1–2–3–1–2–3–4–5 and backward). Scales were played in sixteenth notes, and the tempo was standardized at 120 beats per minute for a quarter note, paced by a metronome. Thus, scales were played with 8 note onsets per second (i.e., 125 ms per note). Inter-onset intervals (time between onsets of two subsequent notes) for all individual notes of the scales were analyzed using a researcher-developed software. Scale analysis was performed for each hand and in both directions separately. Mean standard deviations of inter-onset intervals (msdIOI) were calculated for all scales of each hand and playing direction. The msdIOI parameter was previously shown to be a reliable indicator of temporal evenness in pianists' scale playing (Jabusch et al., 2004).

On average, 27 months after this baseline measurement (Test 1), all participants were reinvited to undergo a follow-up test (Test 2) conducted in the same manner (the period between Test 1 and Test 2 will be referred to as follow-up period). Only at the time of the reinvitation were they informed about the follow-up test. This was done to avoid any bias in participants' practice habits (e.g., practice with focus on scale playing) during the follow-up period due to their knowledge of the study. During the follow-up period, participants were practicing according to their individual practice habits. After the first procedure, participants reported their current daily practice time, their accumulated life practice time and their age at commencement of piano playing. Accumulated life practice time was calculated retrospectively. For each participant, total practice quantity was calculated for time periods with similar practice durations (normally between 1 and 5 years) and summed up over the total duration of their piano training. This calculation was carried out with the assistance of one of the researchers. After the second procedure, participants reported their current daily practice time and their total practice time accumulated during the follow-up period. Furthermore, they completed a questionnaire in which they documented information about their practice habits applied during the follow-up period. In particular, participants reported how much time they had usually spent with technical exercises on the piano (as percentage of total practice time) and whether they had changed the amount of scale practicing during the follow-up period compared to before the baseline test. They documented whether or not they had applied special strategies for scale practicing such as playing in rhythms or with special articulations (e.g., separation of note groups). They were asked about their favorite technique (running passages vs. chordal passages). Finally, participants were asked about their number of public performances per year in the follow-up period.

2.3. Statistical analysis

To assess the overall temporal evenness of note onsets in each pianist, the median of the msdIOI results of both hands and both playing directions was calculated (MIOI) for each participant. Thus, assessment of participants' performances was possible regardless of their handedness. Within-group performance results before and after follow-up were compared using paired samples *t*-test. Between-group differences of groups with different practice habits were analyzed by *t*-tests for independent samples. Pearson correlations were calculated to detect associations between interval-scaled variables, Spearman rank correlations for ordinal-scaled variables. Stepwise Multiple Regression Analyses

were used to assess predictability of performance results. The two-tailed level of statistical significance was set at $p < .05$.

3. Results

3.1. Performance and practice habits

At the beginning of the study, pianists had already been playing the piano for 21 ± 6 years (mean ± standard deviation) and reported an accumulated practice time of 21,600 ± 10,900 h. All participants were able to play the C major scales according to the instructions at the initial test and at the follow-up test. MIOI values indicated the temporal precision of note onsets: low MIOI values indicated high temporal evenness, and vice versa. Therefore, in the following, MIOI is also referred to as "temporal unevenness". MIOI values of the baseline tests (MIOI-1) ranged between 6.9 and 13.6 ms (10.2 ± 1.8 ms). After a period of 27 ± 8 months, the follow-up tests were conducted, and the resulting MIOI values (MIOI-2) were between 8.1 and 15.9 ms (10.6 ± 1.9 ms). Within the follow-up period, participants had an average daily practice time of 3.3 ± 1.8 h and reported an accumulated practice time of 2800 ± 1800 h. At the time of the follow-up test, they had a total practice time of 24,500 ± 11,300 h.

Participants reported that they had usually spent between 0 and 50% of their practice time with technical exercises (13 ± 16%). One pianist had increased the amount of scale practicing during the follow-up period, 6 (32%) reported a decrease, and 12 (63%) reported no change in that sense. The following practice strategies were used with the particular aim to improve scale playing: (1) Twelve pianists (63%) practiced scales in various rhythms; (2) three pianists (16%) practiced scales with special articulations (e.g., separation of note groups). Concerning the favorite technique, 6 participants (32%) preferred running passages over chords, 13 participants (68%) preferred chordal passages over running passages. The number of public performances per year was 20 ± 17 during the follow-up period.

3.2. Development of temporal evenness and correlations with practice habits

No within-group difference could be observed between MIOI values of the baseline test and the follow-up test (MIOI-1 vs. MIOI-2: $t = -1.4$, df = 18, $p = .18$, [two-tailed]). A correlation was seen between the results of both tests (MIOI-1 vs. MIOI-2): Pearson $r = .82$, $p < .001$. Results of individual performance in the baseline tests and follow-up tests are displayed in Fig. 1. The difference of performance values before and after follow-up (MIOI-d = Median of the differences of msdIOI of both hands and both playing directions (Test 2 minus Test 1)) did not significantly correlate with MIOI-1 (Pearson $r = -.34$, $p = .15$), thus an association between the baseline performance and the development of performance could not be shown.

A correlation was found between MIOI-d and the total practice time accumulated in the follow-up period (Pearson $r = -.68$, $p = .001$), indicating that pianists who practiced more showed less temporal unevenness in the follow-up test than in the baseline test, and vice versa. Additionally, MIOI-d correlated with the average daily practice time during the follow-up period (Pearson $r = -.60$, $p < .01$, see Fig. 2).

The baseline results MIOI-1 correlated with the total life practice time at the beginning of the study (Pearson $r = -.47$, $p < .05$) indicating that pianists with a high amount of total life practice time showed less temporal unevenness. The analogous correlation between MIOI-2 and the total life practice time after follow-up was not significant (Pearson $r = -.40$, $p = .09$). Furthermore, the daily practice time at the end of the follow-up correlated with MIOI-2 (Pearson $r = -.46$, $p < .05$), whereas the daily practice time at the beginning of the study showed no significant correlation with MIOI-1. No significant correlation could be found between the performance parameters of the baseline test or the follow-up test (MIOI-1; MIOI-2) and the total number of years of piano playing at the respective dates, or between MIOI-1 or MIOI-2 and the age at commencement of piano playing.

The change in performance MIOI-d did not significantly correlate with the change of the daily practice time (Pearson $r = .3$, $p = .4$) or with the amount of scale practicing during the follow-up period (Spearman $r = .22$, $p = .4$). The relative practice time spent with technical exercises did not significantly correlate with any of the performance parameters at follow-up (MIOI-2: Pearson $r = .01$, $p = .9$; MIOI-d: Pearson $r = -.06$, $p = .8$). No significant influence of the application of the following strategies for

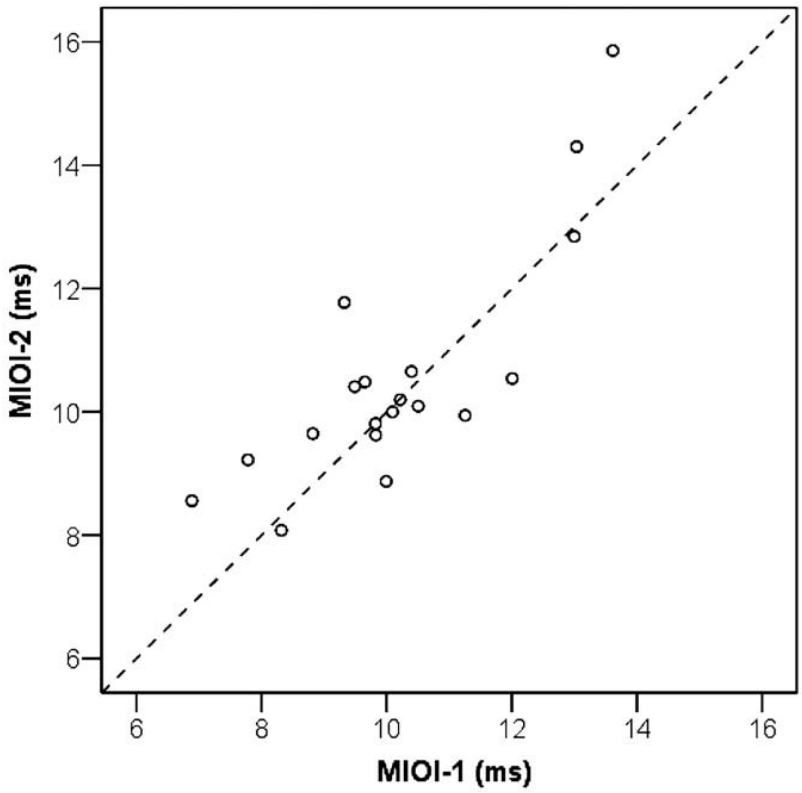

Fig. 1. Temporal precision in pianists playing C major scales. Low MIOI values indicated a low temporal unevenness, and vice versa. Results of baseline tests (MIOI-1) and follow-up tests (MIOI-2) are displayed for individual participants (Pearson $r = .82$; $p < .001$). Circles below the dashed line of equivalence indicate a decreased unevenness after follow-up, circles above dashed line indicate an increased unevenness after follow-up.

scale practicing on any of the follow-up performance parameters was observed: playing scales in rhythms (MIOI-2: $t = 0.03$, df = 17, $p = .9$; MIOI-d: $t = 0.99$, df = 17, $p = .3$, [two-tailed]), or playing scales with special articulations (MIOI-2: $t = -0.42$, df = 17, $p = .7$; MIOI-d: $t = 1.2$, df = 17, $p = .3$, [two-tailed]). There was a tendency towards an association between the favorite playing technique of participants and the performance at the baseline test and the follow-up test: participants who preferred running passages over chordal passages had lower MIOI values compared to participants who preferred chordal passages over running passages (MIOI-1: $t = -1.96$, df = 17, $p = .07$; MIOI-2: $t = -1.72$, df = 17, $p = .1$ [two-tailed]). No significant correlation was seen between the number of public performances per year and the performance values at the follow-up test (MIOI-2: Pearson $r = -.26$, $p = .3$; MIOI-d: Pearson $r = .21$, $p = .4$).

3.3. Predictability of performance

Multiple regression analysis revealed a model predicting 17% of the variance of the baseline performance values MIOI-1. The accumulated practice time (in hours) at the beginning of the study (APT1) was the only predictor (Regression equation: MIOI-1 = 11.9–0.000076 APT1; adjusted $R^2 = .17$). The regression procedure did not identify any of the following variables as significant predictors for MIOI-1: age at baseline test; gender; age at commencement of piano playing; number of years playing the piano; daily practice time at beginning of study. Multiple regression analysis using MIOI-1 and the parameters related to practice habits during the follow-up period as additional independent variables revealed two models for predicting performance at the follow-up test MIOI-2 (see Table 1).

The following independent variables were not identified as significant predictors for MIOI-2: age at follow-up test; gender; age at commencement of piano playing; duration of follow-up; number of years playing the piano at follow-up test; daily practice time at follow-up test; percentage of practice time spent with technical exercises during the follow-up period; change of the amount of scale

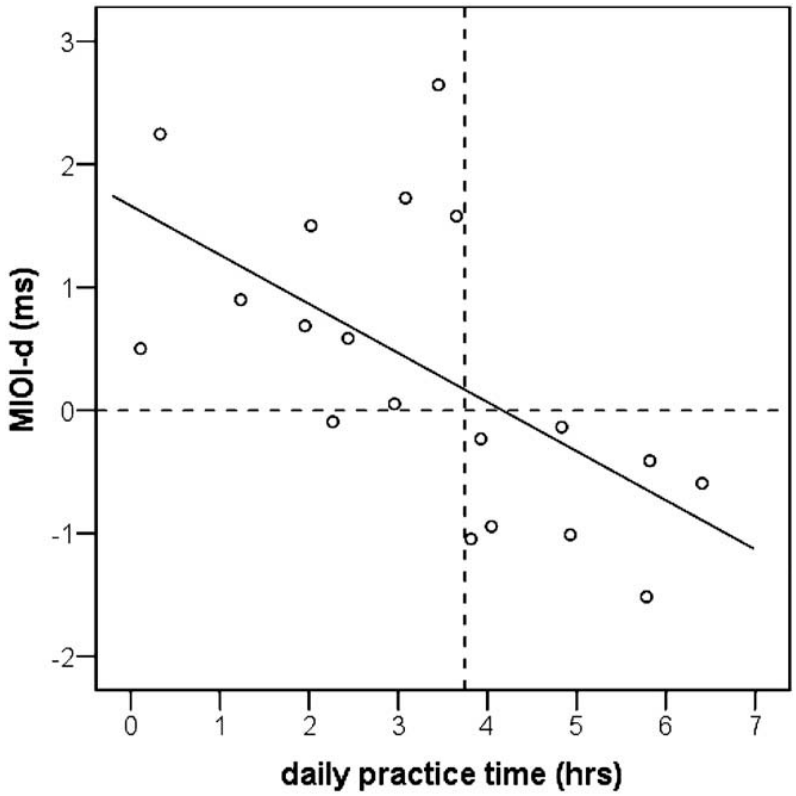

Fig. 2. The correlation between the development of temporal precision in pianists playing C major scales and the average daily practice time (Pearson $r = -0.60$; $p < .01$). MIOI-d: Median of differences of performance values before and after follow-up; negative values indicate a decreased unevenness after follow-up, positive values an increased unevenness. All participants with an average daily practice time of more than 3.75 h (vertical dashed line) showed a decreased unevenness after follow-up. Black line: regression line.

Table 1
Details of two models revealed by stepwise multiple regression analysis which predicted the performance at the follow-up test MIOI-2

Model	Variables	Regression equation	R^2 adjusted	R^2 change	p
1	MIOI-1	MIOI-2 = 1.45 + 0.89 MIOI-1	.65	.65	< 001
2	MIOI-1; APTd	MIOI-2 = 2.06 + 0.94 MIOI-1–0.00038 APTd	.77	.12	.006

APTd: accumulated practice time (in hours) during the follow-up period.

practicing during the follow-up period; playing scales in rhythms as strategy for scale practicing; playing scales with special articulations as strategy for scale practicing; favorite piano technique (running passages vs. chordal passages); numbers of public performances per year during the follow-up period.

For prediction of the change in performance over the follow-up period (MIOI-d), multiple regression analysis was conducted with the same independent variables as for prediction of MIOI-2. A model was revealed predicting 43% of the variance of MIOI-d, with the practice time accumulated during the follow-up period (APTd) as the only predictor (Regression equation: MIOI-d = 1.60–0.00044 APTd; adjusted $R^2 = .43$). The following independent variables were excluded as predictors for MIOI-d: MIOI-1 and all independent variables which were excluded as predictors for MIOI-2.

4. Discussion

The aim of this longitudinal study was (a) to assess the long-term development of pianists' scale playing abilities as a basic motor skill in a relevant musical context and (b) to investigate which elements of piano practice have an influence on this development. For this purpose, motor performance

was assessed twice with an average follow-up period of 27 months. To avoid any biasing influence on the participants' practice during the follow-up period, the questionnaire focusing on their practice between the two tests was administered to the participants after the second test. The setting of both tests was identical in order to rule out systematic differences between both test occasions.

4.1. Baseline test vs. follow-up test

The comparison of the baseline performance results and the follow-up results revealed no within-group difference after the follow-up period. One could have expected that practice activity of participants during the follow-up period would have increased the performance in the studied aspect. The above mentioned finding, in contrast, may lead to the interpretation that this practice activity was necessary to *maintain* participants' performance level, i.e., to avoid deterioration of scale playing abilities. The pianistic biography of the participants indicated that they were experts with an average duration of piano playing of more than 20 years and with an average accumulated practice time of more than 20,000 h. Practice activities in experts with the purpose of maintenance of performance have already been described in other domains. For example, elite swimmers have measurable decreases in their muscle metabolism if they do not train for 48 h (Ericsson et al., 1993). Many physiological changes revert back to normal values with the reduction or termination of deliberate practice (Ericsson, 2006, 2007a,b). The important role of practice in the maintenance of skills in older musicians has been described by Krampe and Ericsson (1996).

4.2. The role of practice quantity

In our study group, development of individual performance was heterogeneous, with an increase of temporal evenness in some pianists and even decreasing evenness in others (see Fig. 1). In order to detect determinants in the practice habits which might predict the development of temporal evenness in scale playing, we retrospectively recorded the quantity of practicing and investigated several qualitative parameters connected to the practicing of scales. The strongest predictor for the follow-up performance was the performance value at the baseline test (accounting for 65% of the variance of the follow-up performance) followed by the accumulated practice time during the follow-up period (accounting for 12% of the variance). Follow-up performance correlated with the daily practice time at the end of the follow-up. The development of performance results during the follow-up period correlated with the practice time accumulated during that period. This association was seen in the total practice time accumulated between Test 1 and Test 2 and in the average daily practice time. The latter association is shown in Fig. 2: the majority of pianists practicing less than 3.75 h per day showed an increased temporal unevenness after follow-up and all pianists practicing 3.75 h or more showed a decreased unevenness. These findings were underlined by the results of the regression analysis. Prediction of 43% of the variance of the performance development during the follow-up period was possible with the variable 'practice time accumulated between Test 1 and Test 2' as the only predictor. These results additionally underline the aforementioned argument that a certain amount of practice served to maintain performance in the investigated group of expert pianists during the follow-up period. Successful maintenance of performance in the selected motor skill was achieved by all participants who practiced 3.75 h or more per day during the follow-up period. Fig. 2 additionally displays the results of two pianists who practiced less than 3.75 h per day and showed MIOI-d values close to 0 ms indicating that their temporal unevenness did not increase during the follow-up period. This finding may indicate that besides the practice quantity there are other determinants of the development and maintenance of the studied motor skills that were not addressed in this project such as the practice intensity. The importance of practice intensity has been observed in other domains such as, for example, in running. Amateurs and athletes were able to maintain the aerobic capacity although they decreased the volume of running (by a factor of 2–3) as long as the intensity of running was kept at a very high level (Ericsson, 1996).

The total life practice time at the beginning of the study correlated moderately with the baseline performance values and predicted only 17% of their variance. No other predictor was found. The correlation between the performance values at the second test and the total life practice time after

follow-up was not significant. Based on these results we hypothesize that the role of practice quantity in the *acquisition* of the investigated motor skill may be limited. The acquisition of motor skills may substantially be associated with other determinants which were not addressed in this study. Other behavioral and motivational and environmental factors are currently being investigated in the frame of another project in young pianists during the period of skill acquisition.

4.3. Findings in the light of the literature

In previous publications, the amount of practice was frequently reported to be a determinant for overall musical performance achievement (e.g., Ericsson et al., 1993; Krampe, 1994; O'Neill, 1997; Sloboda & Davidson, 1996). In addition to practice time, however, Ericsson et al. (1993) and Ericsson and Lehmann (1999) emphasized the crucial aspect of the quality of practicing and used the term 'deliberate practice' which describes a structured, goal-oriented, and monitored activity to improve the level of performance. For example, as Gruson (1988) could show, repeating sections instead of single notes is the most important variable for the discrimination of advanced instrumentalists' practice from that of beginners. Investigating long-term musical achievement in children over three years, McPherson (2005) found that long-term achievement in the sub-skills 'performing rehearsed music' and 'sight-reading' was best predicted by the variables 'amount of practice' and 'application of strategies' (McPherson, 2005). For the musical sub-skills 'play from memory' and 'play by ear', the application of practice strategies was the only predictor for performance achievement. Williamon and Valentine (2000) prospectively investigated the process of practicing of a complex musical task. In pianists who prepared an assigned composition for a recital, the authors found that the quantity of practice was not related to performance quality. They concluded that further investigations should be focused on the content and quality of practice rather than on quantity.

Surprisingly, no parameter specifying the content of practicing or strategies of scale practicing significantly correlated with the performance at the follow-up test or with the development of performance during the follow-up period. We investigated the variables "change of the amount of scale practicing during the follow-up period", "relative practice time spent with technical exercises", as well as "playing scales in rhythms" and "playing scales with special articulations" as strategies for scale practicing. None of these variables was identified as a sufficient predictor for the performance at the follow-up test or for the development of performance during the follow-up period. It is possible that the aforementioned strategies chosen as variables for qualitative analysis of practice might not be sufficient to describe those elements of practicing that are crucial for the development in scale playing. Alternatively, our results might suggest that pianists' practice varied greatly across the sample. A possible explanation for our observation that there was no clear association between certain practice strategies and long-term development of motor skills in scale playing derives from findings in music perception research. Altenmüller (2001) examined brain activation patterns in participants during a music perception task after they had participated either in a declarative or in a procedural musical training. Altenmüller reported that participants with these different training backgrounds displayed different cortical activation patterns during the same music perception task. Brain substrates of music processing reflected the individual auditory learning biography. The way of learning music determined the strategies of music processing in the individual participant. It may be speculated that an analogous phenomenon occurs in the acquisition of a complex motor skill such as scale playing, and that the particular practice biography determines to a certain extent the strategies which are effective in the individual pianist. Thus, aside from the crucial influence of practice quantity, there might be individually different practice strategies which allow achievement of psychomotor optimization as required for virtuoso scale playing only in the individual pianist. This might explain why no practice strategies were identified as predictors for motor skill development for the entire group of pianists.

4.4. Discussion of the methods

4.4.1. Motor performance test

MIDI-based analysis of scale playing has been described previously to measure sensorimotor precision in pianists (Jabusch et al., 2004). The tool was originally developed for the indirect quantification

of motor control in pianists with and without movement disorders such as focal dystonia. For validation of the msdIOI parameter, msdIOI results were compared with the results of a blinded rating procedure of three experts (one neurologist expert in musicians' movement disorders and two concert pianists and piano teachers) who judged the quality of scale playing based on a four-point scale. Correlation between msdIOI values and the results of the rating procedure was high ($r = .96$, $p < .0001$ Spearman rank correlation) indicating that the performance values corresponded well with the subjective impression of playing ability (Jabusch et al., 2004). MIDI-based msdIOI values, however, provided a higher resolution as compared to the established rating scale. The question arises how the MIOI performance values relate to the acquisition of piano performance. In a parallel project, MIOI performance values were assessed in 30 school-aged children with a total duration of piano education between 9 months and 12 years (Jabusch, Yong, & Altenmüller, 2007). C major scales were played in a slow tempo (375 ms per note) due to the children's lower motor abilities. Their MIOI performance values ranged between 16 ms and 32 ms (median: 21 ms). Although the comparability of these results and the performance values of the adult expert pianists in the present study is limited due to the different playing tempo, they may indicate that temporal evenness in scale playing was lower in the children pianists than in the expert group of the present study. The exact relation between sensorimotor precision and overall musical achievement, however, remains to be clarified.

4.4.2. Retrospective assessment of practice

Practice habits were assessed retrospectively in order to avoid any bias in participants' practice habits during the follow-up period due to their knowledge of the study. Retrospective interviews were already shown to be a reliable method for the calculation of accumulated practice time: from previous studies on expertise-related skills, we know that retrospective interviews on the amount of time spent on domain-specific practice are reliably reported by participants. For example, Lehmann and Ericsson (1998) found a high correlation between retrospective estimates of accumulated practice time and accumulated time from the participant's practice diary. An estimation error of only 10–15% was observed (for similar findings see Ericsson et al., 1993; Krampe, 1994). In a recent study, Bengtsson et al. (2005) were able to show, by means of a retrospective interview, that practice times reported by professional pianists for different phases of life have a high test-retest reliability if assessed one year later. Reliabilities of the measures of childhood, adolescent and adult practicing were $r = .81$, $r = .86$, and $r = .95$. These previous findings suggest that retrospective assessment of practice quantity was a successful and reliable approach to obtain the desired information in the present study.

In contrast, it has to be taken into consideration that retrospective estimates of specific practice strategies such as "change of the amount of scale practicing during the follow-up period", "relative practice time spent with technical exercises", "playing scales in rhythms" and "playing scales with special articulations" have not been validated. Therefore, it is possible that these estimates are less reliable than the reports on the amount of practice.

4.5. Limitations

The assessment of specific practice strategies related to the changes in scale playing abilities might have been limited due to the relatively small sample of pianists. Future projects will be necessary to investigate whether diary studies might uncover relations between specific practice activities and changes in performance.

We would like to emphasize that long-term development in pianists was investigated with respect to just one single technical element (motor skills in scale playing) and that the observed development in timing evenness does neither reflect the musical achievement nor the overall pianistic development during the follow-up period. Manual skills are a necessary tool for pianists, they are, however, not a sufficient condition for excellent music playing abilities or for successful musicianship. This is, for example, reflected by the missing correlation between the performance values in scale playing and the number of public performances per year. In addition to an instrumentalist's technical abilities, many other artistically important elements – such as the expression of images, emotions, and the experiences of life – influence the overall quality of music making and musicianship. However, investigation of these elements is beyond the scope of this paper.

5. Conclusions

The present study demonstrated the strong influence of practice quantity on the long-term maintenance of motor skills in adult expert pianists in a selected, relevant motor task. A parallel study is being carried out to identify predictors for the acquisition of motor skills in children pianists who have not yet achieved expert pianistic ability.

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