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EFFECTS OF TRAINING ON MASS BALANCING OSCILLATIONS IN THE BOWING OF (PRE) TEEN VIOLIN STUDENTS: A QUANTITATIVE MICROMOTION STUDY

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ABSTRACT

In a first study on mass balancing oscillations in the bowing of violinists (Hasselbach et al. 2010) the results supported the theoretically derived assumption that mass balancing oscillations constitute a characteristic pattern of expert violinists' motion. The question emerged as to whether it is possible to learn and train this ability within the scope of violin lessons in children. The present micromotion study uses 3D-kinematics and aims first to reveal the incidence of this characteristic pattern in the bowing of violinists between the ages of 10 and 15, and second to investigate to what extent a specially developed training affects mass balancing oscillations.

Two samples of ten string instrument players – with different teachers but matched in age and year of instrumental instruction – performed the same musical task as the adult university violin students in the 2010 study: repetitive motions in a G-major scale, but at different tempi. Mass balancing oscillations were measured and quantified as complementary motion of hand and elbow (CM). The incidence of mass balancing oscillations within the (pre) teen violin students was comparable to the lowest expert level in the 2010 study (see Figure 1). The difference between the mean values of the two samples was not significant and did not exceed 30% of systematic variance at the outset. One of the samples was investigated further in regard to possible training effects based on a repeated-measures design. The second sample served as a control group. In consequence of eight special exercises, the children tended to increase their mean value of CM significantly from 31% to 56% after fifteen weeks, whereas the control group increased the mean value of CM from 23% to 28%. Thus practice effects caused by the repeated measurement and maturation effects did not lead to significant differences.

Specific training of mass balancing oscillations as a supplement to musical training seems to be an advisable procedure in the instrumental instruction of children as early as the teenage years. It might enhance the chances of achieving higher expert levels. To

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show lasting effects, especially at higher tempi, training should probably continue over a longer period of time.

1. INTRODUCTION

Three-dimensional computer supported analysis of arm kinematics in violin players has been published since 2003 (Shan and Visentin 2003). Successive studies by Shan and Visentin aimed to provide data to reduce the high percentage of performing artists suffering from overuse syndromes. Biomechanical knowledge of playing string instruments has been expanded through empirical research since the beginning of the 20th century (see Steinhausen 1903/1928 and Trendelenburg 1925/1974). In particular, August Eichhorn, a solo cellist, university professor and researcher, succeeded in synthesizing his scientific and artistic ideas with prolific results (see Hopfer 1941 and Hasselbach et al. 2010). As revealed in depth in Hasselbach et al. 2010, Eichhorn analyzed the movements of his teacher, the famous cellist Emanuel Feuermann. He presumed that Feuermann was utilising the benefits of mass balancing oscillations to compensate for inertia, as presumably David Oistrach later did in the field of violin playing. Eichhorn proposed a complex theory of leverage in string instrumental playing corresponding to the sound-physical demands of string instruments. Playing with an economic leverage system involves the use of small force pulses and a dynamic change of mass positions. In recent decades empirical studies have also emphasized that expert violinists' motion is characterized by small muscle activity with appertaining ballistic effects (see Palac 1992 and Hasselbach 2009 for reviews). Mass balancing oscillations can be simply explained by imagining a seesaw and its mechanical characteristics. Some well-known pedagogues such as Katŏ Havas (Havas 1964/2003) or Gerhard Mantel (Mantel 1973/1976) have used this image. However, Eichhorn's theory of leverage is quite complex, with longitudinal and transverse seesaws working together in a mobile chain. The study of Hasselbach et al. 2010 was the first empirical support of Eichhorn's theory. (In fact, this theory of leverage is a reconstruction based upon a method which has been taught by one of Eichhorn's former cello students up to the present day: J. Schwab, at the 'Hanns Eisler' University of Music, Berlin).

Expertise is often connected with virtuosity, which is partly based on physical economy of physical execution, and musically convincing virtuosity depends on excellent sound quality (see Meyer 1978). The activity of balancing masses within the kinematic chain of the bowing arm and the application of ballistic effects in the interplay with the instrument should facilitate playing at faster tempi while maintaining good sound quality and a feeling of ease. (For detailed descriptions of significant relations between artistic sound differentiations and biomechanics, see Hasselbach et al. 2010). Instrumental instruction in teen violin students sometimes prepares for admission procedures at university or for participation in excellent youth orchestras. The achieved level of expertise is a crucial factor in a successful application, which often takes place for musicians at quite early ages. The 2010 study of Hasselbach et al. analyzed the incidence of mass balancing oscillations in the bowing of adult university violin students. Mass balancing oscillations were measured and quantified as complementary motion of hand and elbow (CM). The students were divided into three expert levels according to their success in the admission procedure for a chosen degree as 1. school music teacher, 2. violin teacher, 3. solo performer (Figure 1).

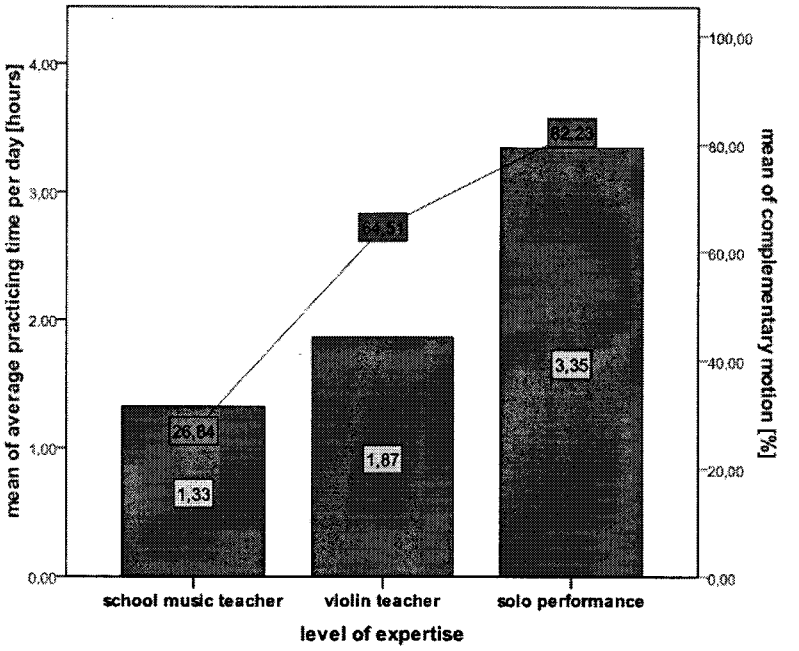

Figure 1. Comparison of the average practicing time per day with the percentage of complementary motion found at three levels of expertise in violin playing subjects, shown in Hasselbach et al. 2010.

The study revealed significant differences between the mean values of CM within the expert levels (one-way ANOVA with F=27.18 at the .05 level). Thus, a low level of expertise is suggested at CM values lower than 40%, a medium level of expertise at CM values between 40% and 70%, whereas a high level of expertise is characterized by CM values up to 95%. There is a lack of research on the incidence of mass balancing oscillations in the bowing of (pre) teen violin students. Additionally, the extent to which mass balancing oscillations can be stimulated by training has never been investigated. The purposes of this study are to reveal the incidence, and to evaluate the possibility of training mass balancing oscillations in violinists between the ages of 10 and 15. Because mass balancing oscillations within the use of an economic leverage system help to avoid static muscle tension in fingers, hand, arm, shoulder, neck and trunk, the results of this study may finally provide data for a later comparative analysis of healthy violin players and violin players suffering from overuse syndromes.

2. Method

Two samples consisting of ten secondary school children (2m/8f) each were compared cross-sectionally in their bowing movement in an experimental repeated-measures design. Students in both samples were in their third year of instrumental instruction, on average, but they had lessons with different teachers. One of the samples was investigated further in regard to possible training effects. The second sample served as a control group. Since the sample to be trained had already had up to three years of normal violin lessons with the first author, who

instructed the performance of the exercises in this study, the possible mediating influences during previous violin lessons had to be controlled for effects on the CM values, especially due to an applied knowledge of biomechanics within the musical training. Thus, the obtained values of the control group additionally served as a cross-validation to check whether the subjects had already significantly higher values in complementary motion at the outset than other (pre) teen violin students. The children of the control group study at a municipal music school with a teacher who is less grounded in theoretical knowledge, but highly renowned as a violinist. As teachers change occasionally in the course of violin students' musical education, it was considered important to have a matched mixture of students in both samples who had either started playing violin with a certain teacher, or students who had joined a teacher after two years of violin playing in secondary school string classes. Additional data concerning the handedness of the subjects were collected via the Edinburgh Handedness Inventory. As the training measured motor and cognitive skills, additional tests concerning diverse aspects of intelligence seemed to be interesting. Therefore, the German version of the Wechsler Intelligence Scale for Children-IV ("HAWIK-IV") was applied to the trained subjects. The WISC-IV generates a Full Scale IQ (FSIQ) which represents overall cognitive ability. The four composite scores are Verbal Comprehension index (VCI), Perceptual Reasoning Index (PRI), Processing Speed Index (PSI) and Working Memory Index (WMI). All subjects and their parents gave informed consent.

Because of its simple application, without requiring complex calibrating, adjusting or programming, an easy transportable 'Zebris CMS 20' three-dimensional ultrasonic movement analysis system (Zebris Medical GmbH; Isny, Germany, Figure 2) was used to capture bowing movements on site during the violin lessons. The measurement method assesses the travel time of ultrasonic pulses, and guarantees high measuring accuracy (error for z-coordinate after triangulation < 1 mm in a distance of x < 1m). The movements in the musical task did not exceed a coverage radius of 1m. The coordinates were recorded with a rate of 65 measurements per second and marker. The miniature transmitters (markers) were placed on the distal ends of first and fourth metacarpal bones, that is, on the back of the hand in front of index finger (marker 1) and little finger (marker 2), and near the elbow on the lateral epicondyle (marker 3). Thus, at least one of the two hand markers transmitted the movement properly, if the other marker turned out of sight while playing on the G- or E-string. Additionally, the mean of the two hand marker values was taken into account for further calculation, in order to even out differences between the marker values due to possible slight transversal movements or trembling. The weight of these three markers (1g per marker) and cables did not considerably restrict the freedom of movement. The coordinates of the movements (triangulated raw signals) were gathered by the analysis software Win Data (Zebris Medical GmbH; Isny, Germany) and exported into Microsoft Excel to calculate the percentage of complementary motion.

The children were asked to perform the same musical task as the adult university violin students had done in the preceding 2010 study. They had to play a two-octave G-major scale ascending and descending in pitch, with four repetitions of each note. Thus, 112 tones in a repetitive motion pattern could be investigated, in which one down-bow and one up-bow could form a more or less neat oscillation. The motions of elbow and hand can be complementary dephased in cases of mass balancing oscillations (see Figure 4), or run in parallel, in cases of inefficient activity of muscles working against the tendency to compensate for inertia (see Figure 3).

Figure 2. Violin student in the three-dimensional measurement of her bowing movement using the ultrasonic system Zebris CMS 20 (Zebris Medical, Isny, Germany).

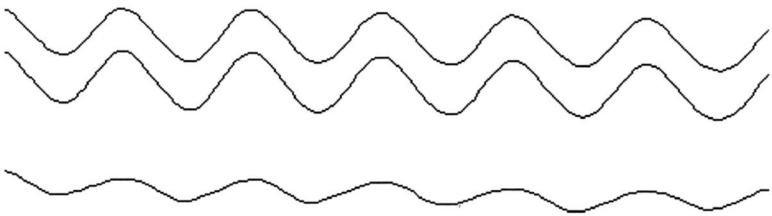

Figure 3. Parallel movement of elbow (lower line) and hand (upper two lines) from a subject with only 18% of calculated complementary motion.

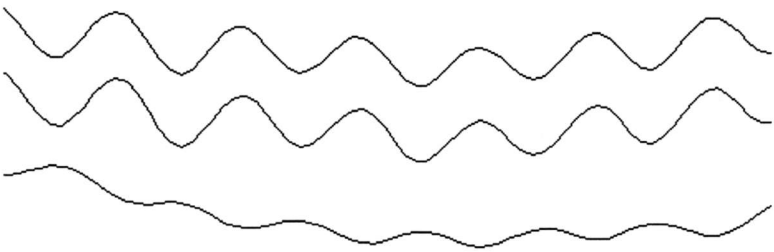

Figure 4. Dephased movement of elbow (lower line) and hand (upper two lines) from a subject with 85% of calculated complementary motion.

The musical task had to be played at three different tempi given by a metronome: first at about 30 M.M. per quarter note, second at about 60 M.M. per quarter note, third at about 80 M.M. per quarter note. But the children were free to perform the tempi very approximately, to

avoid affecting the movement quality due to reduced concentration or a stiffening of the joints potentially triggered by metronome stress. Last, the task had to be played at a free fast tempo. The instruction was: "Play fast sixteenths with a good sound quality while feeling at ease – with a nice devil running after you!" The resulting tempi chosen differed widely, as did the tempi matched to the metronome pace as well. The mean values and the peak values of CM out of four trials for each subject were taken into account for statistical calculation. (For detailed information concerning the algorithm to quantify the movement quality, see Hasselbach et al. 2010.)

The children in the control group were aged 9.4 to 15.1 years (mean age 12.8) at their assessment (henceforth called "C"); they were aged 9.7 to 15.4 years (mean age 13.1) at the controlling assessment ("D"). The children in the sample to be trained were aged 10.4 to 14.4 years (mean age 12.1) at their first assessment (henceforth called "O" as in "outset") and they were aged 11 to 15 years (mean age 12.6) at the final assessment in February 2011 (called "B", whereas the intermediate assessment is "A"). The first measurement (O) took place shortly before the beginning of the 2010 summer holidays to avoid measuring after a longer interruption of practice, because the average practicing time per day was correlated with the percentage of CM in the previous study. The subjects in this study were also asked to divide their practice session times for the duration of the study into two parts, "practice time" of the study exercises and normal "musical practice". Both practice time and musical practice had to be logged.

The first period of systematic training took place in autumn, 2010. During 15 minutes within the scope of their normal violin lessons, the children learned how to practice eight basic exercises. Learning by imitating the teacher (average CM 79.37%, max. 92.41%, min. 69.83%; see Figure 5) was supplemented by explanations of the exercises, regarding the sound-physical and biomechanical basis of their musical necessity. The explanations intended to teach why and how the exercises relax muscles, why they require small force pulses, how they help to make use of gravity, weight balances and inertia, how they increase the awareness of sound-physical laws of the instrument, and finally, how the interplay of forces promotes good sound quality. After the subjects had learned the exercises for five weeks, an intermediate measurement of the dependant variable "complementary motion" took place (A). After this learning stage, an additional ten-week period of training and refinement followed (holidays excluded). For statistical analysis, three levels of training were defined as the independent variable in an ANOVA with repeated-measures: 1. before learning the exercises (O), 2. after five weeks of training (A) and 3. after fifteen weeks of training (B).

A description of the eight essential exercises of different types used for training follows below. The exercises were selected and/or developed to promote technical skills that advance sonority, especially mass balancing oscillations, since these are interrelated. To reduce complexity, only the longitudinal seesaws in the bowing arm were investigated in the measurement, although the exercises included training of all indispensable levers in the oscillating chain of balanced masses:

1. Détaché with mass balancing oscillations at the center third of the bow (middle)
2. Détaché with mass balancing oscillations at the lower third of the bow (nut)
3. Détaché with mass balancing oscillations at the higher third of the bow (tip)
4. Portati over the whole bow (ca. eight dots), powering mass balancing oscillations via forearm rotation

5. Roaming portati back and forth over the whole bow (quasi rhythmic pattern) while rhythmically changing the direction of the arm's "macro"-oscillation in accordance to the bowing direction (upward-moving elbow while down-bowing and downward-moving elbow while up-bowing)
6. Free drift in bowing (changing the contact height without losing sound quality by means of guiding the bow angle)
7. Relaxation of retaining muscles to make good contact with the string and then making swinging flights from nut to tip and vice versa, in order to produce sonorous tones (using effective bow and arm weight, i.e., gravity, inertia, and short force pulses)
8. Tensing and relaxing the left hand fingers with intermediate forearm rotation, to avoid straddling in the left hand and muscle tension in bowing due to co-innervations

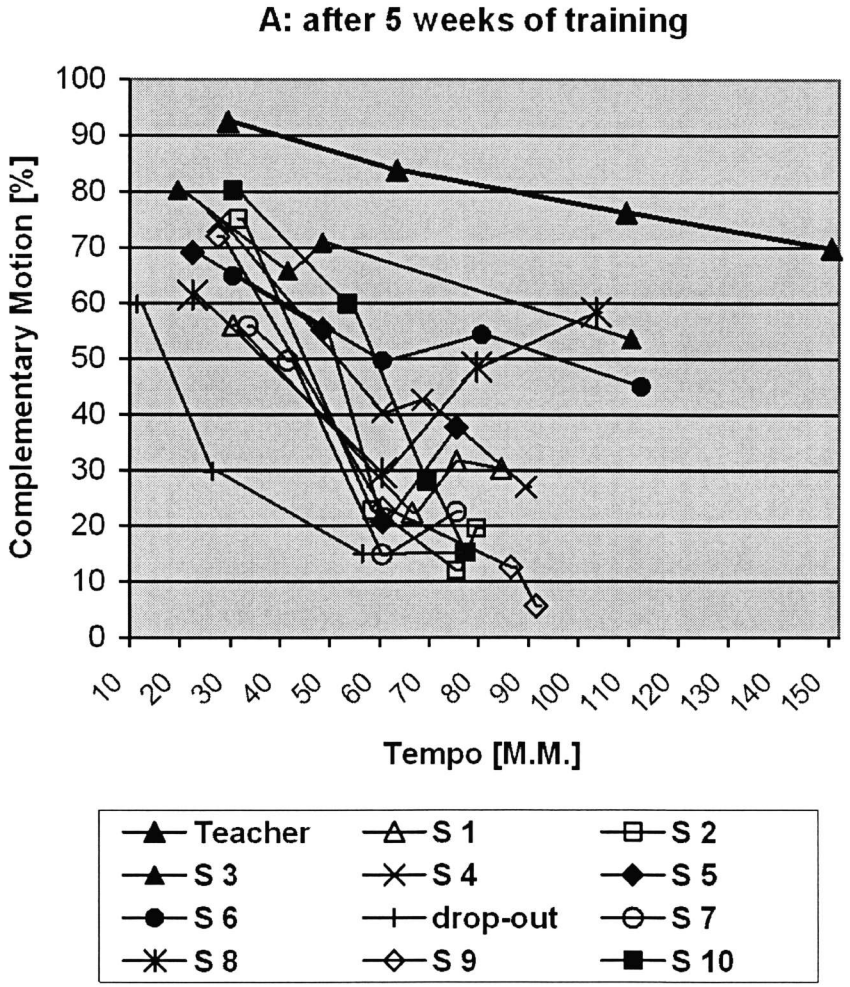

Figure 5. Visual graph of the data in measurement A.

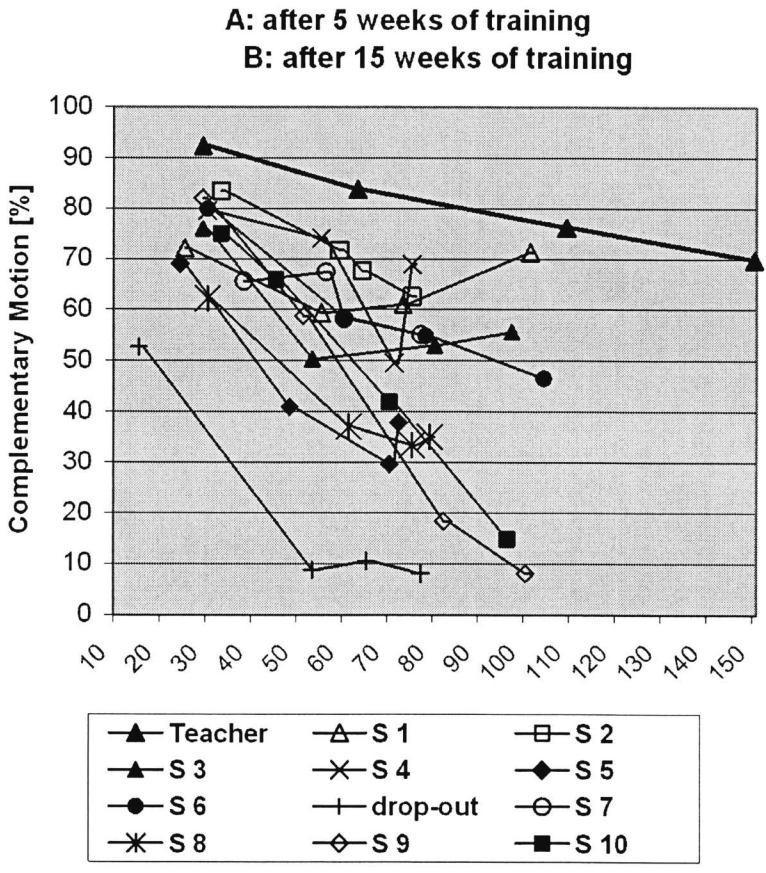

Figure 6. Visual graph of the data in measurement B.

The study started with twelve children, but after the first training period, one of the younger subjects quit the study due to a lack of motivation. A second subject was removed from the statistical analysis because of illness and a missing initial measurement.

3. Results

At the outset the control group was characterized by correlations (on the .05 level) between the year of instrumental instruction and 1. the age of the subjects (.643), 2. the average tempo (.665), and 3. the peak values of tempo played (.677). In contrast, the sample to be trained showed none of these correlations, but revealed correlations (on the .01 level) between the year of instrumental instruction and 1. the average CM (.931), and 2. the peak values of CM (.924). This indicates that the preceding years of instrumental instruction and perhaps the instruction methods of their teachers influenced the achieved CM values or the achieved tempi, respectively. Nevertheless, the mean value of average CM (regardless of the tempo played) within the sample to be trained (31.09%, max. 66.73%, min. 7.54%) did not differ significantly (mean difference: 8.15%, significance .277) from the mean value of CM

within the control group (22.94%, max. 39.2%, min. 13.6%). The mean of peak values of CM within the sample to be trained was 39.21% (max. 76.14%, min. 10.03%) at the outset, and 30.89% (max. 49.08%, min. 17.59%) within the control group. In addition, the means of the peak values of CM did not differ significantly (mean difference: 8.32%, significance .33). As the purpose of the study was to detect considerable effects of training with regard to expert levels as mentioned above, effects of training could have a medium range of perhaps 10% to 30% up to a maximum of ca. 90% of CM. Therefore, one could accept these null hypotheses concerning the differences between the samples at the outset with a power of 90% for the small sample size (N = 20) provided the systematic variance exceeded 30% of the total variance ($\Omega^2 > 0.3$).

After the first training period A, the mean value of average CM within the experimental group increased to 43.98% (max. 67.61%, min. 28.32), and the mean of the peak values of CM to 68.93% (max. 80.27%, min. 55.78%). After the second training period B, the mean value of average CM increased to 56.33% (max. 68.05%, min. 41.83%), and the mean of the peak values of CM to 74.64% (max. 83.42%, min. 62.15%) (See Figure 8). As the Mauchly test was not significant, the sphericity was hypothesized, and it was possible to apply an ANOVA with repeated measures to investigate whether or not the mean values of CM within the three levels of training O, A and B differed. The probability for F = 8.439 was p = 0.003. Therefore, the effect of training on the dependent variable "complementary motion" is significant at the .01 level. The factor "level of training" accounts for 48.4% of the variance of complementary motion within the sample (effect size). Post hoc analysis (Bonferroni confidence interval) revealed that only the variance between the level O (outset) and the level of training B (fifteen weeks of training) was significant at the .05 level (mean difference B-O: 25.24), whereas the variance between the outset and the level of training A, as well as between A and B, might have been incidental (mean difference O-A: 12.89, A-B: 12.35; HSD: 14.95). Power analysis had a value of 93.1%.

For the control group, the mean values of CM did not differ significantly between the assessment and the controlling measurement after approximately fifteen weeks (mean of average CM: 27.53%, max. 54.60%, min. 11.18%; mean of peak values of CM: 37.46%, max. 66.37%, min. 19.00%; mean difference of average CM: 4.58%; mean difference of peak values of CM: 6.56%). The handedness within the control group (mean: 26.58, SD: 83.55) differed extremely from the handedness within the experimental group (mean: 88.20, SD: 16.10), but handedness did not correlate with the achieved CM values within both groups. Handedness showed only a very marginal negative correlation with the achieved CM values within the control group; therefore, it seems improbable that the left-handedness of several subjects in the control group caused the lower mean values within the control group, although the left-handed children played the violin in the right-handed position. In addition, gender had no significant correlations with the achieved CM values within both groups.

Considering the discrete measurements, there were no significant correlations between the CM values and the tempi played at the outset, neither for the experimental group nor for the control group. Only after training did correlation increase to .573 (A) and .529 (B) at the .01 level. The visual graphs of the data (see Figures 5 and 6) show that the CM values declined with increasing tempo. Figure 7 shows that some peak values of CM could be found at higher tempi within the control group, as well as within the study sample at the outset, whereas after training, the former peak values were reached from 'above' with increasing tempo.

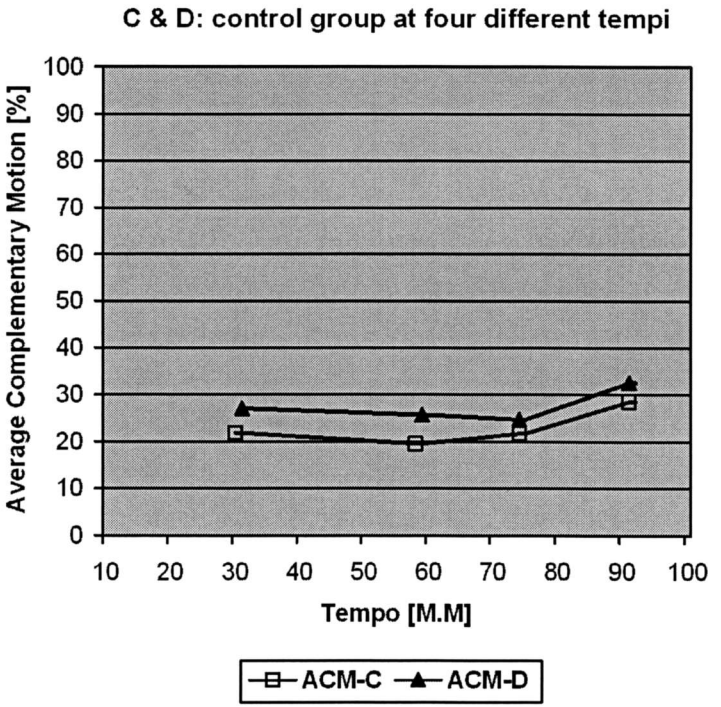

Figure 7. Visual graph of the data within the control group at the measurements C and D.

An astonishing result might be that neither the total practicing times during the training periods (including musical practice sessions) nor the separately gathered practice times of the exercises showed significant correlations with the achieved amount of complementary motion – neither with the average nor with the peak values of CM (mainly achieved at the slow tempi), but only with the tempi played. At the level of training A there were correlations of .916 between practice times and peak values of tempo (.01 level), of .781 between total practicing times and average tempo (.01 level), and of .677 between practice times and average tempo (.05 level). At the level of training B there were correlations of .71 between practice times (in B) and average tempo, as well as .71 between the accumulated practice times (in A and B) and average tempo (.05 level).

After the first training period, neither the year of instrumental instruction nor the age of the subjects had significant correlations with the achieved CM values, but after the second training period, the subjects' ages correlated with the achieved average CM (.725 at the .05 level). Cognitive skills might have influenced the achievements. Most of the subjects within the trained sample revealed outstanding IQ indices (mean: 123.7, min: 108, max: 139, SD: 8.79). There were no correlations between the CM values and the Full Scale IQ or the indices of the composite scores at the outset. After training, the achieved peak values of CM correlated significantly with the Working Memory Index (.632 at the .05 level). Surprisingly, the average CM values revealed significant but negative correlations with the Perceptual Reasoning Index (-.827 at the .01 level) and with the Processing Speed Index (-.666 at the .05 level).

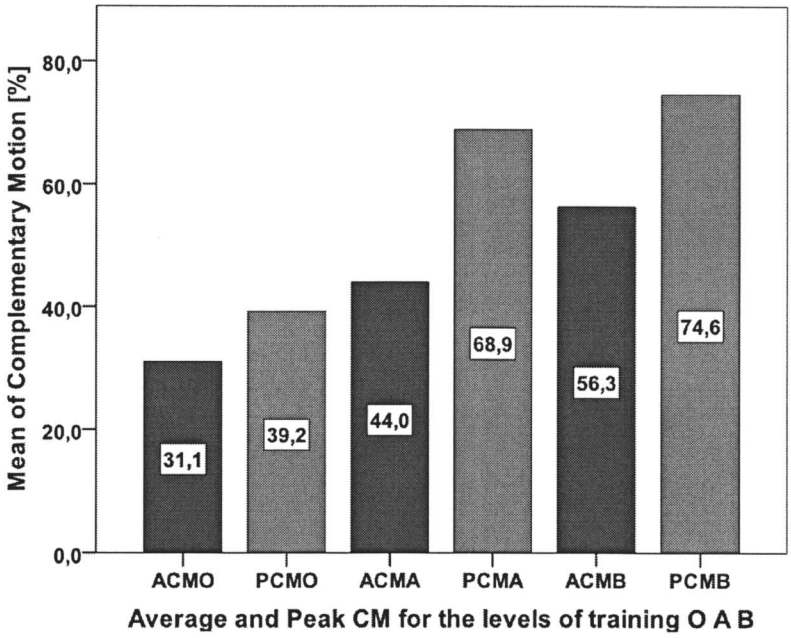

Figure 8. Means of average and peak values of complementary motion at the training levels O (Outset), A (after five weeks of training) and B (after fifteen weeks of training).

Discussion and Implications

The average incidence of mass balancing oscillations in the bowing of (pre) teen violin students – as far as they were achieved within the study samples – lies at a low level of expertise, comparable to the lowest expert level within the adult violin students (mean of CM<40%; for reference values in the bowing of adult violin students at different levels of expertise, see Figure 1). Only two of the subjects (20%) to be trained showed average CM values at a medium level of expertise higher than 60%, and peak values of CM higher than 70% (up to 76.1%) at the outset of the study. Within the control group, only one (10%) of the subjects had average CM values higher than 40%, but 50% of the subjects had peak values of CM higher than 40%. After the second training period, all trained subjects had average CM values higher than 40%, and all peak values were higher than 60%, up to 83.4 %, which lies within the range of high expertise. But the peak values of CM were not found at the peak tempi. The Figures 5 and 6 show the tendency in the teacher model and the similar tendencies in the subjects' data. When comparing this tendency with the correlation of .886 (at the .05 level) between the tempo played and the respective CM values in the 2010 study, in which the subjects with the higher CM values played at higher tempi, one can see an obvious inconsistency. One explanation could be that a decreasing tendency can be found within individual subjects, probably because more time at a slower tempo helps them control and feel the motion needed to produce the desired sound-quality, whereas accuracy decreases with increasing tempo. But for a sample of subjects, who did not play the task at fixed different tempi, the statistical result of higher CM values at higher tempi can be seen in relation to the

respective individual level of expertise. The extent to which mass balancing oscillations are used may influence the feeling at ease and thus the tempo chosen and correctly played. In addition, both decreasing tendency and a change of the motion pattern applied at higher tempi (as suggested by Shan and Visentin) may occur within individual subjects, depending on how consciously the movement has been trained.

In addition, the 2010 study showed a high correlation between the subjects' accumulated practice times per day and the developed amount of CM (.896 at the .05 level, see Figure 1). This could not be confirmed directly by the results of this study. The amount of short-term practice time seems not to be a primary factor for the quality of bowing movements with respect to mass balancing oscillations in trained children, because mass balancing oscillations can be made consciously at slow tempi. But long-term practicing is important for the process of automating mass balancing oscillations, in order to have them at one's disposal at higher tempi. This may be confirmed by the finding that the trained children tended to increase the extent of mass balancing oscillations within 5 weeks to an average CM of 44%; however, the effects turned out to be significant only after the second training period of ten weeks, due to a stabilization of the movement quality at higher tempi. Thus, the mean values of CM from four trials at different tempi increased to an average CM of 56.3%. (See figures 5 and 6) To show lasting effects, especially at higher tempi, training should probably continue over a longer period of time.

Within the control group, effects of practice caused by the repeated measurement and maturation effects did not lead to significant differences, but a tendency toward increased values after fifteen weeks may be indicative of a slow development over time in normal violin lessons. A sudden improvement occurred in one out of the ten subjects. This improvement accounts for nearly the whole difference between the mean values of the measurements C and D. The distribution of CM values within the adult university violin students suggests that CM values can remain stable at a lower expert level over the whole span of instrumental instruction. The intra-individual development of CM values with increasing tempo makes a pattern strikingly stable, as it was within the mean values of the whole group (see Figure 7). The teacher of the violin students in the control group as the imitated model may be the causal factor for this pattern. The teacher did not want to have his CM values measured, but this characteristic pattern of a change at higher tempi was estimated by sight and suggests an interrelation.

The results of the WISC-IV intelligence indices are plausible in the positive correlation of the peak values of CM with the Working Memory Index causing an intense processing at slow tempi. The negative correlations of the average CM with the Perceptual Reasoning Index and the Processing Speed Index are unexpected and oppositional to previous assumptions. It may be that the high scores at these indices are associated with a tendency to overly control the movements, which can be counterproductive at higher tempi.

The study suggests that mass balancing oscillations can be learned and trained at an early stage of instrumental instruction with (pre) teen violin students. Specific training of mass balancing oscillations as a supplement to musical training seems to be an advisable procedure in violin lessons. It might promote the artistic development and enhance the chances of admission to violin studies at higher university levels. As the effects of training correlated not with the practice times, but with the age of the subjects, training with teenaged children may be more effective than training with preteen children (see the data visual graphs in Figures 5 and 6, with the results arranged according to declining ages of the subjects). It may be that the

crucial factor for successful training is not only the ability to intellectually understand the theoretical backgrounds of the exercises, but the emotional openness to reap the musical benefits of good sound production while using mass balancing oscillations. Especially with very young children, motivation to train as rigorously as was done within the study might be problematic. The younger children seemed to participate only because of a good relationship with the teacher, but without personal enthusiasm, whereas some older students seemed to realize the importance and the musical benefits of the training. Especially when struggling with technical difficulties while learning musical pieces, these students benefitted from the transfer of the trained movements which led to sudden insights and to a desire for further related success in playing the violin.

Although the ill subject was left out of the statistical analysis, it is nevertheless interesting to look at this subject's CM values. As shown in Figures 5 and 6, the CM values were extremely low. Significantly, this subject suffered from a spinal blockage. This may indicate the relevance of mass balancing oscillations for a healthy approach to playing. Furthermore, it underlines the necessity of measuring the movement qualities, because the teacher did not completely realise the scope of the 'bad' movements by sight alone during the training period. Training of mass balancing oscillations holds some risks if not done carefully with an experienced instructor whose listening is constantly tuned for the resulting sound quality. Research on the effects of the training approach with regard to artistic development or to medical aspects must be undertaken in further studies.

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