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The Development of Motor Coordination and Musical Abilities in Pre-School Children

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Abstract

Movement and musical abilities develop simultaneously. This study investigates the correlation between musical and motor development. Observational data were collected from musical, cognitive and motor tasks. Twenty-eight children, aged 3.6- to 6.6- years-old, performed a standardized motor test measuring fine motor abilities, balance, motor reaction, and motion control, as well as a music aptitude test and three nonverbal subtests of a cognitive assessment test. Motor abilities and musical aptitude as dependent variables were related to gender, age, and cognitive state as independent variables. The results revealed a significant correlation between motor and musical abilities, as well as a linear progression. A second experiment introduced biomechanical and neurophysiological data from a subset of the sample and related these data to the measures of music aptitude. In general, these findings support the results of the first experiment.

Keywords: motor coordination; motor control; balance; postural stability; music aptitude; electromyography; proprioceptive amplification ratio

Introduction

It is a common everyday experience that people often move to music. Moreover, music is typically more likely to evoke body movements than are other expressive modalities, such as speech. A behavioral study reported motor behaviors stimulated by listening to either music or speech in two groups of infants aged 5 – 24 months (Zentner and Eerola, 2010). The children engaged in significantly more rhythmic movement to music and other metrically regular stimuli compared to speech. This can be interpreted as an early and quasi-"natural" connection between music and movement that becomes strikingly obvious in dance-like

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activities performed in children at play. Later on in life musical activities are often driven by the intent to develop excellence in high performance. In such situations movement is mainly related to the physiological conditions of finger, hand and arm movements in instrumental practice. The focus on training for technical achievement in music, then, parallels instrumental practice with competitive sports.

Until now, little attention has been paid to the general structure of an interaction between motor development and musical abilities in childhood. In music learning theory, body motion has become a major indicator of musical abilities in general (Gordon, 2001). Therefore, the relation of body movement and music learning has been stressed in music education (Danuser-Zogg, 2002; Gruhn, 2010; Hodges, 2009; Malinowski, 2000). This can be traced back to the ideas of Émile Jaques-Dalcroze (Jaques-Dalcroze, 1977) or Moshe Feldenkrais (Feldenkrais, 1976). In recent times, the awareness of body consciousness and music (Shusterman, 2008) appears in the broader context of the philosophical dimensions of music perception and cognition, and has introduced the concept of somaesthetics (Bowman, 2010).

In a developmental context, a study on neonates underpins the evidence for the presence of a sense of pulsation in humans that is related to a regular motion sequence. The perception of a regular pulse in an auditory signal might be innate or learned by very early exposure to the mother's heartbeat (Winkler, Háden, Ladinig, Sziller, and Honing, 2009). Newborn infants who listened to a rhythm that kept a regular beat quickly developed an expectation for the onset of a new metric cycle, even when it was not marked by stress. The omission of the downbeat caused a clear ERP signal associated with violation of an expected regular continuation. A regular pulse which determines an underlying rhythmic structure is fundamental to human perception and underpins how rhythmic regularity and perception are related.

A strong relationship between music and movement becomes evident in the ability to synchronize movements with an external sound stimulus. Young children are able to synchronize their body movements to a musical pulse, i.e., they move their hands or feet in synchrony with a tapped rhythm or a sung tune without having visual contact with the sound source (Thaut 2003; Trevarthen, 1999). This has also been documented in parrots, which can adapt their head nodding to the pulse of the music they hear (Patel, Iversen, Bregman, and Schulz, 2009; Schachner, Brady, Pepperberg, and Hauser, 2009). The ability to entrain movements to an external timekeeper raises the question as to whether there is an endogenous predisposition to connect sound and movement by auditory motor integration.

If we consider the literature regarding the development of coordinated motion (e.g., as reflected by the child's first walking independently) relevant studies show that coordination and proprioceptive motor sensitivity are interrelated (Berger, Altenmüller, and Dietz, 1984; Chang, Kubo, Buzzi, and Ulrich, 2006; Kubo and Ulrich, 2006; Thelen and Cooke, 1987). It seems reasonable and obvious that especially music has a considerable impact on the development of fine motor control caused by instrumental practice which, in turn, also impacts aural differentiation, melodic and rhythmic accuracy, and metric stability. Hence, observational studies have demonstrated that children who can sing more properly in tune and keep a regular steady beat also exhibit well-coordinated body control and the ability to move in space more smoothly in a continuous sustained flow (Gruhn, 1999).

All of these studies support the efficiency of a strong auditory-motor link which is prevalent in vocal learning. This was first demonstrated by research on birdsong (Jarvis, 2004; Marler, 2000; Zeigler and Marler, 2004). A unique neural mechanism connects auditory and motor processing in songbirds, some cetaceans, and humans. Physiologically, a neural connection is established at a very early stage of the central auditory pathway of sound propagation, presumably in the inferior colliculus, where sensory input and motor stimulation are connected. With respect to young children little research has focused on the first appearance of auditory-motor interaction, and it is still unclear whether there is an endogenous disposition for an auditory-motor interaction. This link might be found in the vestibular system, which is located in the inner ear and is responsible for the sensation of balance and motion.

In general, research has shown that body movement plays a crucial role in the learning process. Children do not acquire abstract knowledge, but concrete experiences are holistically acquired by the entire body.

It has been demonstrated that children prefer rhythms to which they were bounced for some time (Phillips-Silver and Trainor, 2007, 2008). The body and its movements generate those proprioceptive signals that are equally important for aural perception and discrimination. In the light of these findings it seems reasonable to investigate the proprioceptive and neuro-physiological mechanisms of a potential correlation between music and body movement that is evident in early childhood, and that may determine the synchronous development of motor and auditory abilities.

2. Experiment I

2.1. Aim of the Study

Given the scientific evidence of an auditory-motor link that is especially effective in vocal learning, and from the importance of body movement in all children's musical activities, the present study sought empirical data to determine parallels in the development of motor and musical abilities in young children. The main hypothesis is that body control and motor coordination is more pronounced in children who exhibit higher scores in musical aptitude tests.

Accordingly, more details and clearly defined tasks are needed to investigate this connection. Information regarding motor and musical abilities was drawn from a standardized motor test and a musical aptitude test. These data were complemented by teacher ratings of the children's tonal and rhythm abilities. Finally, selected nonverbal subtests of an assessment test provided a measure of the children's cognitive development. The authors suggest that examining the mechanisms that impact on musical and motor development will enable a better understanding of children's mental growth and musical learning.

2.2. Participants and Measures

Twenty-eight German-speaking children (5 male, 23 female; aged 3.6 to 6.6 years, median age 4.9 years) from an early childhood music class participated in the study. All children participated in an Early Music Learning Program based on Edwin Gordon's Music Learning Theory (Gordon, 1997).

All children were of good mental and physical health, and did not exhibit any motor or auditory impairment. Four evaluation measures were used:

1. *Primary Measures of Music Audiation* (Gordon, 1979). The PMMA is an aural discrimination test that measures musical aptitude. Forty pairs of short melodies and rhythms are presented, and the children are asked to compare the patterns and decide whether the second is the same or different from the first.
2. *Motoriktest für vier- bis sechsjährige Kinder* (Zimmer and Volkamer, 1984). The MOT 4-6 is standardized for pre-school children with a test-retest reliability of .97. Eighteen test items are divided into four major performance areas evaluating motor coordination (e.g., jumping rope), fine motor control (e.g., collecting matches into a matchbox with two hands simultaneously), balance (e.g., standing on one leg), reaction time (e.g., catching a falling stick), and action speed (e.g., carrying balls from one box into a distant other box as quickly as possible). The data provide a measure of overall motor abilities.
3. *Kaufman Assessment Battery for Children* (Kaufman and Kaufman, 2007). Three age-appropriate non-verbal subtests of the K-ABC were administered: Gestalt Recognition (pictured objects which are not completely visible), Triangle Reconstruction (replicating triangles from patterns consisting of several two-colored elements), and Digit-span (replicating an increasing number of hand gestures combining fist, angle, or palm gestures). The scores reflect children's cognitive development.
4. *Music Performance Scale.* Three performance abilities (singing of tonal patterns, chanting of rhythm patterns, and movement) were rated by the music teacher during early childhood classes prior to the experiment to provide a measure of children's performance skills.

2.3. Procedure

All parents signed a consent form and completed a questionnaire providing information about socio-graphic data and children's preferred leisure activities (such as sports, choir, or instrumental lessons) as well as hobbies (preferred games and entertainment such as watching television, solving puzzles, viewing picture books, romping, or climbing).

All children were tested individually in a large gymnastic hall, although they arrived in small groups (mostly three at a time).The intention of this arrangement was to increase the children's motivation and stimulate their collaborative spirit. The testing was presented as an entertaining game and was accomplished by providing small incentives (small tokens of toys) after each section (motor test, music aptitude test, intelligence test).

The tonal subtest of the *Primary Measures of Music Audiation* (PMMA) was administered first, followed by the eighteen tasks of the *Motoriktest für vier- bis sechsjährige Kinder* (MOT 4-6). The individual tasks were presented as a course of different "games" to be played. Then, an experimenter administered the three nonverbal subtests of the *Kaufman Assessment Battery for Children.* Finally, all children completed the rhythm subtest of the PMMA following the same procedure as for the tonal subtest.

Children were permitted to rest, move around, or play in the hall as they pleased between all test batteries. Raw data from both the motor and music aptitude tests were standardized according to peer norms, and were transformed into a motor quotient for the MOT 4-6 and a percentile rank for the PMMA.

Since all children had comparable socioeconomic status and similar musical experiences from their early childhood music program, a split-half method was applied based on their music aptitude percentile ranks, with children scoring lower than 50% in one group and children scoring 50% or higher in the other group. The MOT 4-6 and K-ABC scores of both groups were then compared. Correlations between all measures were also calculated.

2.4. Results

The music aptitude, motor, and cognitive scores of the two groups were significantly different. Table 1 shows the data for the PMMA and the K-ABC as a function of music aptitude. The two groups differed significantly on all subtests, including the tonal and rhythm subtests of the PMMA. They also revealed a significant difference in their motor skills. Figure 1 shows the rhythm, tonal, and total PMMA scores as a function of high versus low motor skills.

Similarly, significant correlations were found for all motor-test components (i.e., coordination, fine motor skills, balance, and motor control) and PMMA music aptitude scores (Table 2). The total mean scores for motor ability and music aptitude showed a clear linear progression (Figure 2). Subjects who exhibited higher motor scores also had higher percentile ranks in music aptitude, and vice versa ($r = .579$, $p < .05$, two-tailed). The higher the motor scores (as reflected by the motor quotients) the higher the percentile ranks for tonal, rhythm and total PMMA scores. One could argue that these findings simply reflect an age effect. In fact, a one-way within-subjects analysis of variance (ANOVA) with age as a factor and music aptitude, motor, and cognitive scores as dependent variables found a main effect of age ($p < .01$). However, a partial correlation with age as a control variable still demonstrated significant correlations for PMMA and the motor quotient ($R = 417$, $p = .034$) and, more interestingly, it showed a significant correlation for rhythm scores and fine motor abilities reflected by the motor test ($R = 469$, $p = .016$). Consequently, since motor control and music aptitude were positively correlated, musical sensitivity and auditory abilities accounted for more of the variance in motor coordination than age.

Table 1. Significant correlations of two independent (split half) samples

	melodic perform.	Rhythm perform.	rhythm PMMA	tonal PMMA	total PMMA	K-ABC
Mann-Whitney-U	86.500	93.000	27.500	38.500	29.000	26.500
Wilcoxon-W	191.500	198.000	132.500	129.500	134.000	131.500
Asympt. Significance (2-tailed)	.590	.810	.001	.011	.002	.001

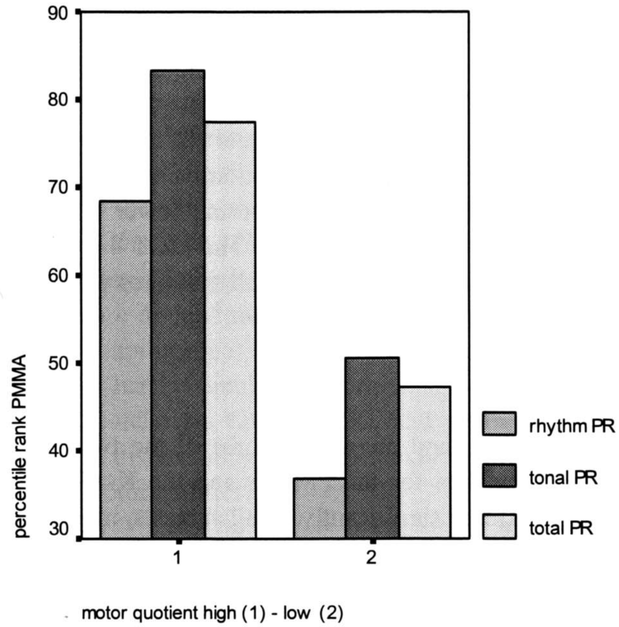

Figure1. Percentile ranks (PR) of the PMMA-test and subtests (tonal and rhythm) according to the split-half groups of high and low motor quotients.

Table 2. Correlations for MOT motor variables and PMMA music aptitude scores

MOT scores	**PMMA scores**		
	PR rhythm	PR tonal	PR total
coordination	r =.608** p = .001	.495** .009	.581** .001
fine motor abilities	r = .714** p = .000	.616** .001	.726** .000
balance	r = .635** p = .000	.615** . 001	.636** .000
motor control	r = .527** p = .004	.510** .007	.628** .000

The musical activities in children's leisure time did not contribute to this association, that is, children with and without extra-musical activities were both equally distributed over the total sample. However, the advancement of motor coordination is reflected by the distribution of those children who are engaged in extra-musical activities in their leisure time (singing in a children's choir or learning a musical instrument).

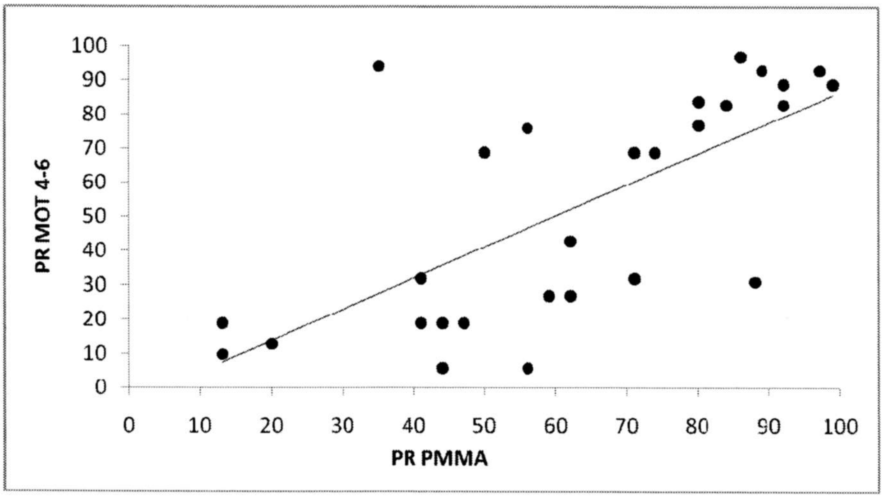

Figure 2. Correlation between the percentile ranks (PR) for movement (MOT 4-6) and music (PMMA). A Pearson correlation of 0.579** is highly significant.

Seventy-nine percent of the children with extra-musical activities were found in the high motor quotient group, whereas only 21% were found in the low motor quotient group. In contrast, those children who more preferentially engaged in motor activities like scramble, or gymnastics in their leisure time were equally distributed amongst the two motor groups (~ 50% in each group). Differences between motor groups for children with musical hobbies (like singing, listening to music, etc.) could not be investigated because all parents reported these hobbies for the children in this study.

The finding that children who engage in extra-musical activities were over-represented in the high motor group is not surprising, since playing a musical instrument requires motor coordination and motor control. However, if we look for differences in the development of motor behavior for children who sing in a choir compared to those who play a musical instrument, the data unexpectedly suggest that singing seems to have a stronger effect on motor development than playing an instrument. However, it should be noted that the number of children who sang in a choir (n = 5) is too small to permit any valid conclusion. A multivariate within-subjects analysis of variance (MANOVA) for the factor "extra musical activities" found a main effect only for the motor quotient ($F = 7.121$. $p = .004$), but not for intelligence or music aptitude.

3. Experiment II

3.1. Aim of the Study

Because the results of the first behavioral study revealed a correlation between motor control and musical development, the question arises as to whether this might also be reflected by physiological and biomechanical data. Therefore, a second experiment was conducted with the same children using their behavioral data from the first experiment. The rationale for the possibility of a physiological correspondence between music and motor abilities is that muscle activation, balance, and body oscillation might indicate a transformation from spinal to cortical motor control. The implementation of biomechanical measures aims to investigate a possible correlation between music aptitude and the neural foundation of proprioceptive sensitivity. If a relationship can be found, children with high music aptitude could be differentiated from children with lower music aptitude by their motor behaviour in the experimental tasks. The motor test data of Experiment I were thus correlated with the biomechanical measures of Experiment II. Finally, the cognitive scores of Experiment I were correlated with the same biomechanical measures.

3.2. Participants and Measures

A subset of sixteen children from the first sample was chosen. Eight of the children came from the subset of children who had the highest scores on the PMMA in Experiment I, and the other eight children came from the subset that had the lowest scores on this test. In addition to the behavioral data previously collected for Experiment I (motor, music aptitude, cognitive), the following four physiological and biomechanical data were collected:

1. Measurements of the medio-lateral and posterior-anterior displacements during a one-leg stand on the two dimensional, free-floating platform Posturomed®. The test-protocol was performed unilaterally while right-handed children stood on their right leg and left-handed children stood on their left leg. The data provide a measure of postural stability; wider deflections indicate a lower ability to stabilize balance while smaller deflections refer to a more stable balance.
2. Electromyography (EMG) was recorded during a one-leg stand on the Posturomed® from musculus peroneus longus, musuculus tibialis anterior, and musculus soleus in order to measure neuromuscular activity.
3. Two parameters of jumping ability (Squat-Jump, SJ, and Counter Movement Jump, CMJ) were measured on a force plate. CMJ is initiated from a standing position. The child performs a preparatory dip movement and jumps upwards. The reactive strength in a long Stretch-Shortening-Cycle is tested. SJ starts from a static semi-squatting position (knee angle 90°) without any preliminary movement, measuring the maximal concentric jump-height.
4. Body Oscillations, by having the children continuously bend and stretch their knees, were recorded from a Leonardo® Mechanograph. This measure measures the ability to control and coordinate body movements in a rhythmically stable manner.

3.3. Procedure

The children were asked to perform the above tasks in a playful context (staying on one leg like a stork; jumping like a kangaroo etc.). Each child performed three trials that were then averaged. An electromyography (EMG) was recorded during the balance task to measure muscle activity. Activation of the musculus peoneus longus, musculus soleus and musculus tibialis anterior were recorded from the supporting leg by two adhesive bipolar electrodes (Ambu Blue Sensor P, type P-00-S/50, Ag-AgCl) which were fixed at a distance of about 2 cm on the muscle belly of each of the three muscles. A reference electrode was placed on the patella. The raw data were then subjected to an offset-correction and a bandpass filter (Butterworth 4th order bandpass filter 10-500 Hz), and the signals were rectified for further computation of an integral value of muscle activity. These data were used to generate three more parameters indicating the proprioceptive sensitivity of the children. The muscle tension that is needed to stabilize balance is mainly evoked by feedback signals from the proprioreceptors. A higher muscle activity for the same postural displacement indicates better proprioceptive sensitivity. Based on this, a proprioceptive amplification ratio (PAR) was calculated for each muscle. The integrated EMG (iEMG) of the musculus peroneus longus was referred to the medio-lateral direction:

$$PAR_{ML} = \frac{iEMG\ M.\ peroneus\ longus}{displacement\ medio\text{-}lateral}$$

For the anterior-posterior direction, the activity of musculus soleus was used in isolation as well as in combination with the musculus tibialis anterior:

$$PAR_{AP1} = \frac{iEMG\ M.\ soleus}{displacement\ anterior\text{-}posterior}$$

$$PAR_{AP2} = \frac{iEMG\ M.\ soleus + iEMG\ M.\ tibialis\ anterior}{displacement\ anterior\text{-}posterior}$$

The resulting PAR quotient serves as a measure for proprioceptive sensitivity; the higher the quotient, the better the proprioceptive sensitivity.

3.4. Results

The upper and lower PMMA achievement groups are clearly, but not significantly differentiated by their biomechanical data. The proprioceptive amplification ratios (PAR) are also obviously different for the two PMMA groups, but they too did not differ significantly because of the large amount of variability in the data (Figure 3).

Similarly, both groups are clearly differentiated regarding their biomechanical measures of the motor tasks. However, both Jump and Body Oscillation exhibited highly significant differences ($p = .003$ and $p = .005$ respectively). Aside from this, PMMA raw scores and PAR quotients exhibited a slight linear progression and confirm a clear association of both auditory and motor measures (Figure 4).

Significant correlations emerged for the music aptitude test (PMMA) and two motor tasks, Body Oscillation ($r = -.590$, $p = .01$) and Jump ($r = .613$, $p = .01$) for the total sample. A one-way within-subjects ANOVA confirmed that the scores of the PMMA exhibited a significant effect on both Body Oscillation and Jump.

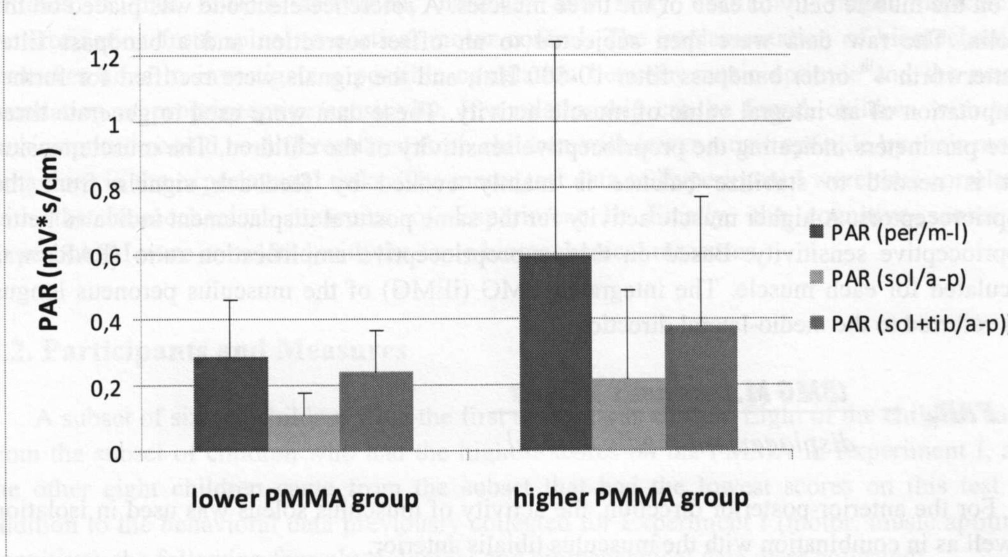

Figure 3. The scores of the two PMMA split half groups yield a clear, but not significant separation with regard to their three proprioceptive amplification ratios (PAR quotients).

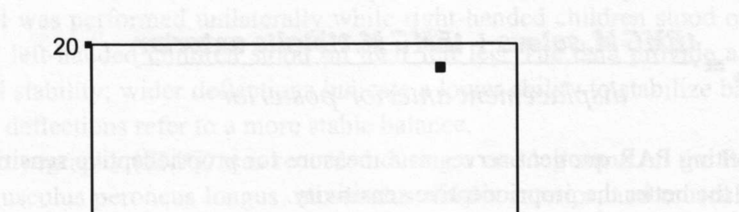

Figure 4. The correlation of musical aptitude (PMMA) and the bio-mechanic amplification ratio (PAR) exhibits a slight linear progression.

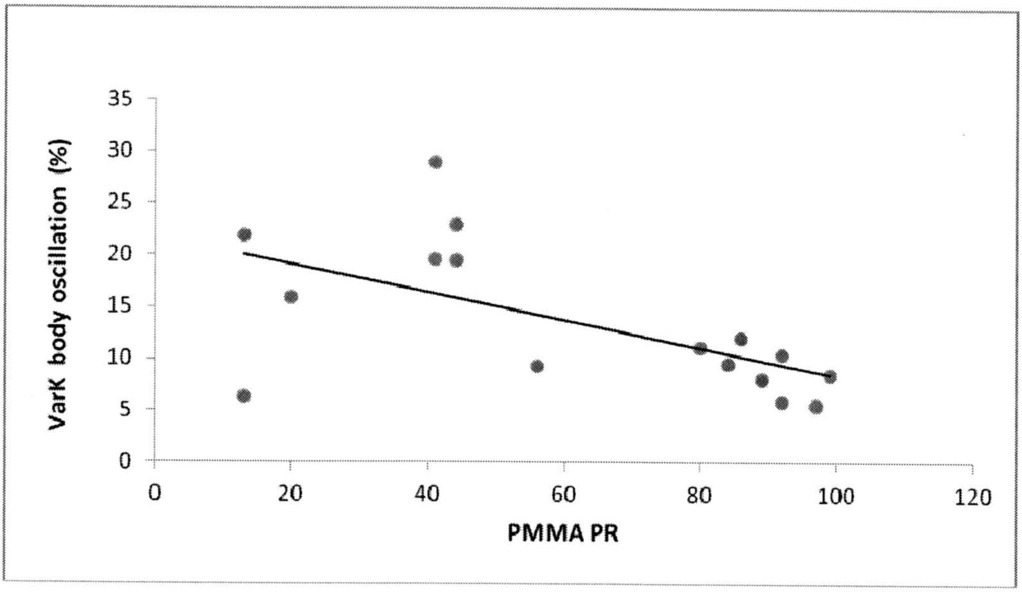

Figure 5. A significant negative correlation (r = – 0.590) is performed for the percentile ranks of PMMA and body oscillation.

Furthermore, the variation coefficients for Body Oscillation exhibited a significant negative correlation with the PMMA values, because small variation coefficients during rhythmic Body Oscillation indicate a more stable and well-balanced variance of the period length. Therefore, a smaller variation coefficient indicates better proprioceptive sensibility. Thus, the higher the participant's PMMA score, the smaller the variation coefficients (r = -0.590, $p < .05$, two-tailed; Figure 5).

Since it is reasonable to expect that Jump and Body Oscillation advance with age, the variable age was factored out for all correlations. The results still demonstrate the same effects on a lower level. A clear association exists, but the significance disappears in a partial correlation without age. Finally, the scores of the behavioral motor test (MOT 4-6) were significantly correlated with Jump ($r = .533$, $p = .049$), whereas no significant correlation was found for the other biomechanical measurements or cognitive development (K-ABC).

Conclusion

The data from both experiments clearly demonstrate a correlation between motor and musical development. Although this result was not expected, it is not surprising given that several studies suggest that an auditory-motor network is activated in speech and music (D'Ausilio, Altenmueller, Olivetti Belardinelli, and Lotze, 2006; Hickock, Buchsbaum, Humphries, and Muftuler, 2003; Rochet-Capellan and Ostry, 2011) In particular, the inferior colliculus in the midbrain, which receives input from the auditory pathway and the auditory cortex, comprises bimodal neurons that are sensitive to both auditory and sensorimotor stimuli.

Age, of course, also plays an important role in developmental processes. However, once age was controlled for, a significant association between auditory and motor development remained in Experiment I. This suggests that musical abilities and motor control are related, and may develop simultaneously. However, it cannot be assumed that music has an immediate causal effect on movement development (or vice versa), although a recent study found an effect of body movement on music listening and emotional preferences (Sedlmeier, Weigelt, and Walther, 2011). Based on our findings it might be concluded that music and movement interact at an early developmental age. The better a coordinated motion can be performed, the better the development of musical discrimination and audiation skills. There is some evidence to suggest that both developmental domains (music and motion) develop synchronously to a certain level of achievement during childhood.

This process is partially reflected by the data of our biomechanical measures. However, coordinated balance and muscle tension have already been developed at this biological stage (i.e., after mature walking). Therefore, the early years warrant further investigation of music-motor-interactions based on the transition from spinal to cortical motor control.

The findings of the first experiment confirm former results of an observational study that has shown a positive correlation between singing in tune and motor control (Gruhn, 2002). Auditory-motor coupling results in fine motor precision of auditory perception and vocal production, which are mutually related in audio-vocal learning. However, this correlation does not indicate a causal relationship. That is, neither sports and motor training nor musical practice can improve the other modality on its own. Rather, motor and auditory abilities are neurally linked and procedurally integrated during neuropsychological development. Children's motor activities that are developmentally relevant are associated with the performance of a continuous flow of movement, the feeling of the metric weight. They are related to body tension, but not with power and force as is found in competitive sports. The ability to perform a fluent movement in time and space calls for the same ability that is needed to frame a melodic line. In music, time and space interact; musical time appears as a projection of sound into space (Gordon, 2007; Laban, 1988). Therefore, empirical evidence of an association between motor development and musical abilities suggests educational application in terms of a more pronounced implementation of movement into music programs in order for children to facilitate and enhance the establishment of the auditory-motor loop.

The results of this study also highlight the importance of developmental effects caused by age. Maturation is always reflected by achievement, in music as well as in motor tasks. However, the question is whether higher scores in perceptive and motor skills can or must be interpreted mainly in terms of maturation, or whether they develop in mutual accordance and to a certain degree independent of age. This interaction was still found when we controlled for the effects of age on motor coordination. Interestingly, the significant correlation (p = .016) between the PMMA rhythm test and the fine motor skills subtest of the MOT 4-6, even when age was controlled for, supports earlier research with infants who preferred rhythms to which they had been bounced (Phillips-Silver and Trainor, 2007), and clearly validated how body movement and rhythm perception interact.

On the other hand, one could speculate that playing an instrument enhances motor coordination and motion control, which is true in general. However, all of the children in this study participated in an early music class that did not include instrumental instruction. Only nine out of 28 children had started with early instrumental instruction outside the class setting, but they did not show any effect, and were rather equally distributed across the entire sample. Furthermore, significant correlations were found only for music abilities, but not for other activities identified by the questionnaires. After all, it seems obvious that auditory-motor coupling is based on a neural mechanism that connects motor and auditory sensorial input, and which is well known as a prerequisite for vocal learning (Brown, 2000; Brown, Martinez, Hodges, Fox, and Parsons, 2004; Merker, 2005; Mooney, 2004).

The current investigation confirms what is already observed in educational practice. For young children, auditory-motor interaction is evident throughout their early developmental age. Further studies on younger children might cast doubt on the presumed neural mechanisms cited in support of the theory that motor control develops together with an increase in cortical motor control which is simultaneously accompanied by a decrease in spinal control. This happens at an age when children develop their fine-grained auditory and motor abilities.

In conclusion, the current findings promote a conceptual argument that underlines the perception of time and space in music as inseparably connected with the performance of time and space in movement. Music can be seen as an art form that integrates time and space in a similar way as movement integrates time and space. As demonstrated earlier, music and movement rely on related neural mechanisms that have been developed at an evolutionarily early stage. The operant age-effect reflects its developmental aspect, but does not contradict the notion of a fundamental correlation between motor and sound processing that can be observed anywhere in music performance, and is strikingly evident in rock concerts and certain dance performances.

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