Movement analysis and musical abilities in pre-school children

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Abstract

Movement and musical abilities develop simultaneously. Interactions and correlations between musical and motor development are investigated. Observational and physiological data are collected from musical, cognitive and motor tasks. Twenty-eight four to six year old children performed a standardized motor test measuring fine motor abilities, balance, motor reaction, and motion control, complemented by a music aptitude test and three nonverbal subtests of a cognitive assessment test. Motor abilities and musical aptitude are compared and related to gender, age, and cognitive state as independent variables. The results exhibit a significant correlation and demonstrate a strong linear progression. Additionally, bio-mechanical and neurophysiological (EMG) data were collected from a subset of the same sample. The new data support the findings of the first experiment.

Keywords

motor control; motor coordination; music aptitude; musical development

1. Introduction

In every-day experience one can observe that music always goes along with movements which are often induced by music. Moreover, music is much more suitable to evoke body actions than any other expressive modality. This is reported by a study where two groups of infants aged 5 – 24 months were observed in their motor behavior stimulated by listening to either music or speech. In this experiment, children engaged significantly more in rhythmic movement to music and other metrically regular stimuli than to speech (Zentner & Eerola, 2010). This can be seen as an early and quasi "natural" connection between music and movement which becomes strikingly obvious in dance-like activities that are performed in children's play. Later on in life musical activities are often driven by the intent to develop excellence in high performance. In this case movement is mainly related to the physiological conditions of instrumental practice. The focus on training and achievement, then, parallels music and competitive sports.

Here, the relationship between music and movement shall be approached from a broader and more general perspective. The study focuses on developmental aspects of music and movement in early childhood. The question is whether one can substantiate empirical evidence for connections between music and movement when children grow up and develop their skills to speak, sing, and move. During that period clear evidence arises that coordinated motion (e.g. as reflected by first independent walk) and proprioceptive motor sensitivity interact (Berger et al., 1984; Chang et al., 2006; Kubo & Ulrich, 2006; Thelen & Cooke, 1987).

With regard to instrumental practice it seems obvious that music has an impact on fine motor control which, in turn, also impacts on aural differentiation, melodic and rhythmic accuracy, and metric stability. Hence it has been demonstrated by observational studies (Gruhn, 1999) that those children who can sing in tune more properly and keep a regular steady beat are the same who exhibit a well coordinated body control and move in space more smoothly in a continuous sustained flow.

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 philosophical dimensions of music perception and cognition and has introduced the concept of somaesthetics (Bowman, 2010).

A recent study on neonates underpins the evidence that the detection of a regular pulse in an auditory signal might be innate or learned by very early exposure to the mothers heartbeat (Winkler et al., 2009). Newborn infants listened to a rhythm that keeps a regular beat. They 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. This indicates that a regular pulse is fundamental in human perception.

Strong auditory-motor coordination has also been evidenced in adult musicians (Bangert & Altenmueller, 2003; Baumann et al., 2007). An experiment which compared silent piano performance (finger movement) and motionless listening exhibited an increase of activation in the concurrently activated cortical areas by imagination of the absent modality. This can be attributed to an intensive musical training. However, with respect to young children little research has focused on the first appearance of auditory-motor interaction, and it is still an open question 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.

The importance of an auditory-motor link on vocal learning was first demonstrated by the research on birdsong (Jarvis, 2004; Marler, 2000; Zeigler & Marler, 2004). A unique neural mechanism connects auditory and motor processing in songbirds, some cetaceans and mainly humans. Physiologically, a neural connection is established at a very early stage of the central auditory pathway of sound propagation, presumably in the colliculus inferior, where sensorial input and motor stimulation are connected. This neural link between auditory and motor activation enables vocal learners to reproduce sounds (single pitches and complex frequency spectra) just by listening (Gruhn, 2009). It has been observed that birds are able to imitate the song of another bird and even the tune of a cell phone which was repeatedly played and perceived in a park.

The neuronal correlates of vocal learning build the phonological loop by which auditory information is needed to conduct vocal sound production by mutual feedback. To perform the precise tension of the vocal cords which is necessary to produce a distinct sound calls for fine motor control which is initially governed by an auditory signal that functions as a target sound to be imitated. An experiment with poor and good singers has demonstrated that poor singers very often do not lack a discrimination ability, they rather fail to integrate auditory information into a motor program for vocal sound production (Pfordresher & Brown, 2008).

The ability to synchronize movements with an external sound stimulus provides another strong argument for the relation of music movement. Young children are able to synchronize their body movement to a musical pulse, i.e. they move their hands or feet in synchrony with a tapped rhythm or a sung tune although they do not have any visual contact to the sound source (Thaut 2003; Trevarthen, 1999), which is also documented for parrots who can adapt their head nodding to the pulse of the music they listen to

(Patel et al., 2009; Schachner et al., 2009). The ability to entrain movements to an external timekeeper raises the question regarding an endogenous predisposition to connect sound and movement by auditory motor interaction.

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 strikingly demonstrated that children prefer a rhythm to which they were bounced for some time (Phillips-Silver & Trainor, 2007, 2008). It is the body and its motion which initiate to develop the proprioceptive patterns for aural perception and discrimination.

In the light of these findings it seems reasonable to investigate a potential correlation of music and movement that already appears in early childhood and determines the development of motor and auditory abilities.

2. Experiment I

2.1 Aim of the study

Starting from the scientific evidence of an auditory-motor link in vocal learning and the observation of the importance of controlled body movement in the musical behavior of children, the present study aimed for empirical data that could unveil parallels in the development of motor and musical abilities in young children. The general hypothesis is that body control and motor coordination is more pronounced in children who exhibit higher scores in music aptitude tests. Accordingly, more details and clearly defined tasks are needed to investigate this connection. Information regarding motor and musical abilities is gained from a standardized motor test and a musical aptitude test. These data are complemented by ratings of children's tonal and rhythm abilities given by the teachers of the involved children classes. Finally, selected non-verbal subtests of an assessment test provide a measure of children's cognitive development. By comparison, the behavioral data are proven if they give empirical evidence of a correlation between motor and music domains. Uncovering the mechanisms that impact on musical and motor development will cause 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 from 3,6 to 6,6 years, median 4,9 years) from an early childhood music class participated in the study. All pre-school children of the study participated in an Early Music Learning Program based on Gordon's Music Learning Theory (Gordon, 1997). All children were of good health, and did not exhibit any motor or auditory impairment. Four evaluation measures were applied to the study:

1. Primary Measures of Music Audiation (Gordon, 1979). The PMMA presents an aural discrimination test which reflects 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.

2. Motoriktest für vier- bis sechsjährige Kinder (Zimmer & Volkamer, 1984). The MOT 4-6 is standardized for pre-school children with a test-retest reliability of .97. The eighteen test items that are arranged in a sequence of mixed tasks evaluating motor coordination (e.g. jumping into a 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 distanced other box as quickly as possible). The data provide a measure for the overall motor abilities.

3. Kaufman Assessment Battery for Children (Kaufman & Kaufman, 2007). Three non-verbal subtests of the K-ABC were chosen which conform to children's age. They include 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 performing skills.

2.3 Procedure

All parents signed a consent form and filled-in 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 entertainments like TV, puzzle, picture books, blustering, climbing).

The entire meeting was conducted in a large gymnastic hall lasting for approximately two hours. All children were tested individually although they came in small groups (mostly three at a time).The intention of this arrangement aimed to increase their motivation and stimulate a collaborative spirit. The testing was arranged as an entertaining game and was accomplished by getting small incentives after each section (motor test, music aptitude test, intelligence test).

Children started with the tonal subtest of the *Primary Measures of Music Audiation* (PMMA). This test was given to each of the children individually conducted by the experimenter who circled the answer sheet. This was followed by the full range of eighteen tasks of the *Motoriktest für vier- bis sechsjährige Kinder* (MOT 4-6). The single tasks were arranged in a cycle which presented a course of different "games" to be achieved. Then, three non-verbal subtests of the *Kaufman's Assessment Battery for Children* were subsequently implemented to each individual child sitting at a table with one experimenter who conducted the test items. Finally, all children completed the rhythm subtest of the PMMA individually. The procedure was the same as in the tonal section.

Between all test batteries children could rest or move around or play in the hall for their relaxation. Raw data from both, the motor and the music aptitude tests were normalized according to the norms of the peer group and were transformed into a motor quotient and the percentile rank of music aptitude respectively.

Since all children came from a comparable higher social background and had similar musical experiences from an early childhood music program, a split-half method was applied. According to the achievement in the motor test an upper and a lower half was set up. Both halves were compared regarding their musical and cognitive skills (PMMA and K-ABC scores) to prove whether both groups were clearly differentiated. Additionally, correlations between all measures were calculated.

2.4 Results

A split-half design was applied to data analysis. Children of the upper and lower half according to music aptitude significantly differ also in their motor and cognitive scores. Data from the Mann-Whitney-Test (table 1) show the differences for the percentile ranks of the PMMA test and the K-ABC assessment of cognitive abilities. A significant difference is reflected by all subtests (tonal test and rhythm test) (figure 1).

Insert Table 1 and Figure 1 about here

Similarly, significant correlations surface between all motor-test components (i.e. measured motor abilities regarding coordination, fine motor skills, balance, and motion control) and PMMA music aptitude scores (table 2).

Insert Table 2 about here

The total mean scores of the motor ability and music aptitude scores clearly exhibit a linear progression (figure 2). Subjects who exhibit higher motor scores show also higher ranks in music aptitude and vice versa. Therefore, it is obvious that the higher the motor scores (as reflected by the motor quotients) the higher ranks are performed in the musical aptitude (percentile ranks for tonal, rhythm and total scores).

Insert Figure 2 about here

One could admittedly argue that these findings simply reflect an age effect. Actually, a one-way ANOVA with age as factor and the musical, motor, and cognitive scores as dependent variables exhibits highly significant effects of age ($p < .01$) on the rhythm and tonal test, the cognitive K-ABC measure and the motor quotient. However, a partial correlation with age as a control variable still demonstrates significant correlations for PMMA and the motor quotient ($R = 417$, $p = .034$) and, more interestingly, it shows a significant correlation notably for rhythm scores and fine motor abilities reflected by the motor test ($R = 469$, $p = .016$). Consequently, since motor control and music aptitude correlate as reflected by the data, musical sensitivity and auditory abilities count for motor coordination in a stronger way than age.

The musical activities in children's leisure time do not contribute to this association, that is, children with and without extra musical activities are both equally distributed over the total population (see figure 2). 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). 79% of the children with extra musical activities are found in the upper half of the children with high motor quotients whereas only 21% assemble in the lower half. This is quite different compared to those children who more preferentially engage in motor activities like bluster, scramble, and gymnastics in their leisure time. Here, the children are equally distributed (50%) among the two groups with high and low motor quotients. No differentiation could be found for children with musical hobbies (like singing, listening to music etc.) because parents report these hobbies for all children of this study.

The effect of extra musical activities is not surprising since playing an instrument requires motor coordination and motion control. However, if we look for differences of choir singing or instrumental play on the development of motor behavior, we unexpectedly find that singing tends to have a stronger effect than playing an instrument. However, it must be stressed that the number of children who sing in a choir ($n = 5$) is too small to make any valid statement. A multivariate analysis of variance for the factor "extra musical activities" indicates a significant impact only on the motor quotient ($p = .004$; $F = 7,121$), but not on intelligence and music aptitude.

3. Experiment II

3.1 Aim of the study

Since the results of the first behavioral study exhibit a clear correlation between motor control and musical development, the question arises whether this might be also reflected by physiological and bio-mechanical 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 be seen as an indication of the state of the transformation from spinal to cortical motor control. The implementation of the bio-mechanical data aims to answer the following research questions:

1. Is there a correlation between music aptitude and the proprioceptive sensitivity? If so, children with high music aptitude could be differentiated from children with lower music aptitude by their motor behaviour in the experimental tasks.

2. Do the results of the motor test (experiment 1) correlate with the bio-mechanical measures of the second experiment?

3. Does the cognitive development correlate with the bio-mechanical measures?

2.2 Participants and Measures

A subset of sixteen children from the first sample was chosen. Eight of them came from children with the highest scores in the PMMA test in experiment I, and another eight children came from those with the lowest scores in this test. In addition to the already collected behavioral data (motor test, music aptitude test, cognitive test), the following four physiological and bio-mechanical data were collected:

1. Measurements of the medio-lateral and posterior-anterior deviations during a one-leg stand (predominantly right handed children on their right leg, predominantly left-handed children on their left leg) on a Posturomed (multidirectional movable board, see figure 3). The data provide a measure of the sense of balance; wider deflections indicate a lower ability to stabilize the balance while a smaller deflections refers to a more stabile balance.

Insert Fig. 3 about here

2. An electromyogram (EMG) was recorded during a one-leg stand on the Posturomed from musculus peroneus, musuculus tibialis anterior, and musculus soleus which are implemented to measure the counterbalance the movements. By this, the power of muscle activation is recorded.

3. Jumps on a power measuring mat where the muscle power and the upthrow were recorded.

4. Body oscillations by continuously bending and stretching their knees were recorded from a Leonardo Mechanograph. This measure relates to the ability to control and coordinate body movements in a rhythmically stabile manner.

3.3 Procedure

The children were asked to perform the above mentioned tasks in a playful context (staying on one leg like a stork; jumping like a kangaroo etc.). Each child performed three trials which then were averaged. The raw data were further processed (offset correction, band-pass filter, integration) to get an integrated integrative EMG and then transformed into a quotient (the *proprioceptive amplification ratio*, PAR) which reflects the power of muscle activity during the movements on the Posturomed and displays a measure of the motor sensitivity.

3.4 Results

When the upper and lower achievement groups according to their PMMA scores are compared they are clearly differentiated regarding the following motor tasks: the jump power ($p = .003$) and body oscillation ($p = .005$) exhibit highly significant differences. The PAR scores are not significant because of the large statistical spread. Only a small linear progression appears for the PMMA scores and the PAR quotient (figure 4).

Insert Figure 4 about here

This is also reflected by a bivariate Pearson correlation which also demonstrates a significant correlation between the music aptitude test (PMMA) and motor tasks for body oscillation ($r = -.590$, $p = .016$) and jump power ($r = .613$, $p = .012$). A one-way

ANOVA confirms that the scores of the PMMA test exhibit a significant effect on the same variables (body oscillation and jump power).

Since jump power and body oscillation can be expected to advance with age, the variable age was factored out for all correlations. The results still demonstrate the trend of a positive correlation, but it is also apparent that all correlations decrease. However, the physiological and bio-mechanical data and the cognitive and motor scores show a significant correlation for the body oscillation and for the jump power. If the age is eliminated as an impact factor, the motor scores still reflect a small significant correlation with the jump power ($r = .533$, $p = .049$). However, no significant correlation occurs for the other tasks of the bio-mechanical measurements (except jump) and the cognitive development (intelligence test).

4. Discussion

The data of the first experiment clearly demonstrate a correlation between motor and musical development. Although age is always a vigorous factor in developmental processes, it has been demonstrated that even though this factor was eliminated, a significant effect still remains apparent. This might explain that musical abilities and motion control are mutually related and develop simultaneously in parallel. However, there is no reason to assume 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 et al., 2011). At an early developmental age music and movement interact. The more advanced the coordinated motion can be performed, the better the musical discrimination and audiation skills have developed. There is some evidence to assume that during childhood both developmental domains (music and motion) develop synchronously to a certain level of achievement.

This process is partially reflected by the data of the bio-mechanical measures. However, at this biological state the coordinated balance and muscle tension have already been developed after mature walking. Therefore, the early years would be more interesting for further investigation of music-motor-interactions based on the transition from spinal to cortical motion control.

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

The results of this study also encompass the importance of developmental effects caused by age. Maturation is always reflected by the 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 as a result of maturation, or whether they develop in mutual accordance and to a certain degree independent of the growing age. Since we could factor out age as an influential factor for motor coordination, this interaction is still confirmed. Interestingly, the significant correlation ($p = .016$) between the rhythm test (PMMA) and the fine motor skills in the motor test (MOT) even when age is eliminated confirms a finding with infants who preferred the rhythms to which they had been bounced on (Phillips-Silver & 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 subjects in this study participated in an early music class which did not include instrumental instruction. Only nine out of 28 children had started with early instrumental instruction outside the class setting. They do not show any effect, and are rather equally distributed across the entire population. Furthermore, significant correlations surfaced only for music abilities, while not for other activities which were identified by the questionnaires. After all it is obvious that auditory-motor coupling is based on a neural mechanism which connects motor and auditory sensorial input which is well known as a prerequisite for vocal learning (Brown, 2000; Brown et al., 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 debunk neural mechanisms that could support the theory that motion control develops along with an increasing cortical motor control that is simultaneously accompanied by a decreasing 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 motion needs time and space to be performed. As demonstrated earlier, music and movement rely on related neuronal mechanisms that have been developed at an evolutionary early stage. The operant age-effect reflects its developmental aspect, but does not contradict the notion of a very fundamental correlation between motor and sound processing which can be observed anywhere in music performances and with especially striking evidence in rock concerts or dance performances.

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