

ARTS BIOMECHANICS

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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 Katō 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).

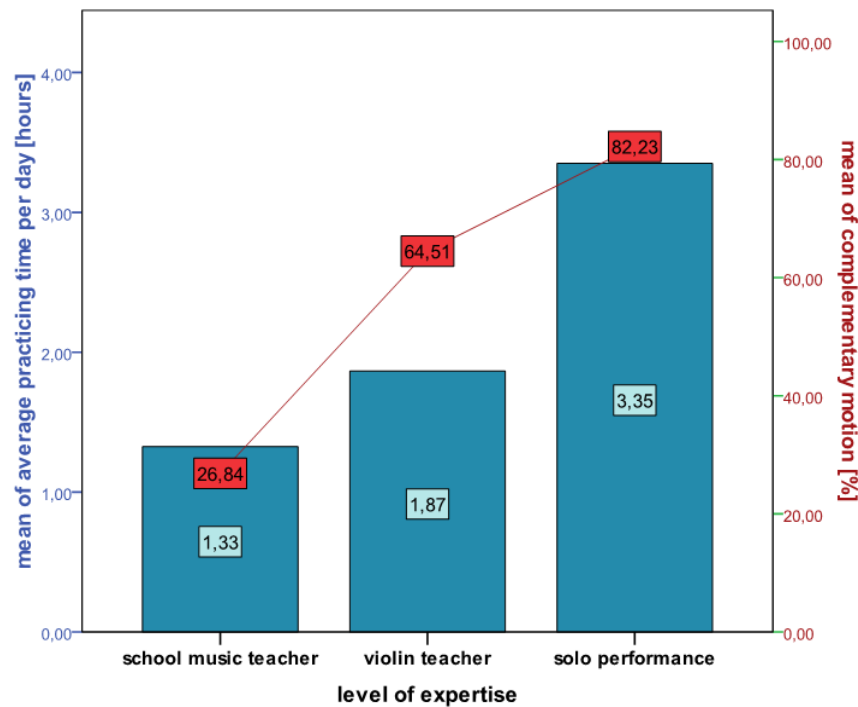


Figure 1. Comparison of the average practicing time per day with the percentage of complementary motion found at three levels of expertise in violin playing subjects, shown in Hasselbach et al. 2010.

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 $x < 1$ m). 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 Zebbris CMS 20 (Zebbris Medical, Isny, Germany).

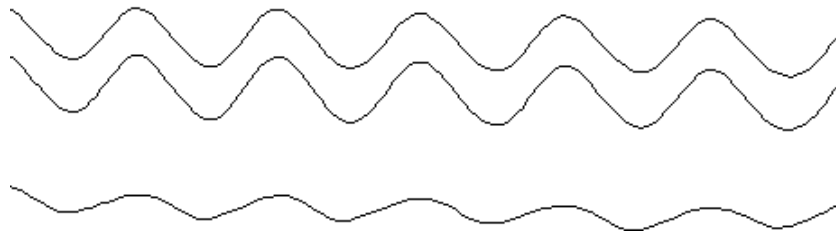


Figure 3. Parallel movement of elbow (lower line) and hand (upper two lines) from a subject with only 18% of calculated complementary motion.

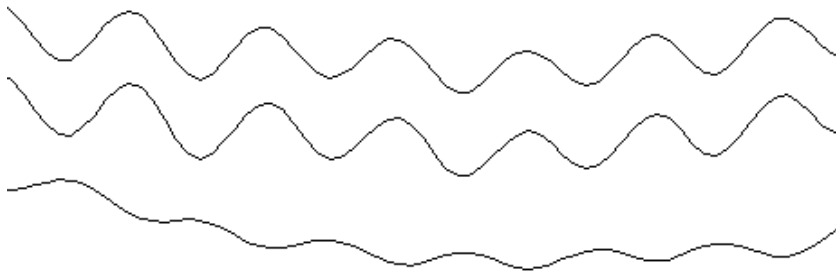


Figure 4. Dephased movement of elbow (lower line) and hand (upper two lines) from a subject with 85% of calculated complementary motion.

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

A: after 5 weeks of training

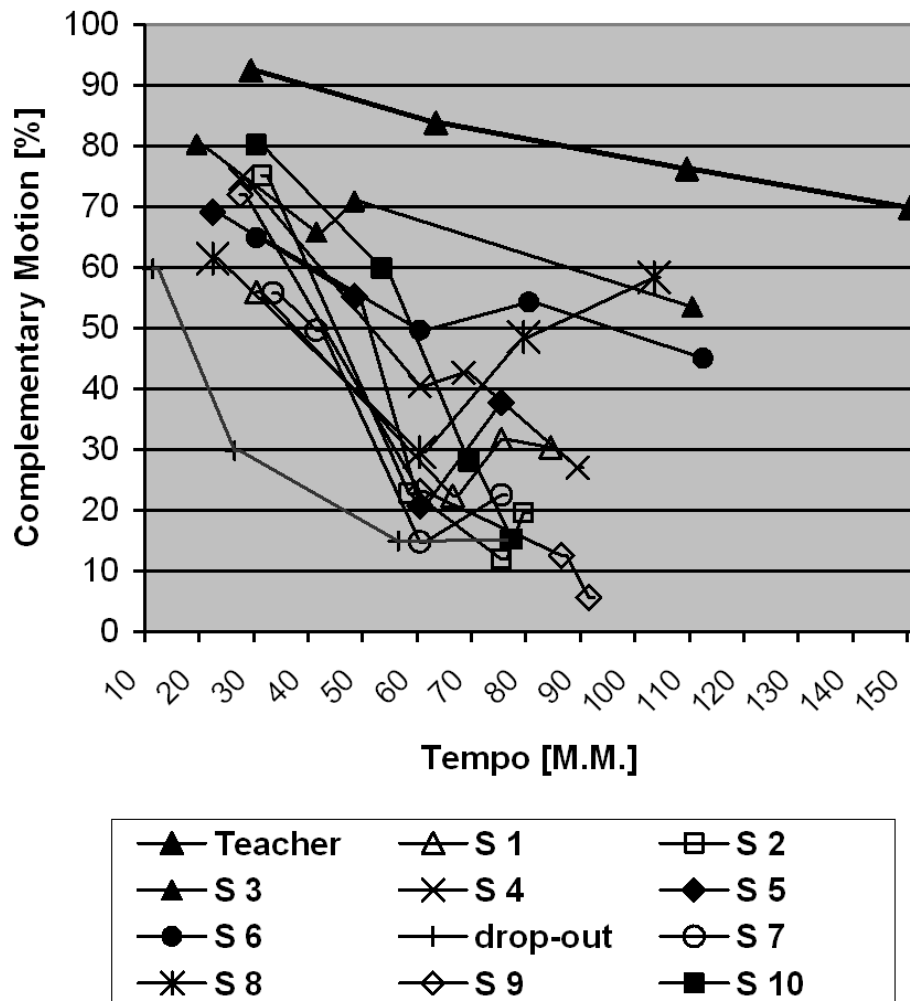


Figure 5. Visual graph of the data in measurement A.

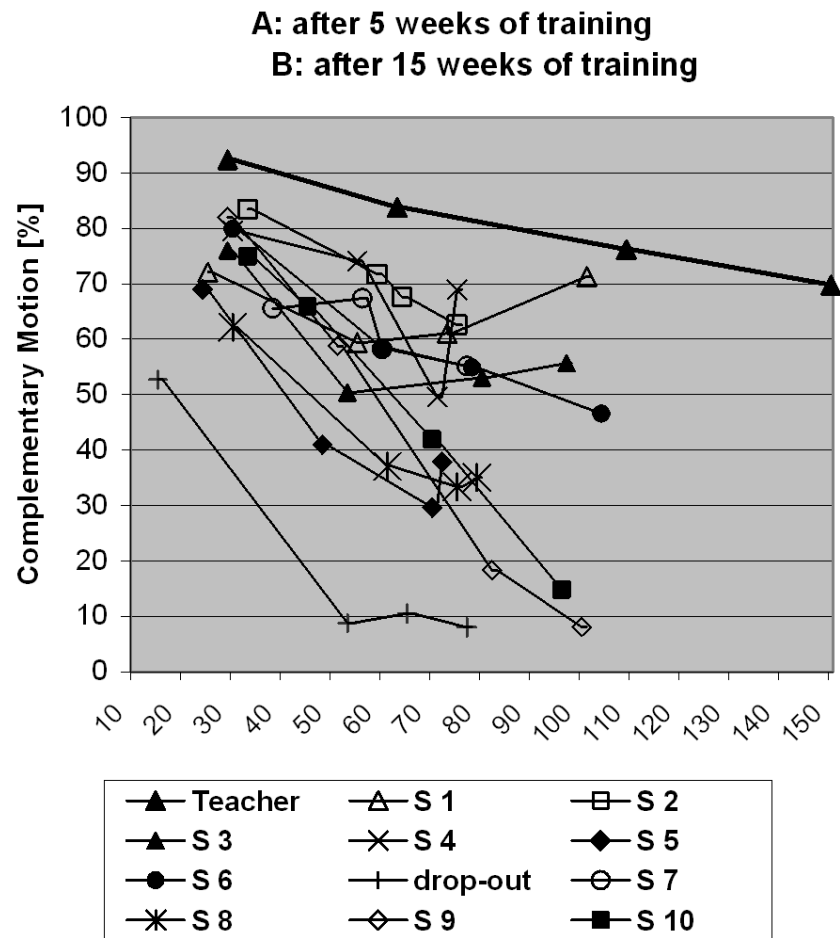


Figure 6. Visual graph of the data in measurement B.

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.

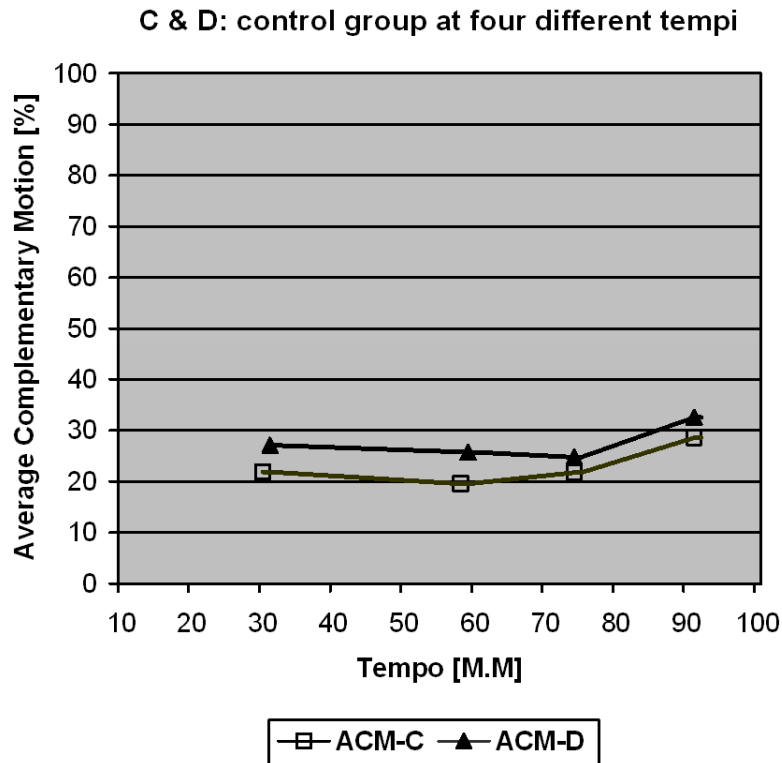


Figure 7. Visual graph of the data within the control group at the measurements C and D.

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).

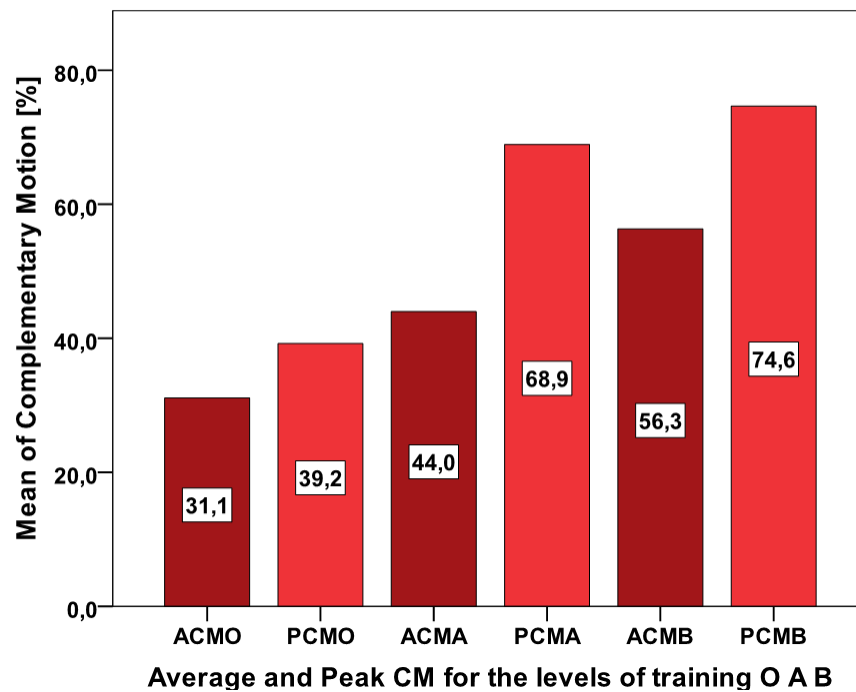


Figure 8. Means of average and peak values of complementary motion at the training levels O (Outset), A (after five weeks of training) and B (after fifteen weeks of training).

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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APPLICATIONS OF EMG PERTAINING TO MUSIC PERFORMANCE - A REVIEW

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ABSTRACT

EMG is a well proven technology in the fields of motor control and motor learning. Performance mastery on a musical instrument requires some of the most sophisticated neurological processes of any human activity (including rapid interlacing of the cortices that control the auditory, visual, and motor sensory systems). Surprisingly the number of EMG studies in music is small. This review article examines the literature from 1973 to 2010, summarizing research trends in three main areas: 1) the potential of EMG in skill analyses, 2) biofeedback in teaching and learning, and 3) applications in injury remediation and prevention. The aim of this article is to both demonstrate the utility of EMG in music performance research and, in doing so, encourage more research in this area.

INTRODUCTION

Applications of EMG technology in the performing arts vary widely depending on the specific discipline. Artists such as dancers or circus performers can profit and, in some instances have benefited, greatly from EMG research directed at their specific vocational needs. Because such artists' motor skills most closely resemble those of "power" athletes where muscle activity is mainly governed by gross motor control patterns, it is easy to adapt mature methodology from sports into the service of these disciplines (Chatfield, 2003). On the other hand, the use of EMG in performance arts such as music, where fine motor control dominates the motor mechanisms, has been more limited. In these cases, the utility of EMG seems less apparent to both practicing artists and researchers. The focus of this paper is to examine EMG applications in music performance.

In spite of meager amounts of EMG research specific to musicians and music performance, there appears to be significant room for EMG to benefit artists and, by extension, their audience. Through scientific research, artists can potentially learn to acquire skills more efficiently and effectively, speeding up the learning process and contributing to

more technically reliable performances. Further, concerns about vocational injuries has become a significant issue in the performing arts and cross-disciplinary research involving scientific methodologies can prove to be powerful influences in areas of both prevention and remediation (Chesky, Kondraske, Henoch, Hipple, and Rubin, 2002; Lehmann and Davidson, 2002; Visentin, Shan, and Schultz, 2004; Wilson, 1986). In this regard, some technologies and methodologies from sports science have already been successfully adapted to music research (Shan and Visentin, 2003; Visentin and Shan, 2003). While EMG research in sports has been an acknowledged aid in improving sport performance for decades (for example, the *Journal of Electromyography and Kinesiology* has existed for more than 20 years), the state of affairs in 2011 remains similar to that expressed by Basmajian and White in the journal *Nature*: “Scientific experiments on musical performance are surprisingly sparse when one considers that neuromuscular control of skilful motor performance reaches its acme in music” (Basmajian and White, 1973). The primary barriers to EMG research in music seem to be both philosophical and practical.

Generally, music performance is rooted in training methodologies governed by aural tradition, with pedagogical frameworks by and large limited by conventions and aesthetic values passed from teacher to pupil. Participants in such a model typically take great pride in the provenance of their traditions – often validating their artistic values by tracing their musical lineage from teacher to teacher, to one or another of the legendary “greats” of the past. Such a mind-set frequently inspires a mystical and, in some cases, a near-religious reverence of the teacher, the traditions, the aesthetic concepts, and more importantly “technique”. Philosophically to some degree, music, even in its most heavily documented traditions (e.g. western classical music), remains an arcane art firmly rooted in centuries of convention.

In Western classic traditions, most recent developments in pedagogy can be understood as a general move from a collective consciousness to an aesthetic with a focus on individual virtuosity. Romantic writers of the 19th century typically viewed virtuosic technique as something superhuman, transcendent of physical limitations (Kolneder, 1993; Metzner, 1998; Samson, 2003).

On one hand, teaching becomes an arcane art both mysterious and incomprehensible, and on the other hand, the period marks the beginnings of music Pedagogy as a Science. Contemporary writing emphasized both “genius” and the development of technique as a means to achieve the highest degrees of artistry (Samson, 2003). “Schools” of teaching arose based on an individual teacher’s influence or on a unique aspect of playing that was deliberately cultivated by the school’s followers (such as use of vibrato).

In order to challenge the inertia of entrenched traditions, researchers and research methods must have a convincing *raison d’être* before they will gain any currency in the music industry. As a technology, EMG still needs to prove its utility in this regard.

Practical barriers to implementation of EMG methods in music research are also significant. Unlike sports or other aerobic activities relying predominantly on gross motor control dominated by large muscles, much music performance is dominated by fine motor skills involving small muscles that are often also deep ones (for example the flexor pollicis longus, extensor digitorum and Interosseous I).

Since surface EMG (sEMG) records any and all seizure potentials released by the muscles over the area of and between the sensors, the possibility of interference (cross-talk) of neighbour muscles increases dramatically when measuring small, deep and/or bunched

muscle groups. One possible solution for such challenges might be to employ fine wire techniques. However, there is a significant concern that this technique has high potential to influence the outcomes of performance, effectively negating some of the research benefits that might be achieved.

The simple fact of the matter is that artistic success or failure is often determined by micro-increments of skill, and research results where a potential influence on the outcome is high would likely be viewed by artists as having little practical value.

A further barrier to using sEMG in music research revolves around difficulties in interpreting resultant data. Unlike most applications in sports where larger muscles such as the biceps or quadriceps are targeted, the goals of music research necessarily include both large and smaller muscles such as biceps and triceps in the upper arm, and flexor pollicis brevis and adductor pollicis in the hands. Hence, results will include some data that is easy to examine using well-developed sports methodologies, and some data that is much more difficult to interpret.

One of the most effective uses of sEMG in pedagogy/training involves using measured signals to fractionate the body's response process in order to get timing of neural control as well as the coordination among muscle groups. Small muscles and current configurations of sEMG sensor technology make it very difficult to decipher the dissimulation effect of cross-talk. Existing sEMG technology and data analysis methods need to be further adapted to accommodate the differing conditions and demands of music research.

Since existing research employs, in greatest proportion, surface techniques, the remainder of this review article will use "EMG" to refer to surface electromyography. The article will sample existing the literature where EMG is employed in music research, examining results, their potential significance and discussing research challenges in the areas of pedagogy, injury prevention and technological limitations. In pedagogy, discussions will include skill analysis, biofeedback training, and the evaluation of training methods. In the area of injury research, exemplary remediation and prevention uses of the technology will be presented. Finally, challenges to the effective use of the technology and their importance to ongoing research needs will provide a point of departure for speculation on the future of EMG research in the field of music.

In short, EMG research in music finds itself at a cross-road. Technological and analytical limitations, meaningful research results, and cultural buy-in from the music industry are interdependent.

Currently, the existing body of research is below a critical mass needed to encourage growth in the area. Interesting and significant research involving innovative uses of EMG, it is hoped, can be a catalyst for encouraging new researchers to become involved in music applications and for industry to continue to improve the technology in ways that might not be demanded not only in music but also in other research areas. Further, relevant research results can be a way to show utility of the technology to musicians, especially in the service of pedagogy and injury prevention.

Such work can improve the lot of musicians as a whole by changing attitudes in industry. Just as EMG has become a significant scientific tool in sports research, the authors propose that similar, but as of yet underexplored, potential exists in the music research.

APPLICATION POTENTIAL IN SKILL ANALYSES

EMG provides a non-invasive means to gather data about physiological processes that cause muscles to produce movement. Muscle activity is reflected in seizure potentials measured by EMG, which can then be used to correlate intensity, timing and duration of activity. Consequently this information supplies insight into response processes, neural control, and coordination among muscle groups. Such analyses permit assessments of motor control and technical proficiency, which collectively provides foundational information for biofeedback training and development of new pedagogical methods. As such, one might expect EMG to be a scientific tool of choice for analyzing musicians' motor skills but, perplexingly, the body of EMG research in music pedagogy over the last 30 years is very small (Shan and Visentin, 2011). A review of the literature shows that EMG applications tend to fall mainly into only three broad categories: skill analysis descriptions and establishment of norms, training method evaluations, biofeedback in both pedagogy and injury remediation (Kjelland, 2000).

In the areas of skill analysis and evaluation of training, methods in music research are typically borrowed from human movement sciences, where EMG is used to quantify motor control and development, coordination and skill optimization (Riley and Chong, 2010). To do so researchers must process raw data since EMG signals are dependent on individual biological make-up such as skin thickness, subcutaneous layers of fat or other soft tissues, and placement of the sensors. Thus raw signals are unavoidably *non-quantitative* measures of neural-muscular activity (e.g. a sumo wrestler might generate lower measured signals than a 90-pound ballerina, yet no one would be surprised at the outcome of a basho match-up between them). Processing methods and analysis techniques play a vital role (Shan and Visentin, 2011).

Typically two processing steps are used in order to provide *quasi-quantification* of raw data. Enveloping stabilizes stochastic raw signals. Normalization of enveloped data expresses all measurements as a percentage of a chosen reference value (Kjelland, 2000; Morasky, Reynolds, and Clarke, 1981; Zinn, 1998). In this way, EMG can provide a viable means of comparison among different subjects and trials. Commonly used normalization references include: 1) the maximum signal level during a trial, or 2) a Maximum Voluntary Contraction (MVC) determined in a separate trial under high-load conditions.

Skill analyses using EMG have been undertaken in multiple areas of vocal instrumental music performance (piano, winds and strings). Below are representative examples of skill analyses in each of these areas.

Voice Skill Analyses

One example of music skill analysis in the existing literature looks at the skill of singing onsets (Shan and Visentin, 2010). Onset is a music term used for the articulatory beginning of the sounding of a pitch, whether vocal or instrumental. As such, it is a vital component in musical expression, and the effort used to initiate a tone, if it can be accurately measured, should show something about technical proficiency of the musician. Since consistency of timing and minimization of effort can be used to measure motor control, analysis of onsets

can illuminate preparation and execution during singing or playing. This, in turn, can prove or disprove empirical evidence of traditional learning and teaching.

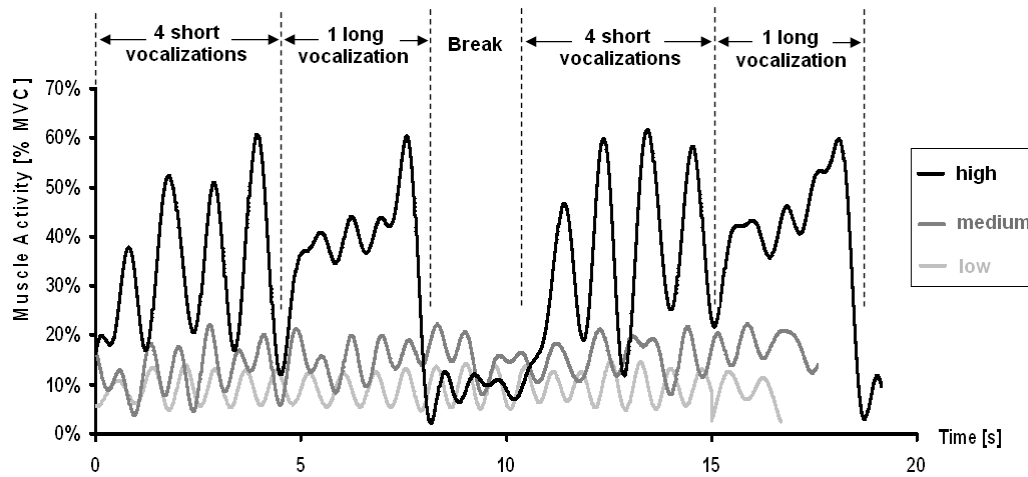


Figure 1. Rectus abdominis activity of a trained mezzo-soprano at three different pitch frequencies (modified from Shan and Visentin, 2010).

Figure 1 shows rectus abdominis activity of a trained mezzo-soprano singer executing onsets at three different pitch levels. It shows ten onsets grouped into two sets of five with a short break in between sets. Each set shows four short vocalizations (approx. 1s. each) followed by one long vocalization (approx. 4s.). Three different pitch frequencies were tested: high, middle, and low. The black line shows EMG activity for the high pitch (F5, or two Fs above middle C on the piano). Dark grey and light grey represent medium and low respectively (or F4, just above middle C on the piano, and F3, just below Middle C).

This kind of analysis can be used to evaluate the effects of training. It is normally expected that, for training *in any* kind of activity involving motor control, stability is a measure of ability; novices will have a less consistent pattern than experts. The consistency and repeatability exhibited in Figure 1 shows the subject to have a high level of competency. Additionally, varying amplitudes at different pitch levels also show us something. Significantly different amounts of physical effort are required at different pitch levels. At high pitch, peak levels of EMG were above 60% of the MVC with breaks between short vocalizations around 15%-25% of MVC and the longer break between sets under 10% of MVC. For medium and low pitches peak levels, EMG was significantly lower and there was no insignificant difference in EMG data between singing and rest (all ranging between 5%-20% of MVC). A non-linear relationship between pitch and effort is shown. For this singer, control was very consistent and, especially from EMG data of the high pitch, the disciplined preparation and execution is typical of individuals that are highly skilled. In the hands of a knowledgeable and skilled teacher, such results have implications for teaching and learning because it provides biofeedback information that can help improve training methods and technique acquisition.

In an earlier EMG study of voice, Englehart and his colleague examined the relationship between vocal tone quality and preparatory psychomotor sets (Engelhart and Major, 1989). His concern was that existing research had overlooked the issue of preparation, rather

concentrating on tone quality post phonation. A second thrust of his dissertation was to examine how training using the Alexander technique (which focuses on body alignment and posture) could influence outcomes. He found that training using EMG and the Alexander technique could positively influence muscular tensions in the neck and upper back, particularly in the upper trapezius muscle. Further he found anticipatory muscle activity changed significantly on higher pitches but not in response to increased dynamic levels beyond forte. Because limitations of the study were significant, some of his initial hypotheses could not be proven. However, this research is important since it initiated the use EMG for the purpose of skill analyses in relation to specific pedagogical techniques associated with relaxation and vocal production.

Piano Skill Analyses

In a literature review published in 2000, Kjelland found that the majority of studies since 1985 employed EMG as a descriptive/diagnostic tool for the purposes of establishing performance norms (i.e. skill analysis), comparing teaching methods and techniques, and diagnosing performance difficulties (Kjelland, 2000). A 1989 study used EMG to compare three different technical approaches to playing the piano (F. Bejjani et al., 1989). In this case study, a single player was asked to perform three pianistic tasks from a single composition, using three defined postural orientations of the hand. Although it may appear to have been somewhat artificial to have the same player adopt multiple postural orientations, rather than simply using his/her normal one(s), the study validated the utility of EMG as a means to discriminate technique-related differential muscle activity in pianists. In another study, Montes and his colleagues summarised some interesting skill analysis applications where the EMG activity in forearm and elbow were examine for pianists at different levels of proficiency (Montes, Bedmar, and Sol Martin, 1993). Muscular patterns of activity establishing skill norms were defined using the data from advanced pianists. Phases of EMG activity examined included preparatory key attack (before piano keys were pressed), key rest (lowest levels of EMG activity) and key holding (where EMG varied according to the attack strength). These characteristics were not observed in beginners; rather, the EMG signal showed an overall tension to be present in the muscles. These studies can be used as exemplars of the first necessary steps in any EMG application – i.e. targeting specific phenomena and evaluating the characteristics of the activity.

Skill analyses prove to be a first step for other piano studies where EMG was used as part of an effort to integrate multiple technologies for use in retraining of complex technical skills (Riley, Coons, and Marcarian, 2005). Such work builds on results from previous EMG studies where professional pianists were examined and it was determined that, after depressing a key, they seem to relax immediately (Montes, et al., 1993; Zinn, 1998). Contrarily, in beginners and novices a truncated tension-relaxation cycle was identified as a problem.

In a more detailed skill analysis study, EMG and strain gauge were used to examine whether pedagogical training, a potential cause of structural adaptations in hand intrinsic muscles, was aerobic or anaerobic by nature. Changes in EMG power spectrum during incremental isometric muscle contractions were studied to evaluate the effects of training using pianists and an untrained control group (Penn, Chuang, Chan, and Hsu, 1999). Although the MVC was similar in both groups, the effects of training resulted in pianist

having increased endurance as measured by time to induced fatigue. The authors of this study suggested results to further indicate that piano training should be classified, endurance training rather than power training. Such evaluations of skills using EMG can identify muscle recruitment strategies and provide information about fine motor training for music learners and professional and physical adaptations (differences in muscle fibre composition) because of training. In piano performance, it is generally accepted among researchers and performers that sustained levels of muscle contraction inhibit smooth motor movements and contribute to fatigue in both practicing and performing. EMG provides an excellent tool for measuring these characteristics during human movement.

Brass/Winds Skill Analyses

In wind instrument performance, it is also generally agreed that unnecessary muscle tension not only leads to physical problems but also can interfere with performance quality (Morasky, Reynolds, and Sowell, 1983). In this study, EMG was used to examine muscle tension in eight intermediate to advanced clarinet players where skill analysis assessed short-term and extended generalizations of EMG levels along with trill and scale speed scores. In a series of four other studies from 1991 to 1998, Heuser and McNitt-Gray undertook skill analyses associated with trumpet embouchure and tone production. These linked studies go well beyond the merely descriptive. Skill analyses were contextually correlated to articulatory attack (1991) by examining EMG potentials as the performers prepared for the commencement of playing a tone. Results indicated that EMG was an effective way to identify some aspects of tone production difficulties. In the second study (1993), the researchers examined asymmetrical mouthpiece placement. Asymmetry is frequently a compensatory mechanism used by trumpet players where embouchure placements differ from the theoretical “centred” ideal to accommodate oral-facial make-up variance or other technical difficulties.

The study compared professional trumpet players who use asymmetrical placement of the trumpet mouthpiece with a sample of players who perform with the mouthpiece centred on the embouchure. Although results indicated that there was no significant difference in EMG readings between the two groups, they are meaningful none-the-less.

The data allows us to induce that the compensatory behaviours being adopted by those who played asymmetrically were indeed successful for (at least for this one aspect of the motor mechanism – muscular effort) overcoming challenges associated with oral-facial variance. The question remains whether such compensation is a good long-term strategy for overcoming “technical deficiencies”.

The third and fourth of the Heuser and McNitt studies (1994 and 1998) draw EMG applications into the realm of pedagogy, which will be examined later in this paper. Together, these studies show a progression from description to application of EMG research in music performance. A more recent EMG skill analysis study for brass players was undertaken in 2005 (Iltis and Givens, 2005). The purpose of the study was to use EMG to quantify the activity of selected facial muscles during French horn playing, comparing a performer with dystonic facial muscles to a group of unimpaired players. The findings suggest that a relatively simple EMG testing protocol could be helpful in both skill analyses and comparative research for injury prevention/remediation.

Strings Skill Analyses

In string performance, EMG technology has been used to observe muscle activation patterns and levels as well as making some comparisons to establish norms of musculoskeletal functioning during performance. In a 1988 study, Moore et. al. looked at cellists performing trills in order to determine the characteristics and timing of the finger movement of and the associated of EMG activity of muscles that control the fingers (Moore, Hary, and Naill, 1988). Such information is foundational for generating research questions that permit training method evaluations and biofeedback studies of performance-related problems. A 1992 study examined one of the most fundamental questions for violinists and violists – the effects of using a shoulder rest to improve the position of the instrument and overall posture (Levy, Lee, Brandfonbrener, Press, and Levy, 1992). EMG was used to evaluate Trapezius and sternocleidomastoid muscles (neck and upper back) and findings revealed that use of a shoulder rest had significant implications for the muscles that supported the holding of a violin. Weber investigated EMG muscle potentials during vibrato motion of violin and viola performers during the playing of standardized exercises (Weber, 1995). Results demonstrated consistent firing patterns and found that forearm muscles appeared to be the prime motivators of the vibrato technique. In another violin vibrato study, Bejjani et al. used EMG to study fourteen violinists. The results were analyzed using qualitative assessment of the EMG signals and correlation of muscle activity with vibrato motion and time/frequency parameters (F. Bejjani, Ferrara, and Pavlidis, 1989). Such descriptive work leads to the establishment of norms which set objective and reproducible parameters of musculoskeletal functioning during the performance of musical tasks (Kjelland, 2000).

SUMMARY

In music, EMG applications must begin by undertaking detailed analyses of specific skills. Necessarily there needs to be a body of descriptive research that sets foundational groundwork for research of a more complex nature. Skill analyses of a descriptive nature can be used to establish norms, bases for training method evaluations, and development of new training methods based on a biofeedback approach in both pedagogy and injury remediation. Although the existing body of literature is small, it demonstrates the substantial utility of EMG technology. It shows forward-looking thinking, as researchers appear to have carefully considered both 1) what questions to ask and 2) what issues of greater significance these questions underpin. The authors wonder why the body of research in this area remains so small when demonstrated need, particularly in the area of improving pedagogy, is so apparent. We can only speculate that the necessarily cross-disciplinary nature of application-oriented research in the arts is inhibited by the number and variety of skill sets that need to be brought to the research table. Unlike sports and kinesiology where gross motor control and power dominate applications of the technology, the kinds of fine motor control typically involved in performance pose their own challenges to the capabilities of EMG technology. Further, EMG research in music requires a meeting of the scientific mind with an artistic and creative one that typically eschews definitions and boundaries. Individuality is a part of the creative process and researchers must carefully design their work to negotiate a path where both science and art are equally part of the underlying motivation of the research.

Biofeedback Applications in Music

Biofeedback techniques may help musical performers in a number of ways: 1) promoting general relaxation, 2) helping to reduce performance anxiety, 3) aiding in the treatment of functional disorders, and 4) improving pedagogy and training for musicians. In motor learning, the use of EMG biofeedback as a means to speed up the training process is common. Stress minimization (both physiological and mental) is a valuable function of biofeedback training (French, 1980; Niemann, Pratt, and Maughan, 1993). In music, training using EMG as a tool for biofeedback offers multiple potential benefits beyond the mere controlling of excess muscle tension during performance. Importantly, reduced EMG levels as a result of biofeedback training can generalize to situations in which the feedback is not available (Morasky, et al., 1983).

In the identified study, Morasky et al. came to the conclusion that a reduction in muscle tension from biofeedback training did not result in decreased performance quality for specific skills. This is an important finding because it points toward a debunking of any myths that might be associated with muscular tension as a tool of individuality/expression with regard to skill effectiveness and the creative process.

Biofeedback training can alter basic industrial/workplace preconceptions as well. With the interventions of technology, outcome-oriented thinking should become more process-oriented, and improve both efficiency of skill acquisition in terms of time spent learning and reliability of the skill. Efficiency in learning may have potential benefits for effectiveness of artistic outcomes beyond mere reliability (Visentin, Shan, and Wasiak, 2008). Perhaps most importantly, optimization of skill control is acknowledged to have significant potential in terms of injury prevention (Cummings, Wilson, and Bird, 1984). As a means to speed up the training process in music, while avoiding unnecessary injuries, biofeedback training has an as-of-yet under-explored potential in terms of making skill execution autonomous and freeing musicians' minds to focus on artistic creation (Shan and Visentin, 2010).

Biofeedback studies with direct links to pedagogy have been undertaken in the areas of voice, piano, winds and strings. In spite of initial industrial interest in EMG biofeedback as an aid to pedagogy, particularly in the voice area, there are surprisingly few scientifically credible studies. Similarly, for piano, the body of literature is exceedingly small. In the winds and strings areas, although still small, the representation of scientific work using EMG is larger perhaps because of the more complex and/or asymmetrical postural behaviours associated with instruments such as violin, double bass, and trumpet.

EMG research in terms of biofeedback training for musicians builds on the general theories of the late 1970s and increases to its peak level of activity in the 1980s (French, 1978, 1980; Garrison, 1978; Irvine and LeVine, 1981; Levee, Cohen, and Rickles, 1976; LeVine, 1983; LeVine and Irvine, 1984; Moore, et al., 1988; Morasky, et al., 1981; Morasky, et al., 1983). Over the last 20 years, an unexpectedly small number of biofeedback training studies are found, and those between 1990 and 2000 tend to follow the models and methods of the 1980s (Heuser and McNitt-Gray, 1998; Montes, et al., 1993; Niemann, et al., 1993). After 2000, studies are fewer still, even though new developments in technology make possible the use of multi-modal or multidimensional signal analysis studies (Visentin, et al., 2004).

Most recently EMG has been effectively incorporated in multimodal biofeedback studies using aural (Disklavier recording) and visual (video and computer-based output) feedback,

motion analysis and EMG. Measured signals have been used in both real-time feedback pedagogy as well as data for post-process analyses (Riley, et al., 2005; Yoshie, Kudo, and Ohtsuki, 2008). It remains to be seen if the use of multiple biofeedback sources will improve the effects of training more than well-selected use of individual technologies.

Voice and Biofeedback Training

One of the first contextual uses of EMG for biofeedback training is in the area of voice instruction (Garrison, 1978). His doctoral dissertation looked at problems encountered by students with tightness in the throat and jaw muscles. The study aimed to supply a comparison between students who only received traditional vocal instruction and those who received supplemental biofeedback training using EMG to help overcome tensions or tightness in identified muscles. Subjects of this study were college voice students suffering from tension problems. The results showed that there was a significant difference in “improvement” between those singers with tension problems who received EMG biofeedback training and those who did not.

Piano and Biofeedback Training

In the area of piano teaching, an early study by Montes et al. used EMG biofeedback as a supplemental method to piano teaching. Examining the abductor pollicis brevis as an agonist during selective movements of piano playing, the researchers found an increase in the peak amplitude and the relaxation values for a group using biofeedback compared to a control group. Such results have clear implications for the application EMG biofeedback as an aid in piano pedagogy (Montes, et al., 1993). Similarly, a 1998 thesis also explored EMG biofeedback as a means to enhance relaxation into piano performance (Zinn, 1998).

In a 2005 study, Riley worked to improve piano technique through multi-modal biofeedback training focusing on proper skeletal alignment of hands, arms, and shoulders. The goal was to avoid repetitive practice (typical of student learners) where poor balance between muscles activity and intended outcome might lead to “difficulties with, rather than mastery of, technique and stylistic interpretation and even physical injury” (Riley, et al., 2005).

This new approach utilizes multiple technologies, including EMG, as objective assessors of technical elements traditionally considered to be the subjective purview of a music instructor. As such, it was speculated that learning could become a more interactive process between teacher and pupil because an experience mediated by technology makes both aware of problems in technique and of ways to correct them. The concept of multi-modal feedback as a tool in pedagogy was extended by Yoshi et al. in 2008. In a study examining performance stress and anxiety, EMG was used along with measurements of heart rate, moisture (sweat), and MIDI sound signals. The main findings suggested that psychological stress could increase the risk of playing-related musculoskeletal disorders (Yoshie, et al., 2008). Such results provide convincing rationale for the use of EMG as one element in multi-modal pedagogical applications dealing with both physical and psychological challenges faced by learners and performers.

Brass/Winds and Biofeedback Training

In brass/wind performance, representative EMG biofeedback studies have been undertaken for several different instruments (Heuser and McNitt-Gray, 1994, 1998; Levee, et al., 1976; Morasky, et al., 1983). Since the mechanism of sound production involves the performer blowing into the instrument, most of these studies concentrate on facial and/or throat musculature. The general aims are to explore the minimization of tensions in order to improve performance ability. In the Levee study, biofeedback relaxation training was focused on muscles where EMG showed chronically high tension levels. Results showed biofeedback training to dramatically help reductions in tension levels. Further, it appeared that there was an increase in the patient's proficiency with the adoption of new motor control patterns that could be used in his professional activities (Levee, et al., 1976). Such biofeedback training can have both physiological and psychological benefits for the player. Notably, Heuser undertook a series of four studies, where the first two were skill analyses (previously discussed) and the last two of which used results obtained to underpin biofeedback training (Heuser and McNitt-Gray, 1994, 1998). The 1994 study examined tone commencement (onset articulation) using EMG to measure the training effect on embouchure muscles for learners encountering tone commencement difficulties. The second was a case study of a student experiencing both playing difficulties and pain. It used real-time EMG feedback to provide visual substantiation of improvements related to the learning strategies designed by the instructor. Typical of EMG biofeedback training, these studies employed "1) visual demonstration of how changes in performance strategies relate to changes in muscle activation patterns, and 2) ... visual confirmation of the contribution specific instructions make toward restructuring muscle activation patterns." (Heuser and McNitt-Gray, 1998). All of these studies show that EMG can be an effective tool in biofeedback training by supplementing traditional teaching methodologies and validating pedagogical practices with an objective means.

Strings and Biofeedback Training

EMG studies for string players are more varied than those for any other instrumental/vocal group. The asymmetrical nature of playing the instruments and the awkward postural orientation of violin and viola in particular is a recipe for creating unwanted muscular tensions, something that EMG technology is well suited to explore. Further, the complexity is compounded by the required sensitivity of motor control, making skill optimization a central concern for all players. This is best summarized in the pedagogical writings of Kato Havas, an internationally recognized teacher who focussed on optimizing the mechanics of violin playing in a unique and effective manner; "Playing the violin is never difficult; it is either easy or it is impossible." (Havas, 1961). Consequently, EMG biofeedback seems an ideal tool for demonstrating muscle activation patterns during skill acquisition and validating pedagogical approaches.

This was first recognized in studies by Morasky (1981) and Levine (1984). Both of these studies aimed to see if EMG could be used to reduce unwanted muscle tensions. Morasky found that biofeedback facilitated significant decreases in EMG of the arm muscles. Levine employed EMG as a pedagogical tool to decrease unwanted left-hand tension for a group of

violinists and violists. He noted that improvement was rapid and indeed persisted over a 5-month follow up period (LeVine and Irvine, 1984). Surprisingly, in spite of these early successes, EMG is still not widely applied in strings pedagogy.

For lower strings, double bass and cello studies by Guettler (1992) and Theim (1994), respectively, examined left-hand techniques. The Guettler study additionally examined instrument orientation to the performer's body. Vibrato technique on the Bass was found to be associated with pulsating contractions of two back muscles. A student having problems in producing a proper vibrato was observed to have poor coordination between these muscles (the teres minor and the teres major). A second experiment clearly demonstrated that small changes in positioning the instrument had noteworthy influence on muscular activity in the left and right trapezius muscles (Guettler, 1992). The pedagogical implications of such analyses are foundational for biofeedback work. In the work of Thiem et al., rhythmic cuing (the grouping of several notes together initiated by a single gross-motor-control gesture) was trained over several weeks and evaluated using EMG. Pre- and post-test results revealed the pedagogical strategy to have significant benefits in terms of lowered muscle activity/tension (Thiem, Greene, Perassas, and Thaut, 1994). Bowing techniques have also been the subject of biofeedback training studies using EMG as found in a summary of Koehler's dissertation work exploring two specific bowing techniques (Koehler, 1995). Studies such show the effectiveness of EMG as a pedagogical aid.

Music Performance and General Biofeedback Training

Finally, in addition to instrument-specific biofeedback and pedagogy studies, there is work generalizing the use of EMG as a pedagogical tool across instrumental lines. The use of biofeedback as a means to decrease overall levels of performance anxiety is best exemplified in the work of Niemann (1993) and Reitman (2001). Anxiety-coping strategies were evaluated by using biofeedback training and music relaxation interventions for a group of music students. The work resulted in a significant reduction of performance anxiety (Niemann, et al., 1993). EMG was used to confirm the effectiveness of anxiety reduction strategies through measurements of reduced muscle activity/tension in the frontalis (Reitman, 2001).

SUMMARY

In terms of biofeedback training in the teaching and learning of music, EMG clearly has significant potential to improve skill optimization and skill effectiveness. What is less apparent is that it can aid the creative process by reducing both the physical and mental demands of acquiring and using technical skills, freeing the artist to focus on the artistic ones. The complex behaviours typically found in music performance most certainly benefit from any training method that speeds up the learning process and does so in a way that provides generalized enhancements in skill development and motor control. EMG has particular relevance in terms of reducing unnecessary or unwanted muscular tensions. Thus, it can also provide a means to minimize the psychological pressures that are understandably associated

with live music performance – a high-skill, high-pressure activity that has a zero tolerance for technical errors.

Injury Remediation and Prevention

Musculoskeletal problems among professional musicians are mostly linked to type of work involved in performing on an instrument. Certain body postures and movements are maintained for extended periods resulting in repetitive overuse of the muscles and soft tissues (Hoppmann, 1998; Owen, 1985; Visentin, et al., 2004; Zaza, 1998). The prevalence of playing related musculoskeletal disorders (PRMSDs) is particularly highlighted in epidemiological studies undertaken between 1988 and 1998. In these studies, the rate of injuries for musicians having at least one medical problem severe enough to affect their performance peaks at 76% (Fishbein, Middlestadt, Ottati, Straus, and Ellis, 1988; Middlestadt and Fishbein, 1989; Zaza, 1998). Since, for PRMSDs, it is the very act of “playing” that causes problems, quantification of musculoskeletal stresses during activity could be very important in determining the aetiology of injury. EMG provides a valuable means to begin to differentiate the gestural motivators of the performative act. It can be used to observe and evaluate muscle activation patterns, performance behaviours contributing to PRMSDs, improvements during training or reestablishment of skills post-injury. However, it is important to consider that since performance mastery on a musical instrument requires some of the most sophisticated neurological processes of any human activity (including rapid interlacing of the cortices that control the auditory, visual, and motor sensory systems), injury research in its ultimate manifestation might also need to address more fundamental brain and behaviour phenomena.

Empirical evidence suggests that for fine motor control dominated activities the presence of an injury may necessitate a performer invoking compensatory strategies in order to minimize pain while continuing performing. Applications of EMG that are remedial in nature can help establish the effectiveness of compensatory motor control mechanisms, whether through retraining or medical intervention. In a study of the neck and shoulder area for violin and viola players, EMG activity in the upper trapezius was measured under three circumstances demanding three different levels of effort: rest, performance of an easy piece, and performance of a difficult piece (Berque and Gray, 2002). Although preliminary in nature because of a small subject sample, the results pointed toward potential compensatory strategies, suggesting that injured subjects may have redistributed muscle loading from the measured muscle to other synergistic ones as a strategy to alleviate discomfort. A second representative study goes further (Steinmetz, Ridder, and Reichelt, 2006). It used EMG to confirm the effectiveness of a medical intervention. In violinists, craniomandibular dysfunction is related to increased muscular load in the muscles of mastication, the trapezius and sternocleidomastoid muscles. Steinmetz et al. explored the use of occlusal splints to lower muscle loading in the masseter, temporalis, trapezius, and sternocleidomastoid during violin performance. The main finding was that EMG showed decreased muscular load in symptomatic and asymptomatic violinists, suggesting that splints could have potential roles in both remediation and prevention.

Some of the most intriguing and forward-looking applications of EMG occur in conjunction with electro encephalography (EEG) and, more recently, functional magnetic

resonance imaging (fMRI). In this regard, the work of researchers associated with the Institute of Music Physiology and Performing Arts Medicine, Academy of Music and Drama in Hannover, Germany is exemplary. Among other projects, these researchers have taken on the serious issue of musician's cramp (or focal dystonia) through longitudinal studies. Focal dystonia (FD) is a task-specific pathophysiology associated with repetitively executed complex movements, such as playing a musical instrument (Altenmüller, 2003; Lederman, 1988). It involves an involuntary cramping of single fingers during the execution of complex neural motor movements that is as completely painless as it is almost inescapably career ending or, at the very least, career altering. Given the seriousness of outcome, there is a growing body of research investigating the essential role of the somatosensory system in the pathophysiology of FD. In a representative study, Ruiz et al. investigated neural correlates associated with motor memory in pianists with FD using EMG in conjunction with multichannel EEG (Ruiz, Jabusch, and Altenmüller, 2009). In an earlier study, proprioception (unconscious perception of movement and spatial orientation arising from stimuli within the body itself.) investigated the effects of muscle vibration using transcranial magnetic stimulation on motor cortical excitability in FD patients by comparing that of unaffected musicians (Rosenkranz, Altenmüller, Siggelkowa, and Dengler, 2000).

From the above studies, it is clear that EMG, as a relatively easy to use and non invasive technology, has great potential in the study of musicians' injuries. Perhaps its most important contributions might point toward prevention rather than remediation. In this regard, EMG research needs to incorporate skill analyses and biofeedback techniques as a means to influence pedagogy and industrial attitudes in order to minimize risks of vocational injury among musicians.

CONCLUSION

In conclusion, EMG research in music finds itself at an awkward stage. Unfortunately, the number of existing and published EMG studies related to music is still very small, well below a critical mass needed to clearly highlight the advantages of EMG as a tool in research and teaching. The studies available demonstrate the varied utility of the technology, especially in the service of music pedagogy and injury prevention for performers, but a larger body of research is needed and research methods must be adapted or proven in multiple musical contexts in order to meet musicians' perceptions and expectations regarding the requirements of both the performer and the music industry.

EMG research in music is still at the stage of establishing a basic body of descriptive research, setting foundational groundwork for research of a more complex nature. In order to gain acceptance among musicians, skill analyses, training method evaluations, development of new training methods, and biofeedback studies in both pedagogy and injury remediation need to be application-oriented, a condition that is contingent upon cross-disciplinary research design; thus, research design should have the capacity to negotiate a path where both science and art are equally part of an underlying motivation (i.e. EMG research must have sensitivity to the artistic and creative aspects of the music vocation). Finding common ground with artists will be key. The complex motor behaviours in performance can certainly benefit from efficiencies identified in EMG research. Generalized enhancements in skill development and motor control and avoidance of injuries have particular relevance in today's music industry. It

remains for technology and the body of music performance research to mature to a point that encourages self-sustained innovation and growth.

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TURNOUT IS AN EULER ANGLE

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ABSTRACT

Euler angles are a widely accepted methodology for the description of joint articulation. This paper demonstrates that the third Euler rotation, in accordance with ISB co-ordinate definitions, represents the turnout of the lower limb which is of critical significance in dance.

This novel interpretation of the Euler angle was found to be practical, mathematically rigorous and, in contrast to current methods, applicable to any dance posture for the calculation of turnout. Additionally, it can be applied to calculate the constituent elements of total turnout attributable to turnout at the hip and ankle together with tibial twisting motion.

The technique was applied to a sample of dancers performing demi and grand pliés in first, second, fourth and fifth positions. The mean and standard deviation of the turnouts throughout these movements are presented enabling the identification of atypical turnout patterns which will assist screening and the identification of potential injury risks.

Keywords: Dance, Turnout, Euler angles.

INTRODUCTION

Correct turnout of the lower extremities is the most important anatomical factor in classical ballet and its function is to provide balance, agility, speed and strength essential to performance. To achieve turnout, the legs are externally rotated from the hips although a perfect turnout of 90° at the feet is anatomically rare. Forcing the feet to achieve a turnout position beyond which the hips will allow can aesthetically distort the position of the entire body (Gilbert et al, 1998) and cause injuries (Clippinger, 2005). Moreover, it has been suggested that the encouragement of ineffective and possibly damaging compensatory strategies to achieve the perfect turnout can lead to musculoskeletal injuries (Ryan and Stephens, 1987).

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The majority of ballet movements use turnout at the beginning and end of movements and during passing from one movement to another (Bussell, 2000). It is therefore necessary to measure a dancer's turnout during the whole of a dynamic dance movement, rather than merely for the initial posture, to provide objective analysis of turnout to improve performance and reduce the risk of injuries.

Until recently dance was dominated by qualitative descriptive studies and has only lately embraced the advantages which quantitative methods can provide (Grossman et al, 2005). It is agreed that turnout results from summative contributions of the hip, knee, lower leg and the foot-ankle complex. However the most frequently reported measurement is hip external rotation whilst the dancer is static and in an initial pose although even this is reported in incompatible ways (Champion and Chatfield, 2008). Turnout is currently assessed using a variety of techniques which makes comparison of results from different studies difficult. Assessment techniques include, amongst others, subjects standing in first position on a protractor (Bennell et al, 1999), tracing feet onto paper and measuring the angles formed by lines drawn on the paper (Watkins et al, 1989) or photographs of dancers standing on friction-free disks (Meinel and Atwater, 1988). Orthopaedic assessment of turnout is often obtained by passively measuring hip external rotation (Clippinger-Robertson, 1990) by means of an orthopaedic examination, for example, using a goniometer whilst the dancer lies in a prone position, with hips in extension, knee flexed to 90° whilst the hip joint is passively externally rotated by the examiner moving the dancers' hip joint through its range of motion. This reflects a measurement protocol recommended by the American Academy of Orthopaedic Surgeons and approved by international associations of orthopaedic surgeons (Surgeons, 1965).

However, none of the above methodologies are applicable to measure dynamic choreographed dance movements. Moreover, projection based methods become irrelevant if projecting onto a non-near orthogonal plane. For example, the projection onto the floor of a femoral anterior/posterior axis is reasonable in the initial turnout stance where turnout is normally measured, however the projection is not reasonable in stances where non-orthogonality is large. This situation will occur during significant knee flexion in the grand plié and many other steps.

The International Society of Biomechanics (ISB) recommends co-ordinate systems associated with each of the major anatomical segments, for example the pelvis, the foot, the shank (Wu et al 2002; Wu et al 2005). The ISB also recommend the Joint Coordinate System (JCS) for the description of joint articulations (e.g. hip extension/flexion, abduction/adduction, internal/external rotation). However this method of describing joint movements is identical in concept to an Euler angle based description. The JCS joint articulations are described as three rotations about axes fixed to the proximal and distal segments and about a third axes which is perpendicular to the segmental fixed axes. In the ISB recommendation, the distal segment axis of rotation, the e3 rotation, is about the long axis of the segment which therefore aligns with the turnout rotation. Therefore in this study, Euler angles between adjacent segments of the lower limbs are calculated and the e3 rotation is identified to be a measure of turnout.

This paper will calculate the Euler angles between adjacent segments throughout dance movements in order to observe the turnout. The method provides a robust 3-dimensional definition of the turnout angle measurement for any posture, both statically and dynamically

and is suitable for practice, rehearsal or performance. Such information on turnout cannot be derived from other approaches currently commonly employed to evaluate dance movements.

METHODS

The purpose of this study was to apply the ISB recommended joint articulation definitions and relate that definition to a generalised methodology for calculating ballet turnout consisting of hip joint rotation, tibial twisting motion and rotation at the ankle whilst the lower extremity is in any posture and during dynamic movements.

In accordance with the ISB definitions, each lower extremity was considered to be composed of three segments; the femur, the lower leg and the foot. The pelvis was also considered to be a segment. The turnout of the lower extremity was defined to consist of contributions of rotations between these segments and hence will be referred to as ‘segmental turnout’. The mutual rotation of these segments can be unambiguously calculated using a variety of methods including Euler angles or Joint Coordinate System (JCS), helical screw angles and Cardan angles (Kaplan, 1976). In accordance with ISB recommendations, a co-ordinate system was defined on each of these segments as described by Wu et al (2002) (Figure 1) and the JCS was used to define the joint articulation.

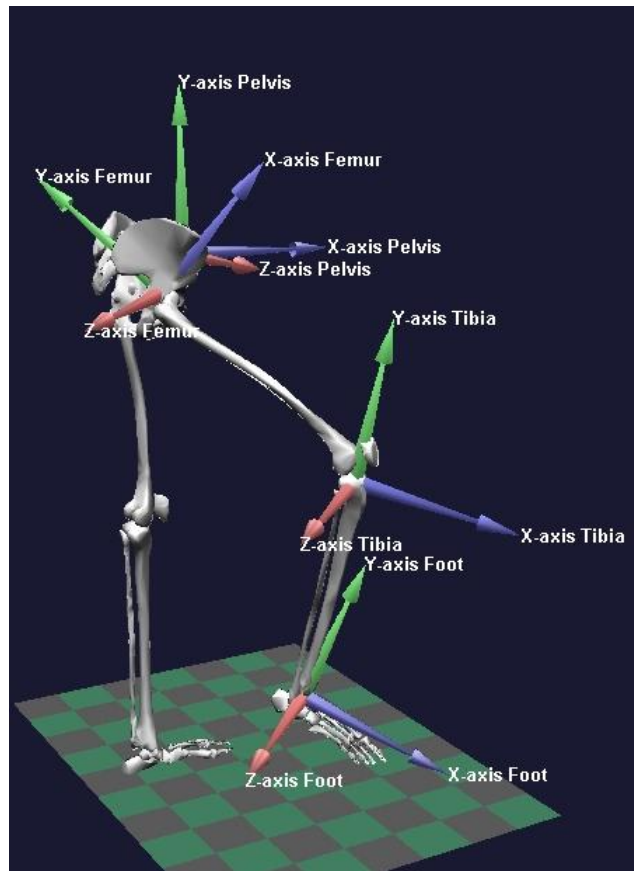


Figure 1. Illustration of ISB recommended co-ordinate definitions.

The Euler/JCS approach specifies the angles which rotate a proximal segmental reference frame to the orientation of a distal reference frame (see Appendix). Euler angles specify rotations about a moving segment reference frame; i.e. the rotation is applied about the axes of a co-ordinate system which rotates with the distal segment. The ISB recommendation for the sequence of rotations at the hip is:

- e1-flexion / extension
- e2-abduction / adduction
- e3-internal / external rotation of the femur

The rotations at the knee are:

- e1-knee flexion
- e2-varus / valgus
- e3-tibial twisting motion

and the rotations at the ankle are:

- e1-dorsiflexion / plantarflexion
- e2-inversion / eversion
- e3-internal / external rotation

The third rotation for each of the above joints is associated with the turnout rotation of the lower limb. Therefore if the Euler angles are calculated for these joint articulations and the e3 rotation is isolated, this will be the turnout at each joint.

Additionally, the angle between the foot and the sagittal plane (FTSP) was calculated. This angle is defined as the angle between the projection of pelvis x-axis onto the floor and the projection of the foot x-axis onto the floor. Hence this angle is an approximation of the traditional turnout angle defined at the feet.

The above Euler angle based approach was used to measure the segmental turnout of ten female professional ballet dancers (hence 20 legs) aged 18 to 28 years who had at least ten years ballet training and no current injuries. The subjects gave informed consent and the study was approved by the University Research Ethics Committee.

The movement of the dancers was measured using a 12 camera MX40 Vicon 3-dimensional optical tracking system. Retro-reflective markers were attached to the dancers in a full-body marker set similar to the Helen Hayes marker set (Collins, Ghousayni, Ewins and Kent, 2009) but the medial markers on the knee and ankle were retained throughout the trial. The movement was sampled at 50 frames per second. The data was filtered using a 4th order low-pass digital Butterworth filter with a 20Hz cut-off frequency implemented in Matlab™. From the movement of the retro-reflective markers, and hence the anatomical landmarks on the twenty lower extremities of the dancers, the orientations of all of the segmental co-ordinate systems were calculated. The data was processed in the SAM biomechanical analysis environment. The only defining landmark to which a marker could not be attached was the hip joint centre. Therefore the location of the hip joint centre was calculated using an interpolation method from the locations of the right and left anterior superior iliac spine markers and the right and left posterior iliac spine markers (Bell et al, 1989).

Prior to the trials, the subjects were asked to stand in a neutral posture and the transformation matrices were calculated from the reference frames in the idealised stance to the reference frames in the measured stance; i.e. the calibration transformation. When the

orientation of the recorded reference frames was measured during the trials, they were firstly transformed by the inverse of the calibration transformation. This reduced the affect of misalignment of the reference frames due to marker misplacement. It also accounted for the anteversion angle of the tibia and excluded this permanent set from the calculation of the tibial torsional angle.

After an initial warm-up period, each dancer was requested to perform two demi pliés and two grand pliés in first, second, fourth and fifth positions without the barre. First position is the posture where the heels are touching. The second position is the posture where the ankles are separated by approximately the width of the pelvis. In the fourth position the heel of the forward foot is aligned with the mid foot of the rear foot, the forward foot is approximately one foot length forward of the rear foot. In fifth position both feet are touching, the toes of each foot reaches the heel of the other. In all positions, the feet are externally rotated.

Demi and grand pliés were selected as this involves large rotations at the hip, knee and ankle and orientations of the lower extremity which is far from orthogonal to the floor; a situation where traditional turnout methods are unsuitable. The subjects were asked to identify which of the two demi and grand pliés in each position they considered to be indicative of best practice and therefore to be analysed. The subjects were not informed that the study was pertaining to turnout nor were the subjects instructed to maximise turnout.

The movements of each of the subjects were measured using the optical tracking system throughout the demi and grand plies. From this positional data the orientation of each of the anatomical segments was calculated. The Euler angles of joint articulations were then calculated in accordance with the ISB recommendations. The rotation of the distal segment about its long axis, the e3 rotation, which represents turnout was recorded.

To compare the turnout angles throughout the movement, the time base of each trial was replaced with a metric which represented the fractional completion of the task. The maximum flexion in demi plié was normalised to 0.33, the maximum flexion in grand plié was normalised to 0.67. The end of the trial was normalised to 1. This common independent variable (i.e. fractional completion of the trial) enabled the calculation of the mean of the hip turnout, tibial twisting motion, ankle turnout and FTSP. Symmetry conditions were used to calculate the mean and standard deviations across the right and left sides of the body resulting in a sample size of 20 lower extremities.

RESULTS

Figure 2 shows the mean e3 turnout angles for each leg as the dancers performed the demi plié and grand plié in the first position. The standard deviation of the hip turnout angle, turnout due to tibial twisting motion, ankle turnout and FTSP for the dancers in the first position are illustrated in figure 2 as grey shading surrounding each of the mean plots.

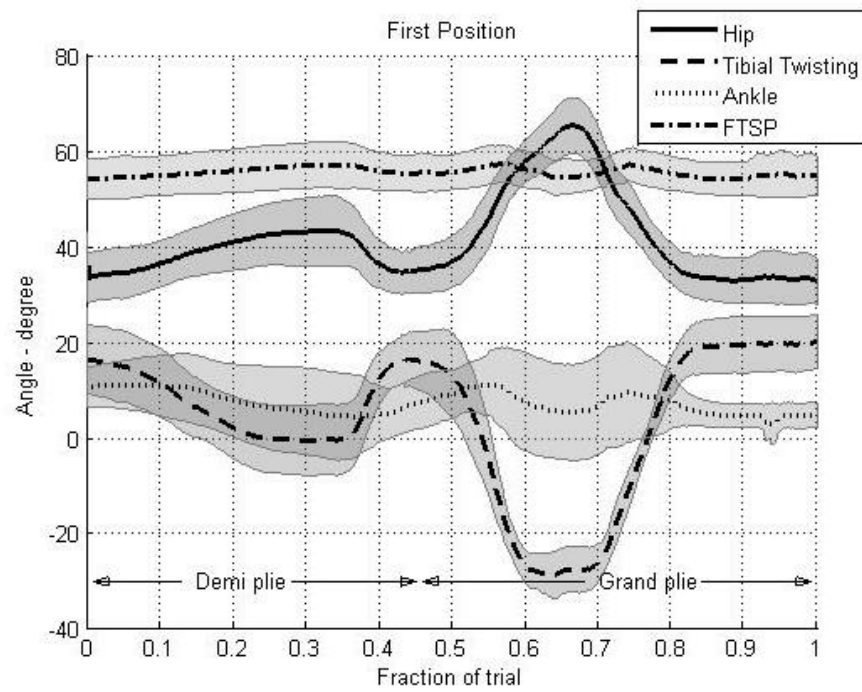


Figure 2. The mean segmental turnout with a ± 1 standard deviation envelope during demi and grand plié in first position.

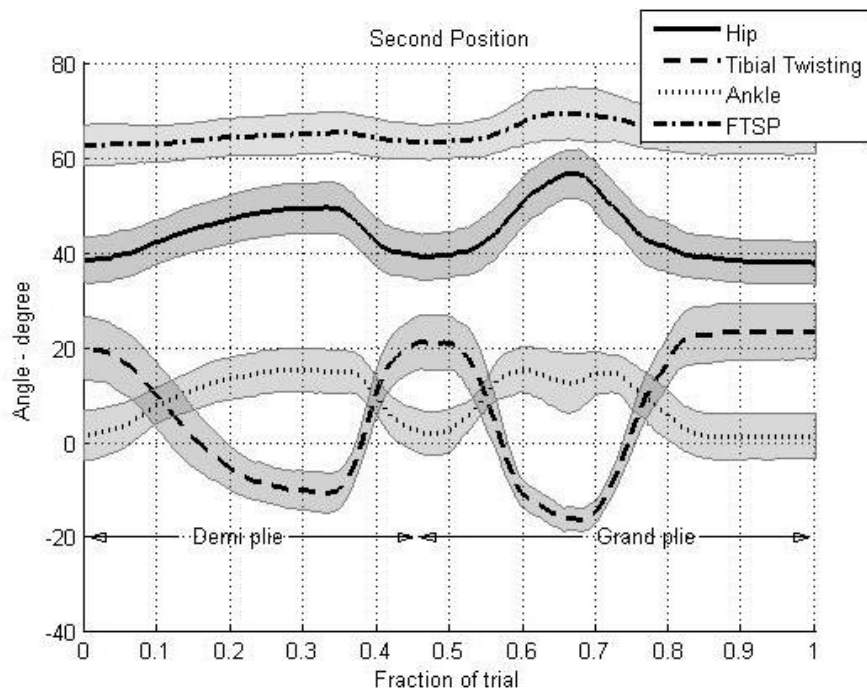


Figure 3. The mean segmental turnout with a ± 1 standard deviation envelope during demi and grand plié in second position.

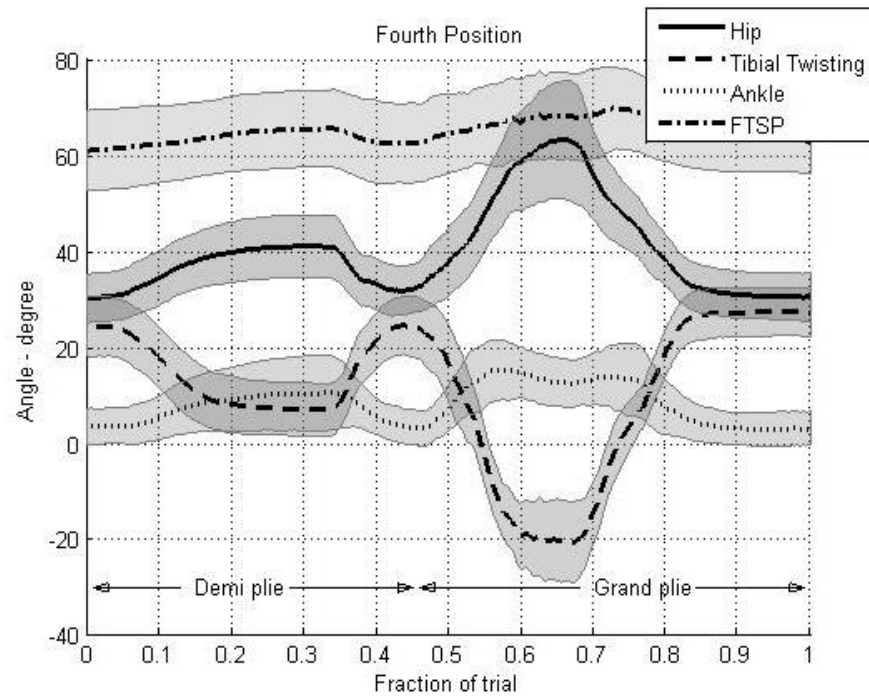


Figure 4. The mean segmental turnout with a ± 1 standard deviation envelope during demi and grand plié in fourth position.

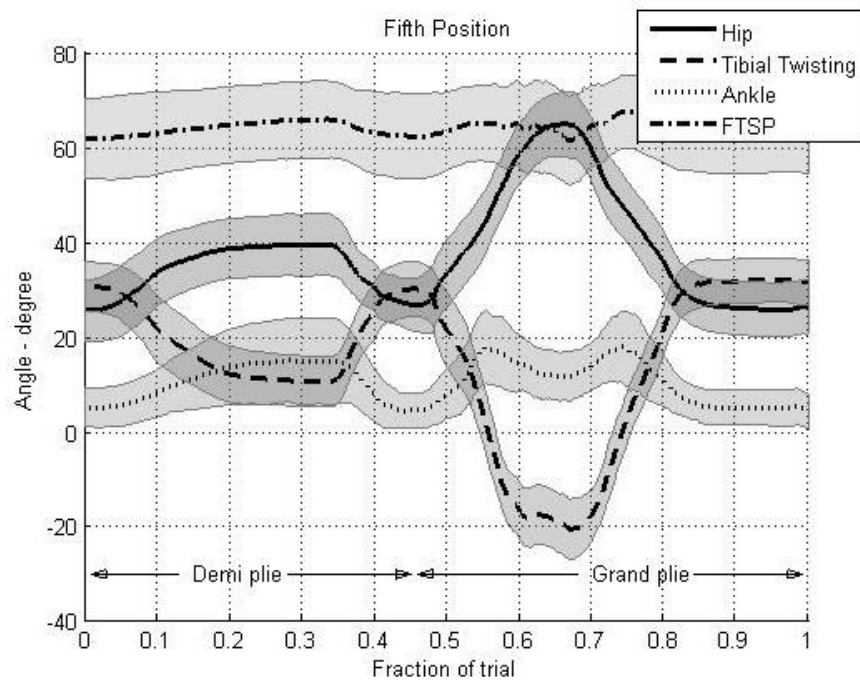


Figure 5. The mean segmental turnout with a ± 1 standard deviation envelope during demi and grand plié in fifth position.

The width of the shaded area represents ± 1 standard deviation about the mean for the sample of dancers. The plots illustrate turnout from the initial stance and throughout the maintenance of turnout during a dynamic movement. It is seen that there are only small changes in the hip, tibial twisting motion and ankle turnout (except tibial twisting motion in demi pli   for the second position) until the maximum flexion of grand pli   is approached. At the point of maximum flexion, the changes in hip turnout were comparable to the change in tibial twisting motion. For all positions in grand pli  , at maximum knee flexion there is observed the increase in turnout at the hip and a retrograde movement in the tibial twisting motion. This consistent with increasing knee flexion increases rotation capacity at the hip and knee.

It should be noted that the sum of the segmental rotations approximates to the FTSP angle only in the initial posture of minimal hip and knee articulation. As a counter example, Figure 1 illustrates the lower extremity in an arbitrary position where the turnout angles are not aligned and hence these angles cannot be simply summed.

DISCUSSION

As Grossman (2003) has indicated dancers are frequently uncertain how much turnout they can achieve. This may be due to the current situation where different techniques for the measurement of hip external rotation produce quite different results (Clippinger 1990) and hence dance teachers are unable to objectively assess the degree to which their students are expressing turnout.

Despite this lack of a unified, rigorous consensus on a protocol for the measurement of turnout, the literature indicates that of the desired 90   of perfect unilateral external rotation, approximately 60% of turnout is generated at the hip (Grossman, 2003; Liederbach, 1997). Additionally, researchers (Bennell et al 1999; Negus et al, 2005; Martin et al, 1998; Kahn et al, 2000) have reported mean first position turnout measurements ranging from 93   to 131   depending on dancers' age and experience and the measurement protocol used. The results from this study are in general agreement with these disparate results, however all of these other measurements relate only to the dancers in the initial posture whereas this study has extended the measurement to a dynamic scenario.

The diversity of results from the literature indicates that there is a need for a standard procedure to be able to accurately measure all the constituent parts of turnout i.e. hip rotation, tibial twisting motion and ankle rotation (Gilbert et al, 1998). Moreover the effectiveness of undertaking measurements during movement has been recommended based on the assumption that such measurements will be beneficial not only to clinicians, teachers, and trainers but also to dancers themselves (Watkins et al 1989; Molnar, 1995) to identify their individual maximum turnout capabilities.

Therefore a mathematically rigorous, 3-dimensional methodology based on the calculation of Euler angles between adjacent segments of the lower extremity has been proposed for the calculation of turnout along the limb. This approach is a novel interpretation of the ISB recommended method for the measurement of joint articulations. This is not limited to a static, initial posture as with traditional approaches but can accommodate any dynamic choreographed movement.

As an application of the segmental turnout method, the technique was applied to dancers performing a demi plié followed by grand plié. It was found that there were small changes in turnout during demi plié and large changes of turnout, both at the hip and tibial twisting motion, around maximal knee flexion of grand plié. This is consistent with the unlocking of the tibial twisting motion occurring during knee flexion. Throughout, ankle turnout was small.

However, the application of this method requires knowledge of the 3-dimensional orientation of each of the lower extremity segments together with the pelvis. To undertake this measurement during movement requires access to a 3-dimensional tracking system. In practicality, this limits the application of the method to dance biomechanics research institutions. However this approach greatly extends the situations under which turnout can be measured. Much of the research into injury associated with incorrect turnout has been undertaken in the initial static position due to an inability to measure turnout in other stances. Using a Euler angle based approach these studies can be extended to study turnout over an entire movement.

CONCLUSIONS

A new interpretation of Euler angles has been presented which express the turnout of dancers in generalised, dynamic postures. This approach follows the recommendation of the ISB on the measurement and reporting of joint articulations. The results in terms of plots of turnout against a metric which represented the fractional completion of the task (i.e. real, or normalised time) can be easily understood by dance students, dance teachers and clinicians. Additionally, the total turnout, FTSP, has been decomposed into its constituent parts of turnout at the hip, ankle and tibial twisting motion. This segmental approach to the measurement of turnout has been found to be practical to apply. The means and standard deviations of turnout for the sample during demi and grand pliés in first, second, fourth and fifth positions are also presented. The small standard deviation in comparison to the calculated turnout angles across the cohort of dancers suggests the robust nature of this approach as a turnout descriptor. An individual dancer whose turnout characteristics are remote from the mean may be susceptible to injury although this will require further research.

ACKNOWLEDGEMENT

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SINGLE LEG POSTURAL SWAY CHARACTERISTICS OF DANCERS DURING A ROTATING TASK: A PILOT STUDY

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ABSTRACT

The aim of this study was to investigate the single leg sway characteristics of dancers whilst balancing on a rotating platform that was being used as part of a specific choreography they were training to perform. Seven professional dancers held a single leg standing posture on a rotating platform for as long as they could. The rotating platform was mounted on a force platform allowing the measurement of sway variability in the antero-posterior and medio-lateral directions. Participants' sway was analysed over the initial and final 10 seconds of the trial. Medio-lateral sway was found to be similar to antero-posterior sway at the start ($p = 0.766$) and end ($p = 0.938$) of the trial. Six of the seven participants showed reductions in both AP and ML sway. Although no statistically significant changes in antero-posterior ($p = 0.201$) or medio-lateral ($p = 0.064$) sway were observed between the start and end of the trial with all seven participants included, reductions in sway were seen that showed large effects ($AP = 0.94$; $ML = 1.55$). With only the six participants included in the analysis that showed reductions in sway, ML sway was found to significantly reduce between the start and end of the trial ($p < 0.05$). This reduction in postural sway over time suggests that postural feedback could be initially perturbed, returning towards baseline levels over the course of the trial.

Keywords: Balance, rotation, sway, standing, centre of pressure.

INTRODUCTION

Many everyday human movements involve rotational actions, which puts increased demands on the balance systems of the body. During quiet stance, the visual, vestibular and somatosensory systems are able to satisfactorily maintain balance. However, if the body is rotated about a vertical axis, both the visual and vestibular systems will be perturbed, placing a greater "demand" on the somatosensory system (Caplan, Johnson, Horsburgh, and Walker,

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2009). This is especially true in dancers during dynamic motions, who are required to move their eyes and head for artistic purposes, as well as to determine their orientation in the performance space. Golomer et al. (1999) found that professional dancers were less vision dependent than untrained subjects. It was suggested that professional dance training shifts the dominant feedback strategy from the visual system to the somatosensory system.

In order to investigate the role of the visual, vestibular and somatosensory systems in the control of posture and balance, studies have used either bipedal or single leg stance tests. Studies looking at single leg stance on a stable base of support have used centre of pressure measures to show changes in antero-posterior and medio-lateral postural sways (Hertel, Olmsted-Kramer, and Challis, 2006; O'Connell, George, and Stock, 1998; Suponitsky, Verbitsky, Peled, and Mizrahi, 2008; Verhagen, et al., 2005). Hertel *et al.* (2006) found reduced variability in sway in the medio-lateral direction compared to sway in the antero-posterior direction. Similarly, O'Connell *et al.* (1998) found slightly reduced ranges of sway in the medio-lateral direction for their control group. As part of a novel dance choreography, a group of professional contemporary dancers were required to perform for up to an hour whilst on a rotating platform that caused their bodies to rotate about a vertical axis. The platform rotations would act to remove the stable base of support normally used to maintain upright posture (Hugel, Cadopi, Kohler, and Perrin, 1999), thus reducing the effectiveness of the balance systems. The ability of the dancers to overcome this reduced effectiveness of the balance systems is an important consideration in the design of rotating choreographies. In order to examine the extent to which the use of a rotating platform for a prolonged period influences dancers' ability to maintain a stable posture, this study aimed to determine the influence of whole body rotation about a vertical axis on postural sway characteristics during a single leg balance task.

METHODS

Participants

Seven professional dancers (4 female) participated in the study, with a mean ($\pm$ SD) height, mass and age of 1.66 ($\pm$ 0.06) m, 60.7 ($\pm$ 9.2) kg and 32 ($\pm$ 7) years, respectively. The dancers were recruited from a contemporary dance company.

At the time of the study, the dancers were rehearsing for at least four hours each day, for five days a week. Ethical approval was obtained from the institutional ethics committee, and the dancers provided written informed consent to take part in the study. The dancers were all using rotating platforms during their rehearsals at the time of the study, and had had one day of familiarisation to the rotational nature of the choreography.

Equipment

A platform was used to generate the required rotation of the participants about a vertical axis. The platform was provided by the dance company, and consisted of a wooden circular horizontal surface with a diameter of 1 m and a height of 0.2 m. The rotating platform was

controlled by a motor (MDEMAXX 071-32, Lenze, Bedford, UK) to allow angular velocities of up to 1.2 rad.s^{-1} . The rotating platform was located centrally on top of a force platform (OR6, AMTI, MA) (Figure 1) that was located in the centre of a large room, with at least 8 metres distance between the platform and the walls. The forces and moments in and about the three orthogonal axes were amplified (gains: $F_x=4000$; $F_y=4000$; $F_z=996.1$; $M_x=4000$; $M_y=4000$; $M_z=4000$) by a strain gauge amplifier (SGA6-4CE, AMTI, MA) before being sampled at 1000 Hz by an analogue-digital board (DT3002, Data Translation, Inc., MA) and stored on a PC for later analysis.

Protocol

The dancers were asked to maintain a static single leg standing posture, with their metatarsophalangeal joints of the supporting foot positioned centrally on the platform (Figure 1). The heel of the non-supporting leg was placed on the knee of the supporting leg, which was slightly flexed, and both hands were placed on the non-supporting knee. The arms were kept relaxed, and the trunk and head remained upright and still in relation to the rotating base of support throughout the trial.

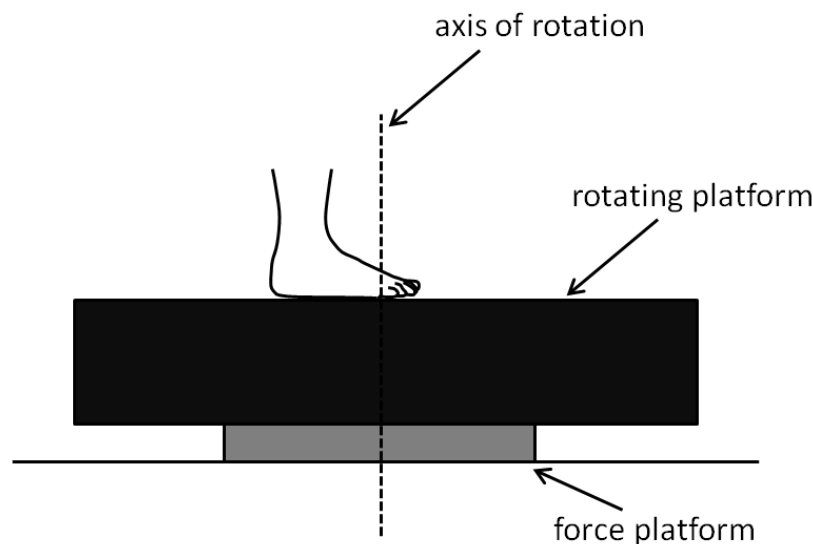


Figure 1. Side view of the rotating platform, showing its position on top of the floor mounted force platform. The position of the foot is also shown, illustrating the off centre location of the foot when the metatarsophalangeal joint was placed over the axis of rotation.

This position, which was one of the postures achieved during the choreography, ensured that the positions of the non-supporting leg and hands were controlled between dancers. The dancers were instructed to maintain a stable posture for as long as they could, whilst the base of support rotated their bodies about a vertical axis at a constant angular velocity of 0.38 rad.s^{-1} . This angular velocity was the same that the dancers used for their choreography. Data collection started at the instant the platform rotations commenced. Each participant completed a single trial.

Data Processing

Due to the rotating platform being mounted on top of the force platform, the x- and y- centre of pressure displacements measured by the force platform did not correspond directly to the antero-posterior and medio-lateral directions of the participants. It was therefore necessary to decompose the x- and y- centre of pressure oscillations measured by the force platform (global coordinate system - GCS) into the antero-posterior (x) and medio-lateral (y) axes in the local coordinate system (LCS) of the platform. Due to the fully enclosed design of the rotating platform, it was not possible to mount a potentiometer on its vertical axis to directly measure the angular orientation of the platform. It was, therefore, not possible to measure directly the angular orientation of the platform in relation to the GCS. Thus, it was necessary to determine this angular orientation from an assessment of the signals measured.

Due to the position of the supporting foot relative to the centre of the platform, there was an offset of the centre of pressure oscillations away from the centre of rotation. This generated sinusoidal changes in the x and y centre of pressure data measured by the force platform in the GCS. As the heel was furthest from the centre of rotation, it was known that the anterior sway was directed towards the centre of the platform and that the medio-lateral sways were tangential to the circumference of the circular motion. However, it was not possible to decompose the centre of pressure patterns relative to the GCS into antero-posterior and medio-lateral sway (relative to the LCS of the platform) without first determining the angular orientation of the platform over time.

To determine the angular orientation of the platform over the duration of each trial, a fast Fourier transform was first applied to the x-axis (GCS) centre of pressure signal. From the resultant fundamental frequency, the angular velocity of the platform rotations was determined. The platform was also filmed at 50 Hz using a miniDV video camera (HVR-A1E, Sony, Japan) in order to determine the time elapsed for 5 revolutions to check the validity of the spectral analysis method. A 3rd order low pass Butterworth filter was then applied to the x-axis (GCS) centre of pressure data with the cut off frequency set to just greater in magnitude than the rotational frequency of the platform (cutoff = 0.1 Hz). This provided a signal containing only the low frequency oscillations of the centre of pressure data derived from the platform rotation. The times of each maxima and minima were found and the time scale adjusted so the first maxima corresponded to $t = 0$. Each maxima corresponded to the point of maximum posterior sway (i.e. away from the centre of platform rotation).

A 2nd order band pass Butterworth filter was applied to the raw centre of pressure signals in both the x- and y- directions of the GCS to remove the low frequency noise component of the signal due to the platform rotations and high frequency mechanical noise from the platform motor. The lower cut off frequency was equal to that used above to isolate the low frequency noise component of the signal and the upper cut off frequency was set to 25Hz as suggested by Morrison et al. (2007).

The antero-posterior, COP_{A-P} , and medio-lateral, COP_{M-L} , components of postural sway, relative to the LCS of the rotating platform, were then decomposed from the x- and y- centre of pressure signals, relative to the GCS, using the equations,

$$COP_{A-P} = COP_y \sin\theta - COP_x \cos\theta \quad (1)$$

$$COP_{M-L} = COP_y \cos\theta - COP_x \sin\theta \quad (2)$$

respectively, where COP_y and COP_x are the centre of pressure signals measured with respect to the two horizontal axes of the GCS, θ is the angular orientation of the rotating platform.

The standard deviations of both antero-posterior and medio-lateral sways were then calculated to give a measure of sway variability, as reported previously for single leg sways (Hertel, et al., 2006), for the first and last 10 second periods of each trial. A paired samples *t* tests was used to determine the significance of any difference found between antero-posterior and medio-lateral sway, and to determine any differences in postural sway between the start and end of the trial. A 95% confidence interval was used. Effect sizes (mean standard deviation of the two groups divided by change in mean between groups) were also calculated according to the method of Cohen (1988) where 0.2 indicates a small effect size, 0.5 is a moderate size, and 0.8 is a large effect size.

RESULTS

Participants were able to maintain the required posture during the rotational task for 66 ± 32 seconds. Figure 2 shows the centre of pressure displacements of an example data set relative to the *x* and *y* axes of the force platform (GCS). The circular pattern generated by the positional offset of the centre of mass of the participant from the centre of the rotating platform can be clearly seen. This offset allowed for the sway signals to be decomposed into AP and ML sway in relation to the rotating platform.

Spectral analysis of these data showed that the rotations of the platform were at a frequency of 0.061 Hz (Figure 3A), equating to a platform angular velocity of 0.38 rad.s^{-1} . This was also confirmed from the video footage. Figure 3B illustrates the sinusoidal changes in the raw centre of pressure location in the *x*-axis (GCS), as well as the filtered *x*-axis (GCS) centre of pressure signal containing only the low frequency signal of the platform rotations. The maxima and minima indicate the points at which the antero-posterior (LCS) direction and *x*-axis of the force plate (GCS) corresponded to each other. The time offset between $t = 0$ and the time of the first maxima for the example shown (Figure 3B) was 7.81 s.

Figure 4 shows the sway patterns (centre of pressure) now expressed relative to the antero-posterior and medio-lateral directions (LCS of the rotating platform). The circular pattern resulting from the positional offset between the centre of rotation and the centre of mass is no longer apparent. For the example participant shown, AP and ML sway was similar, with ranges of approximately 0.05m being seen in both directions.

Six of the seven subjects showed reductions in both AP (Figure 5A) and ML (Figure 5B) sway between the start and end of the trial. One participant showed a slight increase in AP and ML sway between the start and end of the trial.

The mean standard deviations of antero-posterior (AP) and medio-lateral (ML) sway for all participants are shown in Figure 5. Sway variability was similar between the AP and ML directions at both the start ($t = .311$, $df = 6$, $p = 0.766$) and end ($t = .081$, $df = 6$, $p = 0.938$) of the balance trial. When all seven participants were included in the statistical analysis, no significant changes in sway variability were seen between the start and end of the trial for antero-posterior sway ($t = 1.435$, $df = 6$, $p = 0.201$), although a large effect was seen ($ES = 0.94$)(Figure 6A).

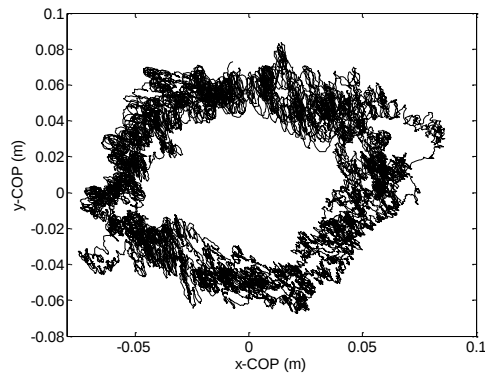


Figure 2. An example sway pattern on the rotating platform. The data is expressed relative to the global coordinate system of the force platform. The rotational influence of the platform can be seen due to the offset between the platform centre and the location of the centre of pressure within the base of support.

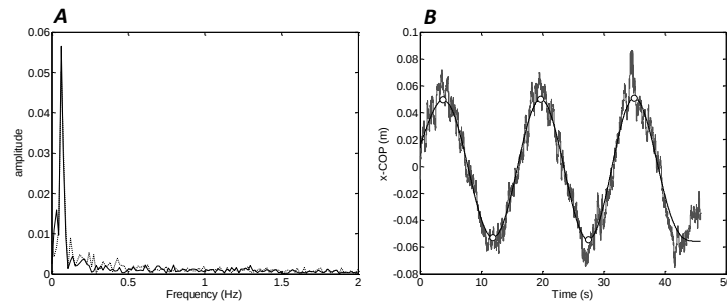


Figure 3. (A) Power spectrum of the centre of pressures in the x- (—) and y- (---) axes of the global coordinate system. The dominant low frequency signal indicates the angular frequency of the platform rotations. (B) Raw and filtered centre of pressures are shown for sways in the x-direction of the global coordinate system. The turning points are illustrated ($\circ$) from which the duration of each platform rotation were determined.

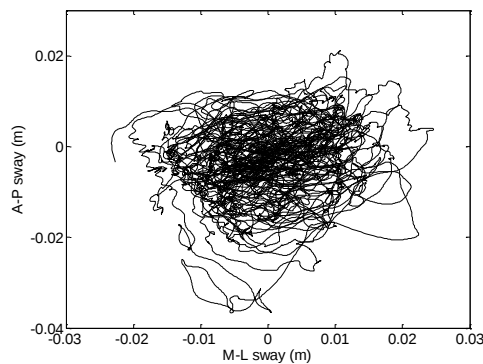


Figure 4. Sway patterns are shown relative to the antero-posterior and medio-lateral axes of the local coordinate system of the rotating platform.

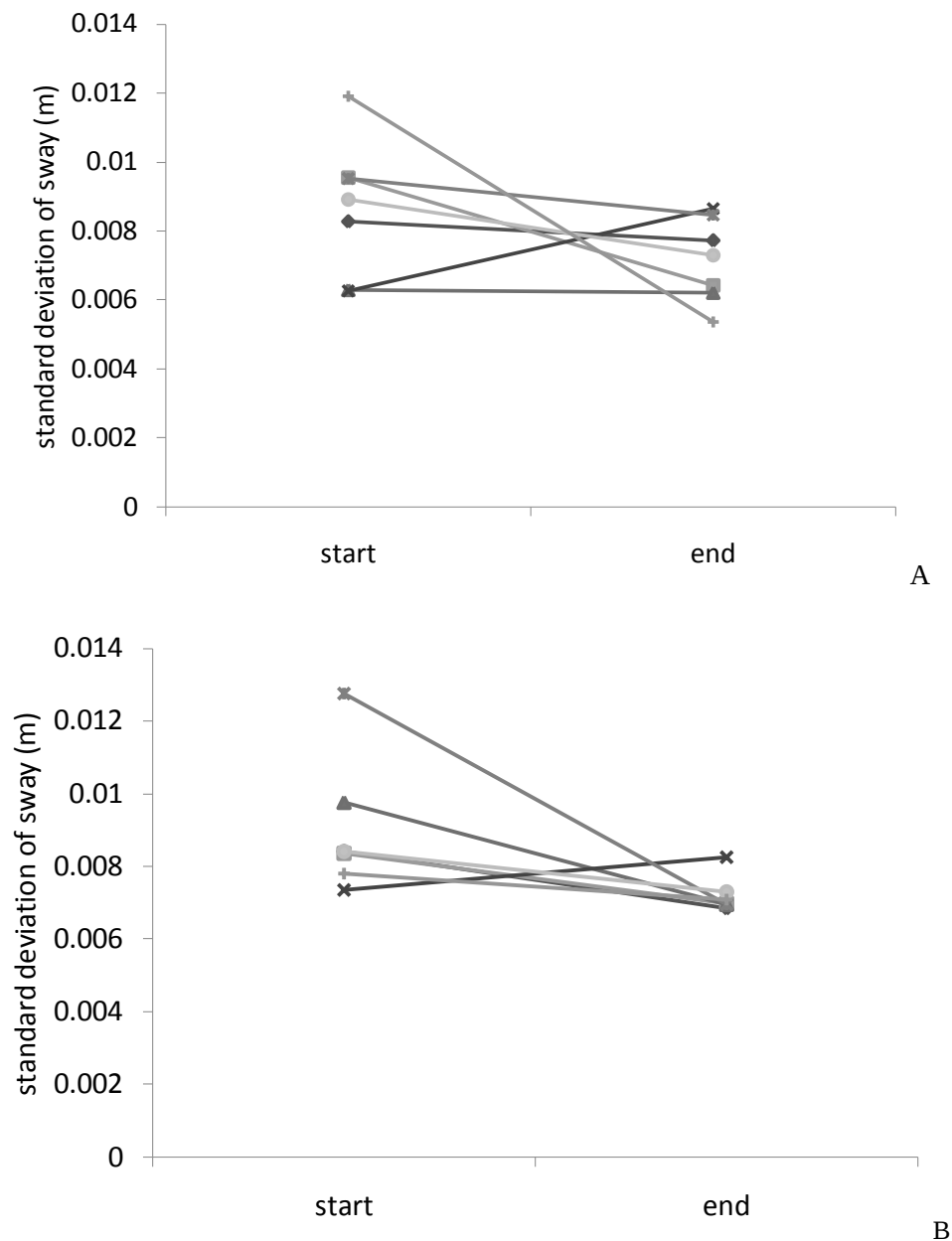


Figure 5. Standard deviations of sway are shown for each individual participant during the first and last ten second periods of their trial for AP (A) and ML (B) directions.

If the subject who showed an increase in AP sway was removed from the analysis, a non significant reduction in sway was still seen ($t = 2.211$, $df = 5$, $p = 0.078$) although a larger effect was observed ($ES = 1.46$)(Figure 6B). With all seven participants included in the statistical analysis, mediolateral sway was also not significantly different between the start and end of the trial ($t = 2.270$, $df = 6$, $p = 0.064$), with a corresponding large effect ($ES = 1.55$)(Figure 6A).

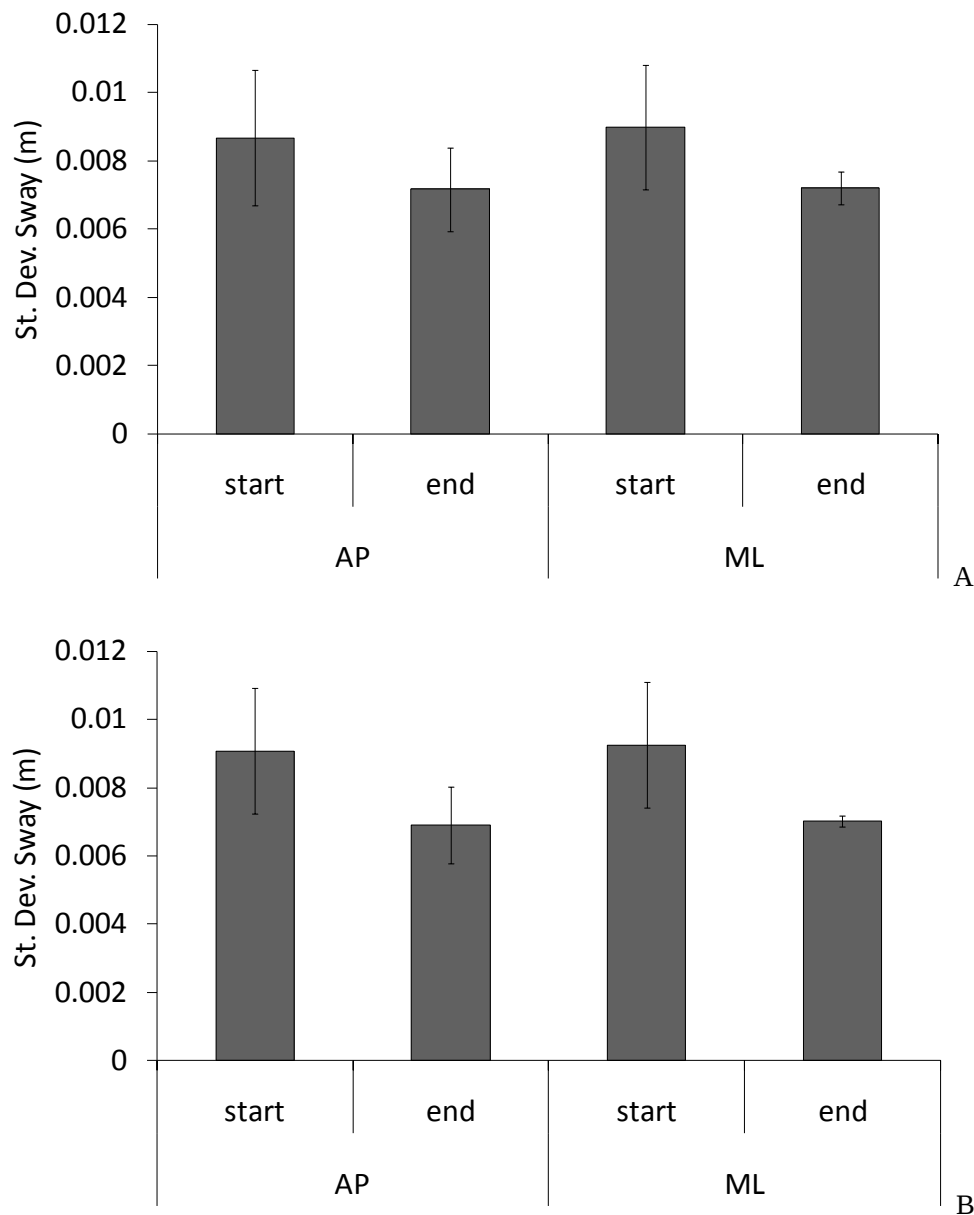


Figure 6. A – Mean standard deviations of antero-posterior (AP) and medio-lateral (ML) sways are shown for all seven subjects during the first ten second and last ten second period of the balance task. Each bar represents the mean of seven single trials (one per subject). B - Mean standard deviations of antero-posterior (AP) and medio-lateral (ML) sways are shown for the six subjects that showed reductions in sway during the first ten second and last ten second period of the balance task. Each bar represents the mean of six single trials (one per subject).

However, when the participant who showed an increase in ML sway was removed from the analysis, a more highly significant reduction in sway was observed ($t = 2.903$, $df = 5$, $p = 0.034$) with a very large effect ($ES = 2.25$)(Figure 6B). The subject who showed increases in AP and ML sway also showed the shortest duration for the maintenance of balance at 28.41 seconds, almost 20 seconds less than any other subject.

DISCUSSION

The aim of this study was to investigate the single leg sway characteristics of dancers whilst balancing on a rotating platform that was being used as part of a specific choreography they were training to perform. When the antero-posterior and medio-lateral sway characteristics were compared to each other, they were found to be similar during both the initial ($p = 0.766$) and terminal ($p = 0.938$) stages of the balance task. During normal (non rotational) single leg stance, medio-lateral sway is typically found to be smaller than sway in the antero-posterior direction (Hertel, et al., 2006; O'Connell, et al., 1998).

The similar levels of sway seen during the rotating balance task in the medio-lateral and antero-posterior directions could have a number of causes. Firstly, both the visual and vestibular systems will be perturbed when the body is rotated. The influence of rotation on the vestibular system will only last while the fluid in the semicircular canals is accelerated. However, this perturbation of the visual system will be constant due to participants maintaining a constant positional relationship between the head and torso. Reductions in the amount of sway in both the antero-posterior and medio-lateral directions were seen over the course of the balance task, although these were only significant for ML sway. This reduction could support the suggested influence of the vestibular system in increasing sway upon the initiation of balance until steady state has been reached. Soeda et al. (2003) suggested that during rotation, any increased vestibular feedback in response to postural sway would detrimentally influence the participants' gaze stability. Thus, in the initial stage of the balance task performed here, the increased sway could be attributed to the already perturbed visual information becoming less useful as a result of vestibular perturbations effecting gaze stability.

Lackner and Dizio (1994) investigated the influence of whole body rotations in a fully enclosed room on postural control. It was found that after approximately one minute of rotation, the vestibular system had returned to resting levels and thus did not provide additional sensory cues. In the present task, the fluid in the vestibular system could have achieved "steady state" by the last ten seconds of the trial, potentially allowing gaze stability, and hence the processing of visual feedback, to improve.

Further support for the notion that the reductions in sway were due to a steady state being reached by the vestibular system is provided by St George et al. (2011). In their investigation, participants were rotated on a platform at an angular velocity of 0.34 rad.s^{-1} , which is very similar to angular velocity used in the present study of 0.38 rad.s^{-1} . Their participants gave an indication of perceived sway which increased at the start of the rotation and reduced to zero after 15.8 seconds. In the six participants who showed reductions in sway in the present study, the last ten seconds of the trial occurred after a minimum of 35 seconds. Thus, their perception of sway, influenced by the acceleration of the fluid in the semicircular canals (St George, et al., 2011), would have reduced between the start and end of the trial.

Another factor that would act to increase sway during rotation is the Coriolis force, C_F , which is given by

$$C_F = -2m(\omega \times v) \quad (3)$$

where m is the mass of the participant, ω is the angular velocity of the rotations and v is the linear velocity of the participant's centre of mass relative to the rotating frame of reference. In a series of studies investigating postural control in a fully enclosed rotating room, Lackner and DiZio (1994, 1998) showed that participants had reduced control of arm movements. Over time, the negative influence of the Coriolis force reduced as a result of adaptations of the sensorimotor system, and participants were able to perform planned muscle contractions in anticipation of the effects of the Coriolis forces. During whole body postural assessments, however, Soeda et al. (2003) did not see adaptations to the Coriolis force within four 25 second rotational periods. This makes it unlikely that such adaptations occurred in the present rotations which were of a similar total duration to those reported by Soeda et al (2003). If postural control adaptations did not occur, then it seems likely that the initial influence of vestibular feedback on gaze stability, as discussed above, was the primary cause of the increased sway during the initial ten seconds of the task. However, future investigations are needed to determine the specific role of each sensory feedback system on the control of stance during rotational standing tasks.

Previous research has commented on the dominance of the visual system in balance and how dancers show a reduced dependence on the visual system after training in comparison to non trained individuals (Golomer, et al., 1999; Hugel, et al., 1999; Perrin, Deviterne, Hugel, and Perrot, 2002). Hugel et al. (1999) showed that classical ballet dancers displayed increased effectiveness of the visual system in the maintenance of balance in comparison to controls. However, they found similar balance abilities when in the ballet specific "on pointe" posture in eyes open and eyes closed conditions. This suggests an increased effectiveness of the somatosensory system to compensate for a lack of visual feedback when the eyes are closed. During the rotational balance task performed in the present investigation, it could be that a reduction in the reliance on visual feedback would help to improve postural control during rotation. Indeed, Perrin et al. (2002) showed that in the sport of judo, where the athlete has to rely more on the somatosensory system for the maintenance of posture, balance control was found to be better than in dancers. If performing a rotational choreography, where the somatosensory feedback has to be used effectively, due to the constant perturbed state of the visual system, specific training of the somatosensory system would likely be beneficial.

Previously it has been shown that both ML and AP sway are increased through rotation during bipedal stance (Caplan, et al., 2009). This suggests an increased demand of rotational balance tasks on the sensory feedback systems, which could be useful for training and rehabilitation purposes. Rotational stance tasks could be incorporated into progressive balance training routines and this should be the focus of future studies. The role of the sensory feedback mechanisms will depend on the type of rotation performed. Although beyond the scope of the present study, it would be interesting to compare how balance performance differs between slow rotational tasks, such as used here, and faster movements such as the pirouette.

This study had a number of limitations. Due to the design of the rotating platforms that were being used by the dance company and were available for the study, it was not possible to directly measure the angular velocity of the platform. Therefore, it must be considered that the decomposition of the centre of pressure data into AP and ML sways was based on signal processing techniques. More accurate assessment of AP and ML sway could be achieved by integrating a force platform into the top surface of the rotating platform. Although our interpretation of the data suggests a role of vestibular feedback, in line with previous

literature, it is not possible to say conclusively that this is the only mechanism influencing our findings. Future research should compare rotational stance to non rotating stance, as well as comparing eyes open and closed conditions. Finally, Only a small sample of dancers was available for the study. This could not be avoided as we required the dancers to be familiarised with the use of the rotating platforms for dance performance. It would be interesting to determine the effect of familiarisation to whole body rotations on sway, and this should be the focus of future research.

CONCLUSIONS

In conclusion, this pilot study has shown that the magnitude of medio-lateral sway is similar to antero-posterior sway when performing a single leg balance task when the body is caused to rotate slowly about a vertical axis. Reductions in postural sway were also seen over the course of the balance task, showing large effects, which were suggested as being attributed to vestibular adaptation. Further research is required on a larger population of dancers, however, in order to confirm the precise contributions of the postural control systems during this type of stance. The use of whole body rotation could be investigated as a training or rehabilitation intervention to stress the balance senses.

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MOUVEMENT CONCRÈTE; MODIFICATION OF BIOMECHANICAL MOTION DATA FOR NON-NARRATIVE AESTHETIC TIME-BASED EXPRESSION

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ABSTRACT

This article explores how traditional biomechanical datasets created through motion, or performance capture technology can be modulated for aesthetic time-based means/ends. At the same time since human motion normally is abstracted from a bipedal figure, and that figure is pictured at a place and time, secondarily-seeming considerations are addressed related to the presentation of motion featured as 3d animation digital choreography.

Keywords: Aesthetic biomechanics, art biomechanics, dance technology, non-commercial mocap application, temporal manipulation of motion, 3D animation variation, temporal tweaking of mocap keyframes, digital choreography.

I. INTRODUCTION

Time-based Art Forms

Movement composition requiring electronic technology developed in the last two decades shares commonalities with other forms of time-based expression - such as film editing, starting in the 1890s; electronic music editing starting in the 1930s; and video editing starting in the 1970s. One of these, *musique concrète* from the currently designated area of electronic music (a musical movement developed in the '30s and '40s when sounds could be recorded and then used as elements for expressive exploration which was subsequently codified, inspiring many composers, in the '50s and later) provides a good model to understand developments of contemporary motion capture.

In one aspect of *musique concrète*, sounds from the same or different sources recorded on audiotape could be manipulated by being spliced next to one another. Additionally they could be slowed down, speeded up, reversed, and blended by using other devices. According to Schrader [1], Schaeffer, a pioneer in this technique, felt that “sounds could be removed from their usual context and changed by manipulation.” Schaeffer employed five basic tape manipulation techniques: loops, cutting and splicing, speed change, direction change, and tape delay.

In hindsight, one may see loops as merely one application of cutting and splicing that forms a closed system, and is a compositional device related to rhythm or a relative time unit. It is not a method, per se. Nevertheless, all of these previous codified precepts for *musique concrète* have contemporary equivalents related to using motion capture (Mocap) data. The physical act of cutting and splicing has now been replaced in the digital realm in all time-based artforms facilitated by computers by ‘cutting and pasting’. But, in fact, more transformation can occur than merely repositioning, as ‘cutting and pasting’ might suggest.

Mocap Method

At its present state, motion capture technology can determine the x,y,z of important joints (or, muscles in facial capture) of body, or rotational aspects (pitch, yaw, and roll of body parts), or both. Samples of spatial location are taken/recorded in time at speeds of up to 1200 frames per second (Hz), or more. After the datasets have been processed (so quickly that it may appear to be instantaneous - or, in other words, in ‘realtime’), often through a rigorous process of reconstruction and clean-up, they can be observed from any vantage point close or far from a point on a sphere surrounding the figure displaying the data.

I use the term *dataset* as a collection of numbers at one sample (Hz) related to sensed objects on the body. If I am using an optical system that calculates the x, y, and z (3 degrees of freedom) of each marker, and my subject (talent) is wearing 53 markers that are tracked, one *dataset* then contains 53x3 or 109 numbers. (It actually contains more, as a *dataset* has its own sequence number.) The plural of *dataset* is *datasets*.

I also use the term realtime to suggest a nearly instantaneous connection with the action of the biological source - the person doing the moving - and the representation of that source doing movement in the digital realm. The representation can be merely a stick-like figure, or can have more surface, seeming corporeal. It can even be a representation of a figure conceptualized for the final rendering of an animation process. Of course, there is computer processing going on, so there might be a lag of microseconds or milliseconds. Thus realtime is subjective; what is realtime for one system and group of people may be different for another. It is about perception. If there is a slight lag in time, an event in the digital space might ‘seem’ still as happening at the moment.

Thumbnail Mocap History

Motion curiosity is expressed in the last quarter of the 1800s in the work of Muybridge, and this connects with the imagination of those currently investigating motion. He used banks of cameras to record actions for sequential analysis and then compared individual frames to

each other. For a summary, see Shan et al [2]. Rotoscoping used moving-picture film to record action and after developing and enlarging the images, the individual frames were guides to hand-drawn (cell) animation. Such a technique is said to have guided parts of the animated Disney feature, *Snow White* (1937). Images over time were also analyzed during the '80s by kinetic research teams using dots on joints and measuring the white spots on video image frames relative to other key points and then plotting them on graphs. Technologies driven by the need to visualize movement in 3d made their appearances in the '90s, and presented a host of solutions - including magnetic, electromechanical, optical, and others.

Mocap Use Today

Mocap is widely used in scientific research. It is used to maximize sport performance, for biomechanical analysis, for perceptual research, to engineer ergonomically designs, and in the medical profession.

A much more widely known application of mocap is in forms of entertainment [3]. Games use precaptured motion datasets to drive digital characters in interactive play, but also use realtime motion capture of the player/user in some systems. Performance Animation in realtime has been a regular process of TV aimed at young audiences since the early '90s. Realtime mocap is also found in some VR immersion. Mocap datasets have also been mapped on digital characters in feature films such as *Titanic*, *Lord of the Rings*, and *Avatar*.

Sampled mocap datasets mapped to 3-D digital models is often part of the story-telling process, but some people explore motion in non-commercial and non-functional applications that are outside of normal/typical interests. Exploring aesthetic movement can be seen as doing something for the sake of its own, and not using action to reach a goal or accomplish some task. For instance, the muscular actions of plucking an apple are undertaken to achieve the goal of having an apple. This is not normally considered aesthetic movement. The action one undertakes in this example is not about the motion, but of the result of motion, something other than motion itself.

Moreover, the motion examined here is not in service of telling a narrative story. It is not a means to reinforce with body motion signifiers such as speech or emotional states. In other words, it is not a referent. It is a primary element of human expression, that is, of digital movement composition.

Preproduction, Production, and Postproduction

Before I share methods of temporal tweaking (using techniques to alter time of an objectively captured sequence of motion datasets) or other techniques I have been using for about a decade, the reader should have some awareness of contextual considerations. Conceptual planning initiates any execution; research starts with an idea. It can be framed as a question, for instance, "What happens when I explore a particular biomechanical movement sequence?" For instance, I was interested in resisting gravity through all forms of jumps, but mainly through *sissonnes* (starting on two feet and landing on one) as the movement basis of the artwork entitled *3 Marys, RGB*. In other works, I was (pre)interested in figure formations,

color, and movement speed, as in “section 4” of *Journey*. In still others I explored gestural shapes, creating a movement palindrome combining non-realistic keyframed interjections with mocap datasets, and having a dynamic environment that featured colored objects (mostly primitive boxes) that changed position or size (e.g. in *Purity* the boxes were used as counterpoint to the white humanoid figure mapped with the mocap data).

There are two scenarios I have faced when assembling a digital motion work - I either already have the mocap datasets I will work with, or I must create them in order to achieve my digital movement goals. The latter suggests a preconception of what I might have at the end. I confess I don’t always know what to expect when I start working with mocap datasets, and . . . such are the results of experimentation that cross science and the fine arts - and some succeed. Of course there is little utility in publishing a failed experiment, and I would wonder why anyone would ever be interested in seeing one.

Some work in this area may start out with a predetermined figure, or environment, and then think about motion. Others can start with motion. There can be no rule in creative processes. Frankly, it might not be important, but in the end, the parts that create the whole need to be orchestrated. They need to work together to bring about the responses in those experiencing the work that were intended by the creator(s). It is possible and likely that a certain combination of parts could evoke imagery/connection to those experiencing an animation that could be more powerful than another combination of parts, or a variant.

There is a synergism of original intent, production experimentation and post-production editing. One tries to get it right prior to starting production. If one is engaged in a process and trying to get it right, one may shift methods to seek a best practice. Finally there is review, reflection, and revision if necessary. At the end, one is trying to make sure the presentation of the movement connects (as I find similarly is going on with the materials/content I am thinking about here, and you, the reader).

Decisions for 3D Aesthetic Expression/Perception with Mocap Movement

Movement: Sometimes a movement question may dominate the research space. That movement data can be pre-existing or can be created within established research parameters. I have done both, with *Broken Egg* - using mocap data I didn’t create, and for instance, with *Gatineau* - where I was really interested in visual polyphony expressed sonically through my research in deconstructing visual imagery into numerical data. I created three sequences of mocap datasets each dependent on a rhythm.

Figure: Any human movement is likely to be represented by a human-like figure with weight supports on two legs. Human movement could be mapped on a tyrannosaurus rex (although I am not certain that I would ever have any interest in doing this). Human perception is also likely to take an interest in the protagonist regarding gender. In some of my work I have chosen male (*Look Where You Land*), female (*Arcadian Women*), and non-sexual/gender (*Journey* and *Getting Business Done*).

And there can also be a sense of age. In *Nuclear Fancy*, a work that is earliest family portrait in movement I am aware of, I asked my daughters and wife to choose the models to represent them. It is interesting that my youngest chose a model older than her and my eldest (at that time, six) choose a baby model and performed movements consistent with that model. My wife, whom I met while she was performing in *Nutcracker* (her movements trained

through repetition are balletic) had been retired for about 20 years at the time of the mocap session, so her actions reflected this reality at the moment of the capture session. In short, this work is sensitive to the fact that mocap datasets represent a unique body with unique experiences with unique mental and other capacities at a certain moment of that body's existence. And, of course, that same body can provide variants in movement over time.



Figure 1. "Gatineau" From Drumming Ottawa from Space(s) Beyond (2007).

As well as male or female, neutral (generic humanoid) figures dominate my work *Blue___onTheBlackSpan*. But they morph - from an animated contorted fabric surface, humanoid figures emerge, then turn into abstracted butterflies. Figures don't have to remain constant.

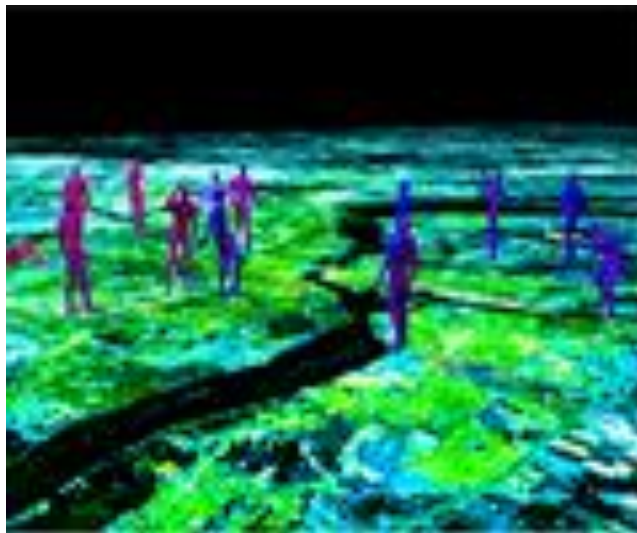


Figure 2. "GettingDoneTheBusinessOfWest,Central,North,AndEast" From Drumming Ottawa from Space(s) Beyond (2005).

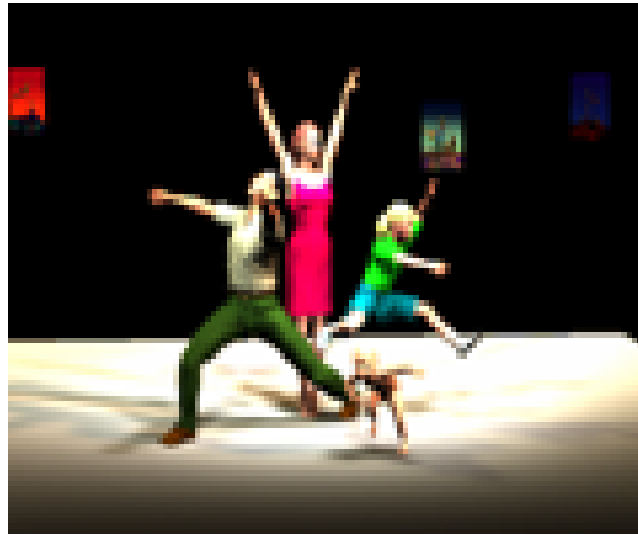


Figure 3. Nuclear Fancy (2003).

Now while representation aspects may be literal or figurative, some of the early aesthetic explorations of mocap movement consisted of painted lines on invisible bodies in *Hand-drawn Spaces* and *Biped* (both by Cunningham), or of glowing dots or squiggles in Bill T. Jones' *Ghostcatcher*. This avoided conceptual issues of reductionism (going from more points to less) in the symbolic space of 3d animation represented early on screens often as 72 ppi and or resolution of 640x480.

While I am interested in two-legged digital models, others may choose non-bipeds. And, still others may map only parts of the mocap datasets, for instance, only the upper body data.

Number of figures: Sometimes, a statement cannot be made by one figure. *Ritual at the Well* seems communal. It was conceived/made at the time my father was dying of pancreatic cancer that blocked his stomach from connecting to his colon, and I was present as he starved to death, and could do nothing. There was a well attended wake, and, in the big scheme of things, I am aware that you, me . . . we all experience death, and there are emotions about loss. It seems so big. It seems (or maybe this is my projection/perception) that death of an individual affects many. It affects a community.

Yet, while *Armed with Reach* is (I think) a proactive statement for females, I don't think additional figures are necessary. One figure expresses the idea. I have daughters, and I want them to earn/seize what they need to be/feel successful.

Costumes for digital figures? Being in the arts, I've never felt uncomfortable with nudity. Nudes are found as statues or paintings going back thousands of years. Now, digital human models always are reductionist in that they have fewer points than a real person. I have never felt uncomfortable with nude digital models. I never felt that I had to clothe digital models simply because we wear clothes in our society.

I have mapped textures as in the *Virilian Hero Dance* that look like body suits that might be found on strange superheroes found in comics or in made-for-the-populace wrestling or other contact sports.

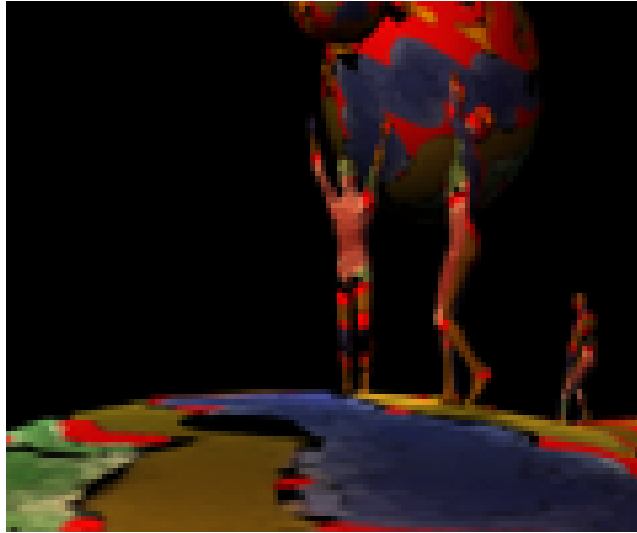


Figure 4. Virilian Hero Dance (2002).

In *3 Marys*, *RGB*, I made the bodies of the figures invisible and only the rubberish-appearing body suits performed the mocap movement.

Environment: I will try to isolate this parameter, but I am not certain how to establish a hierarchy. Certainly environment is not the figure moving (read, foreground . . . often). It must be everything other than that figure represented as moving (and in my interests, that figure moving with mocap data that has been thought about and assembled, forming a composition with a beginning, middle, and end).



Figure 5. Section 8 of Journey (2006).

There is a tone . . . is it dark or light? Is it warm (reds) or cool (blues)?

Space: There can be a sense of limited space or unlimited space; often this is expressed through scenes inhabiting what we perceive as indoors or outdoors. *Broken Egg* was confined

(feels that way when I see it, since the 3d space is so shallow/limited) and section 8 of *Journey* is also confined. At the end of section 8, the camera pulls back and the viewer can see the scene, like a theatrical set. Shakespeare who coined “All the world is a stage . . .” would no doubt have appreciated the layering.

Journey parts 10 and 13 are outdoors. The sky and sun signal that in part 10. The rain and growth of plants do so in part 13.



Figure 6. Section 10 of *Journey* (2006).

Time: Is it day or night? Certainly *Journey* part 6 was night (and outdoors, and big - there were many figures moving while sculptural letters were moving).



Figure 7. Section 6 of *Journey* (2006).

Journey part 2 is daytime with its brightness and shadows.



Figure 8. Section 2 of Journey (2006).

Objects can be active or passive. In *Look Where You Land*, the figure is jumping and objects like land sharks (actually they are cones suggesting impalement, signaling danger) congregate, menacingly; whereas in *shadeGreen*, the figure has a sword that is passive (moves with the hand).



Figure 9. Look Where You Land (2002).

In *Purity* utilizing shapes and colors that might be found in a period of Mondrian's artistic output in late 1919 and very early 1920s, environmental objects seem to interplay with the performer.

Moving-image projection/art. One can project movies within the digital space. I have never opted in my animations to execute this possibility, however I did this in a real

embodied performance *Ten Year of Yours in the Eye of a Sleeping Dragon* (my statement about the process to get tenure).



Figure 10. ShadeGreen (2002).

To me the concept is about time and how we measure it. The projection was of a time-worn animal trail through woods during an early spring/late winter snow. I was aware the deep past of nature and of cycles of weather that go beyond any human's experience. My experience in the workplace seemed inconsequential, pitiful compared to making meaning of life. The projection made sense and augmented the movement composition.

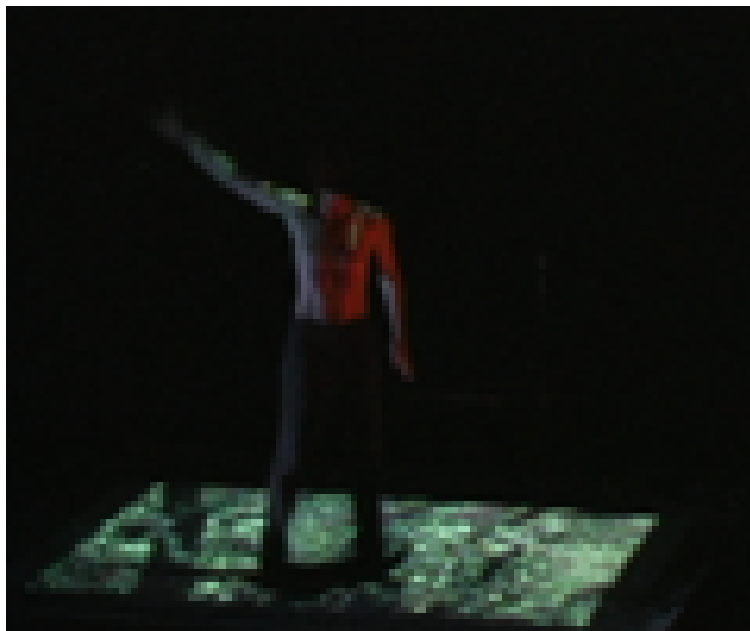


Figure 11. Ten Years of Yours in the Eye of a Sleeping Dragon (2002).

Special Effects

So many possibilities exist; if you can imagine it, well, you can probably create it digitally. It is assumed in this discussion that the special effects connect with the mocap movement and its contribution to artistic intent. In *skinlessNights*, fog existed in the one layer where a figure moved while a second one jumped overhead, landing on small platforms with a series of sparks. At one section of the work, trajectory trails are made from the hands, glowing at the x,y,z point of the 3d animation space lasting seconds before fading. It is about the imperfection of the concept of love, where we, as biological creatures, have DNA encoded genetic imprints on how we respond, yet the levels on which our intelligence, emotions, imagination, and education (maybe, awareness) are different as we partner for what we believe is a life-long journey. Well, . . . it is part of our human condition. So for me, the special effects (I had at the time) used for the work are germane for the visuals.

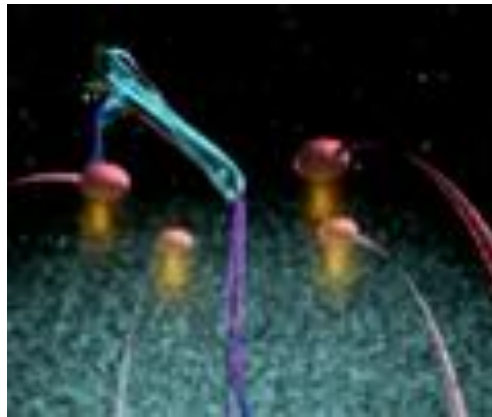


Figure 12. *SkinlessNights* (2003).

Animated Environment: I felt that putting a wave disturbance on the ground was appropriate to what I wanted to express in *UndertheSunOntheLand*. I wanted the world to be dynamic according to my understanding of how first nations people conceived of the world and of their place in it.

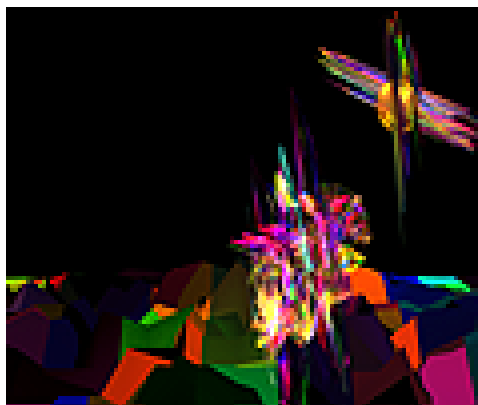


Figure 13. *UndertheSunOntheLand* (2002).

Camera: Limitless viewpoints; Close up seems powerful, far away seems reflective; can pan and dolly; can change cameras or have what I call the omnipotent camera that always sees the action as in *ThreeBlueRocks*. [4].

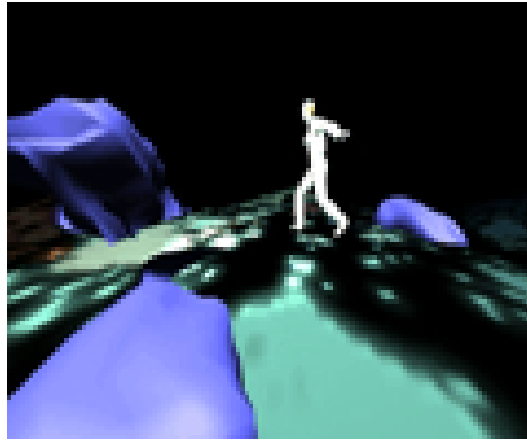


Figure 14. *ThreeBlueRocks* (2003).

The camera can be stationary or move, it can be fast or slow when it moves. If cameras change, pacing as in the length of shots is likely to be considered to maximize the expression. In Weiner's *Dialogos*, the camera moves quite a bit.

Sound: The discussion of making this choice to accompany mocap datasets far exceeds the scope of this article; but sound is very important. The same 3-D rendered movement sequence put to different soundscapes can produce strikingly different responses. To assert this does not mitigate the importance of figural representation or any of the other aspects for which a creator must make decisions to create the whole - that final mocap animation best expressing a movement-related intent.

Post-processing techniques: One can apply effects, filters, and a host of pixel manipulation techniques to a rendered frame, sequence, or entire animation. I did this to *storyTeller* and the final version of *Glasshouse*.



Figure 14. *StoryTeller* (2002).

I also heavily ghosted, desaturated parts, and tweaked the pixels in the xy grid in my keyframed *My Hand*.



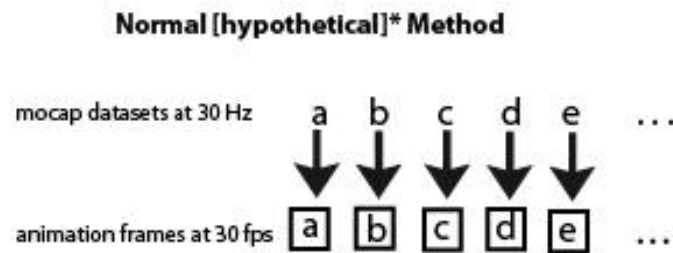
Figure 15. *MyHand* (1998).

All of these parameters and their possibilities are entwined with the movement choices that are discussed next.

II. MANIPULATING MOCAP DATA

As part of a methodology to tweak temporality of mocap datasets, I will discuss compressing, amplifying, progressing, reversing, snipping, blending horizontal, blending vertical, and repurposing, and other aspects. While capture is often at 120 Hz or greater, I am going to discuss the mapping of data captured at 30 Hz to the normal animation frame-rate for video at 30 frames per second. This I believe will make the theory/methodology more understandable (and it will reduce size and unnecessary complication in my diagrams).

Here is an illustration of this paradigm:



*There are too many variants of capture frequency for any one article to address each and every one. Hence, this article addresses the conceptual/theory of how captured data are mapped, using the most basic, or, platform, capture rate.

Figure 16. Normal (hypothetical) Method.

Compression (Faster)

This technique entails discarding mocap datasets. Consider a hypothetical sequence of 30 datasets where you keep the first dataset, discard the second, keep the third, discard the fourth, and so on. The result will be where you once had 30 datasets, you now have 15. Where the normal sequence took a second, the new sequence takes a half a second to get to the same body position. The effect to a viewer of an animation using mocap datasets in this manner is that the motion, originally normal to what a human could do, appears faster.

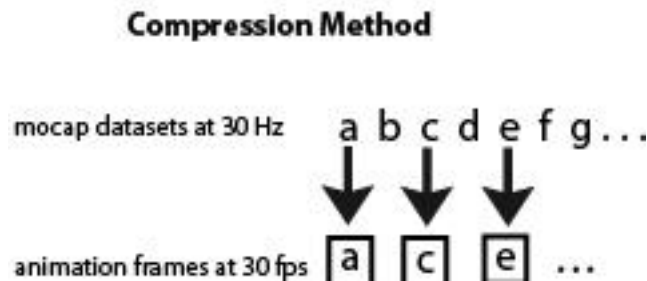


Figure 17. Compression Method.

Were we talking about a motion data captured at 120 Hz, we would keep the first datumset and discard the next seven. You can see why this discussion attempts to link a mapped motion-capture set at 30 Hz to normal 3d animation (and not feature films of 24 fps, rather as 30 fps which is a video standard.)

The technique above can be expressed as a mathematical mapping - where you have one set of numbers (normally designated by x) that is transformed by an equation (or mapped) to another set (normally designated by y). So if the sequence numbers of the mocap datasets mapped to animation frames is equated to y , then we could create a mathematical equation to express how to translate from mocap temporality x to animation temporality y : here, $y=2x-1$, creating ordered pairs of (1,1), (2, 3), . . . , that is for the first animation frame we want the 1st dataset; for the second animation frame, we want the 3rd dataset, and so on. And indeed, there is a way to express an algorithm for each of the following transformation methods of mocap data to animation timeline (amplification, etc), but mathematical expressions are not necessary to express concepts to readers who practice the artform, so this sample should suffice.

How many datasets you eliminate at a time will determine how much faster the result appears. For instance if you keep the first dataset, discard the second and third datasets, keep the fourth, discard the fifth and the sixth, you will end up with 10 where you once had 30. The new sequence takes a third of a second, and will appear faster than one that takes a half of second, and, of course, faster than one that appears normal (30 sets captured at 30 Hz played back as a 30 fps animation).

So you see how it is where you could create a new sequence of 6 datasets by maintaining a pattern of keeping one dataset and discarding the next four, or a new sequence of 5 by keeping one dataset and discarding the next five.

These above examples show constant incrementation within the mocap data, or, in other words, a good mapping since the sum of the kept and discarded datasets as a single pattern are

factors of 30 (e.g. 2, 3, 5, 6) and one can see that 10 and 15 will also work well in the example of this article. But this is relative to an arbitrary temporal marker of 30 that divides a second of time. One should not be limited to thinking that a second is the only referent to establish a standard, for instance - as a measure line in a bar of music might establish a temporal unit of sound. In the end, one can discard any integer and end up with minor discontinuities, as is shown below. For instance, one can also discard three after keeping one datumset, and, at the end of 60 datasets, the cycle of the pattern will be completed, producing a new sequence of 15 datasets. The new sequence will take one fourth the time of its corresponding original. Any pattern can be established.

This technique of compression can be applied to all datasets, as seen in Weiner's *Dialogos* where mocap movement is accelerated by a factor of 2 [5].



Figure 18. *Dialogos* 2002.

Compression can be applied to only sections of a movement piece, not the entire work, and I also have played with one or more figures moving quickly at the same time one or more figures displayed normal biomechanical movement, as in *Virilian Hero Dance*, *Glasshouse*, and “section 4” of *Journey*. [6]



Figure 19. Section 4 of *Journey*.

I telescoped (really speeded up, about 3 minutes of movement animation mapped to 10 seconds) in *While You Were Sleeping*.



Figure 20. *WhileYouWereSleeping* (2003).

This was done in post production, discarding rendered frames, rather than in production, discarding datasets.

In summary for this method called compression, a viewer can perceive that certain motions have been speeded up. This is accomplished by a digital movement manipulator/choreographer using mocap data by reducing the datasets. In contrast, the following discussion of amplification of keyframes corresponds to this methodology by creating the condition of a perception of a slowing down of motion.

Amplification (Slower)

Using a methodology similar to making mocap movement appear faster by reducing data, one can make mocap movement appear slower by adding data.

So if you have a 30 Hz capture and you want make the time of the original to double, you merely duplicate each dataset. So where you had 30 frames in the animation, you now have 60 frames. Where you had a movement/action taking one second, now it takes two. This gives the appearance of the motion being slowed down.

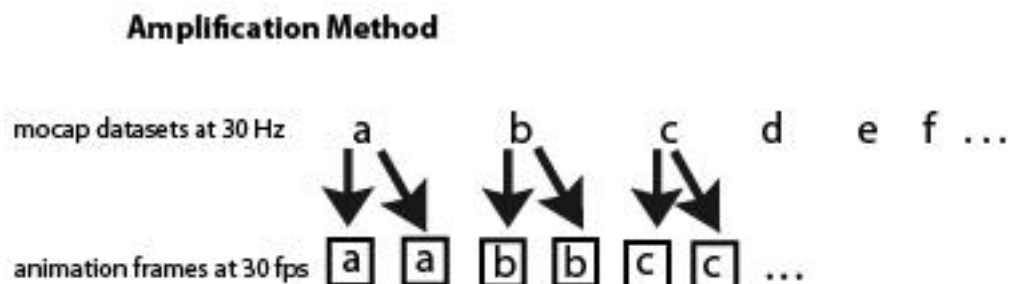


Figure 21. Amplification.

And were one to have each dataset appear three times in the animation timeline, then where the motion took one second it now takes three.

So one can double, triple, quadruple etc a dataset to create movement sequences that are outside of the norm, but serve the aesthetics of the animation expression.

If one has sufficient datasets, then one has to solve a mapping problem, not one of duplication of a dataset, as in the hypothetical 30 Hz captureset presented above in this discussion. For instance, in the major part of *Ritual at the Well*, I mapped a 120 Hz sequence of mocap data to 30 fps animation, essentially slowing it down to a fourth of its original speed. In other words, I mapped each dataset of mocap data to an animation frame, using 120 samples per second for 120 animation frames. [7].



Figure 22. *Ritual at the Well* (2007).

Progression

In general, a human-created biomechanical action has a normalacy to it that we can perceive by our eyes experienced in the laws of physics - that is - the way mass behaves in gravity. For instance, for a forward jump to occur there needs to be a change of angles of joints (bending of knees) forming the preparation, then some muscles contract and others extend, sending a person into the air for a period of time we can calculate with knowledge of weight and measurable forces at normal gravity (it is different in outer space), and then the body lands with some muscles and body parts absorbing the force like a spring. There is nothing magical about this, it happens according to laws of gravity. These laws supercede any desire for something else to happen - at least they do with embodied movement. We can defy natural/normal laws with mocap datasets in 3-D animations that are mutated.

Were there a wish to suspend the body in space, merely slowing it down at a particular moment to a sequence different from the rate of the first might appear abrupt; hence, one might want to treat the addition (or subtraction) of datasets in a non-linear manner. Such a technique gives the impression of deceleration (or acceleration.)

One can make such a sequence gradually slow down by a formula for a treatment of a datumset as in the following computer routine/logic for a sample of 10 datasets

x=0

Repeat to 10

x=x+1

end repeat

This would give a sequence of 1,2,3 . . . 10 that could be schematically shown in the diagram, producing a linear form of deceleration. The first dataset would get mapped to one animation frame, the second would get mapped to two frames, the third to three frames, and so on.

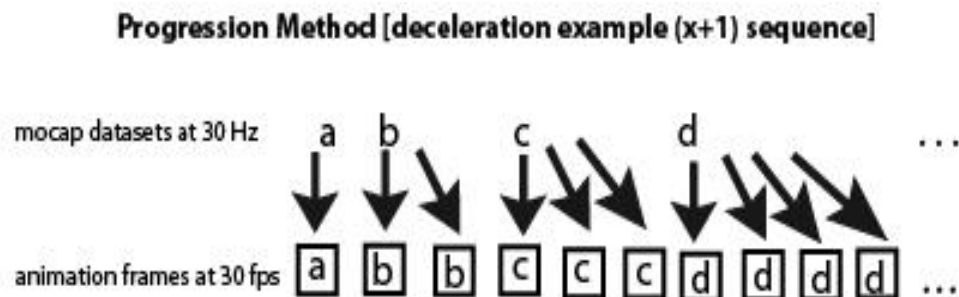


Figure 23. Progression Method x+1 sequencing.

One can find other schemes that might be more satisfying, such as seen below.

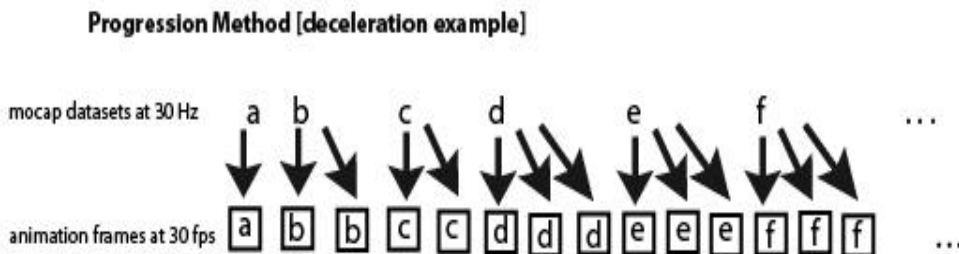


Figure 24. A Variant Schematic of the Progression Method.

A scheme similar to this was used in *3 Marys*, *RGB* to elongate the sense of suspension in the air. Now, while the initial assertion that mocap treatment could be envisioned similar to sound has largely been left unexplored to this moment, a normal sound has an attack, a sustain, and a decay. Comparing what I have done here with mocap datasets to *musique concrète* is to keep the attack, modify the sustain, and eliminate the decay. [8]

A discussion of phenomenological aspects as presented in Kozel [9] is beyond the scope of this presentation, but as someone who moved, was trained in some movement styles, and still moves, and has both memory and imagination of movement, it should be no secret that I felt the sense of eluding gravity at the time of creating the mocap datasets, and still do everytime I view the performance animation/digital choreography.



Figure 25. 3 Marys, RGB (2003).

Keyframing Mocap Datasets

Above, I've discussed the process of duplicating keyframes, that is, preserving the original dataset of the motion captured, however, one can map two successive datasets and produce other data, or nuances that didn't exist in the original motioncapture. To do this an animator spaces two successive datasets out so tweening occurs. (This corresponds in some sense to music's concept of microtonality.) How tweening or interpolation works in most 3-D computer animation programs is that a linear line is imagined between the same joint at two positions in the animation timeline corresponding to two (often successive) mocap datasets, and the line is divided into equal segments according to (the number plus 1) of frames added. So in the following example where three animation frames are created, a joint moves four times: a-ab1, ab1-ab2, ab2-ab3, and ab3-b. Once the equation of the line is determined (as part of the mathematics underlying the tweening process) it is then easy to identify the x,y,z coordinates of the joint, creating new data, for respective positions between the mocap datasets used as keyframes.

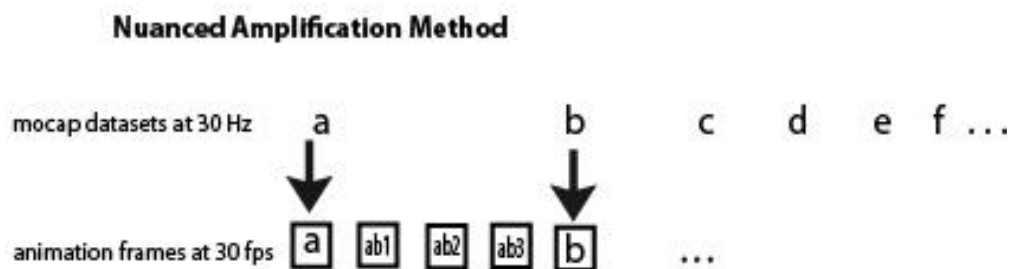


Figure 26. Using mocap datasets to generate new data.

Reversal

One can take datasets and change their order, putting the first one last, and the second-second to last, and so on.

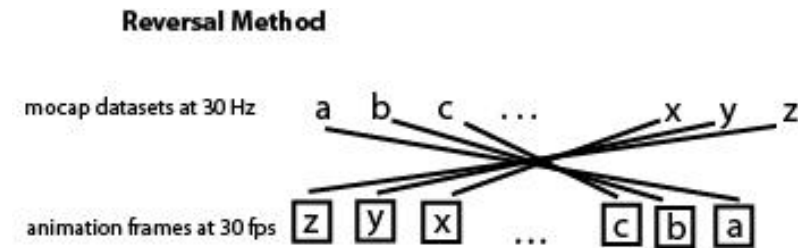
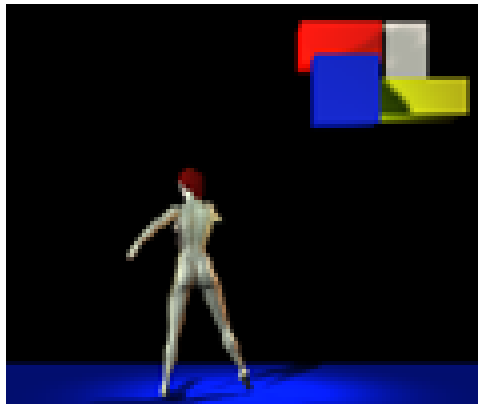


Figure 27. Reversal Method.

This can be for a substantial length of datasets as in *Purity* where for the first half (about three minutes) the 3d figure uses mocap datasets going forward, and in the second half, uses the same ones but in reverse order, creating almost a palindrome (it has some non-mocap keyframing in the first and second halves that are unique, so it cannot be considered a true palindrome).

Figure 28. *Purity* (2002).

But this can happen also to shorter sequences of datasets, for instance, of twenty seconds as in *Virilian Hero Dance*. Such a method can be applied to a single movement idea as in *Glasshouse* and *storyTeller*. [10].

Figure 29. *GlassHouse* (2002).

Snipping to Discontinuity

When one wants to have an abrupt disruption of the laws of physics, one can put one mocap dataset sequence after another, without blending. This disruption can be in terms of movement, spatial location, or both as seen in *3 Marys, RGB* where the motion sequence at the height of the jump is cut off from the normal landing and the figure seems to magically appear in another location ready to begin another jump.

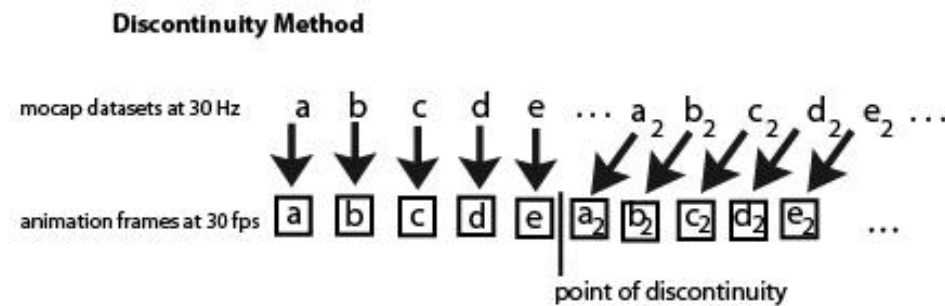


Figure 30. Discontinuous Datasets.

Juxtaposing Non-mocap figure manipulation with Mocap datasets through keyframing

Sometimes it is necessary to use non-mocap data as part of a movement idea/expression. While a mocap dataset is actually a keyframe, keyframing is a term traditionally used in 3d animation discussion where a pose is established by the animator at one point in time, another pose is established later, and the computer determines through human programming, using mathematics, the spatial increments based on distance divided by frames (time) for corresponding body parts to move in their x, y, z dimensions. The computer-generated figure positions between two keyframes are referred to as the inbetween, or tweening.

So if one were to wish to insert ‘passable as natural’ or even physically impossible movement into a realistic mocap sequence, one could use the last dataset of a mocap sequence as one keyframe, set the beginning keyframe of the non-mocap sequence at a point later in time so that the computer could form an artificial, but smooth transition over several frames (suggested 10-40 usually), and use a similar process at the end of the inserted segment to return to mocap datasets.

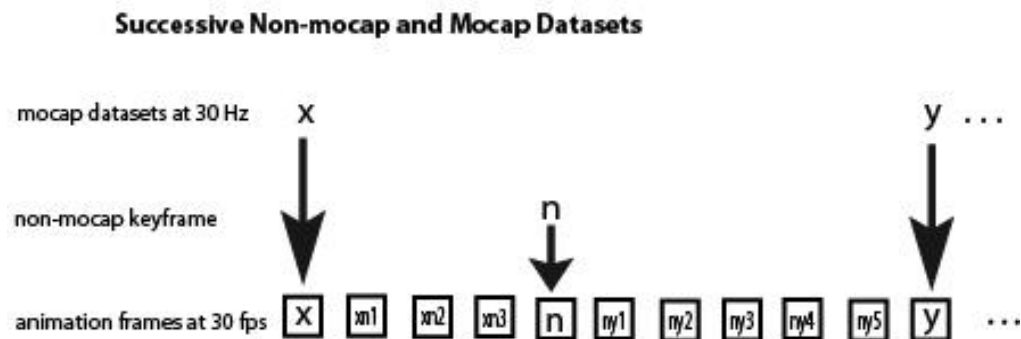


Figure 31. Sequencing non-mocap data with mocap data through keyframing.

I used this technique in *UP, Slammed Against the _____* which expresses my emotions/reaction to an administrator's abuse of power.

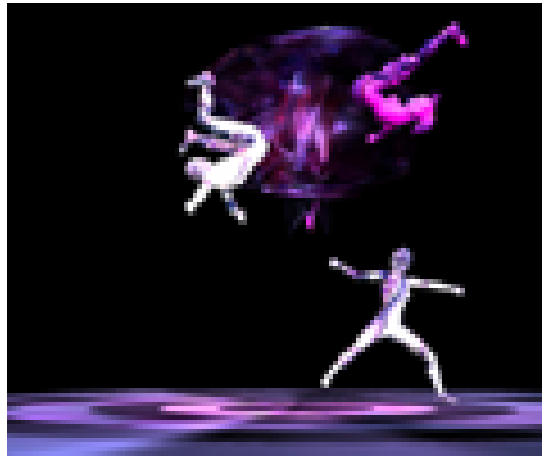


Figure 32. *UP, Slammed Against the _____* (2003).

But I had also used it quite a bit in *Purity* [12].

Using Mocap Data for Non Traditional Figures

While one sees mocap data mapped on variants of a single figure, in *Blue_____onTheBlackSpan*, I used one skin with a mocap sequence in canon (a canon has one time-based participant with a delayed beginning, such as heard in the song/round *Row, Row, Row your Boat*).

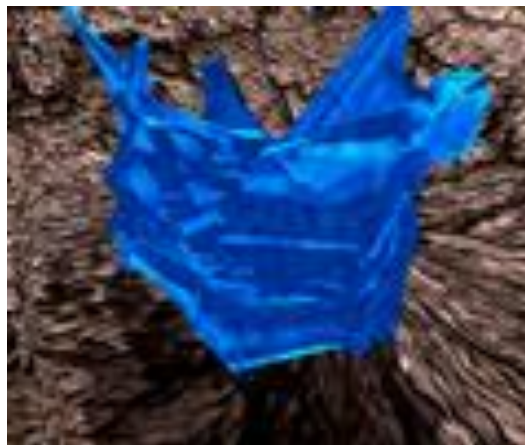


Figure 33. *Blue_____onTheBlackSpan* (2006).

The motion is not mapped directly to one recognizable figure; in other words, a figure might represent several mocap datasets at a single moment but not blend them to create a singular motion experience.

Repurposing mocap datasets created in one context for aesthetic ends.

Prior to having access to equipment where I could create my own mocap datasets, I was thinking about movement in 3-D spaces, and challenged myself to see if I could take existing data make choices, and make that data aesthetically interesting. This technique has connections to art movements of using ‘found’ objects as the basis for artistic expression. If one entertains the liberal construct that anything can be an element in an aesthetic construction, certainly motion can be too. I had access to many sport-related datasets, and used some to create *Broken Egg*.

In one section a figure climbs a wall from out of the ground while other action is going on in the foreground. Here you see the lower figure snowboarding [13].



Figure 34. Broken Egg (2002).

Any mocap sequence of datasets can be the substance for an aesthetic exploration/experiment/expression/composition.

I challenge all readers to think of a repository of mocap data, a free mocap library (maybe named after the Alexandrian library from classical times), where you can check out datasets and formulate new connections. And aesthetic movement need not codified as dance.

Local Gravity Referents of Moving Figures Non-Aligned with the World Gravity Referent

Another technique of using mocap datasets is to apply a pitch, yaw, or roll to figures contrasting that of the world, that is, based on the origin (what is the referent for what is up and down). While this can be simulated for an entire scene by rotating a camera, datasets can be out of sync with the axis of gravity that is portrayed in the 3d world. Who can forget those scenes in *Royal Wedding* (1951) that portrayed Fred Astaire dancing on walls and the ceiling, accomplished by rotating a room with the camera fixed as if setting on the floor, and Astaire

appeared always keeping vertical as the box rotated. This can also be simulated in post-production where green-screened images can be keyed in scenes.

I explored the concept of modifying mocap data through rotation in *Non-Plain Planes* [14].



Figure 35. *Non-Plain Planes* (2002).

Having the mocap motion on figures simultaneously occupying the same space in the 3d world.

In our normal experience of the world, two objects cannot occupy the same space because of physical laws. An embodied movement producer cannot have joints in the x,y,z space of another embodied movement producer. Yet, in the 3-D space of an animation, boundaries are an illusion. This aspect is one I explored in *Arcadian Women* by using a canon of five figures starting in the same space at different times, and overlapping. Each figure has mocap datasets mapped to it, but delayed, and not delayed in a mindless manner. The delay is not in regular intervals. Moreover, each of the five figures associated with the mocap datasets has a certain degree of transparency, which is another parameter that adds interest.

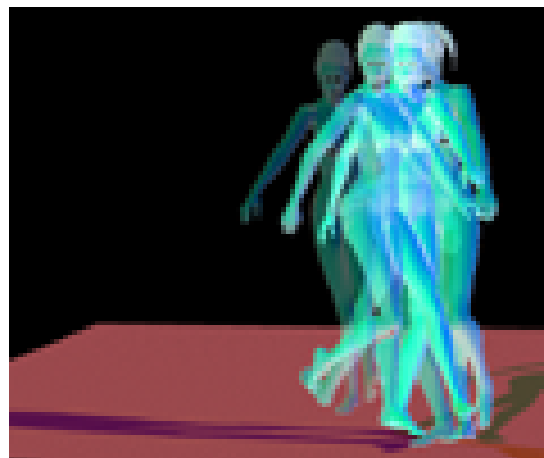


Figure 36. *Arcadian Women* (2002).

Also, in “section 12” of *Journey*, there are three groups in canon with each other, each doing a canon - and as a result of the mocap datasets where the body does not move much in the x-y plane, the figures appear to overlap. They seem to occupy the same space simultaneously. [15]



Figure 37. Section 12 of Journey.

This happens too at various moments in *Glasshouse* and *Storyteller*. In *Ritual at the Well* based on movement ideas constrained by the same parameters to create a unique, or a personalized embodied motion sequence by each of about 10 performers, the digital figures pass through one another. This could lead to a discussion later about 3-D as a symbol or an imitation of our normal experience. I don't think using mocap data in an aesthetic modality need ever to be constrained to laws of physics. I think we, as humans, have the imagination to be able to process movement/motion intent when it goes beyond the reality of normalcy that might be signaled by biomechanical reality. So while we can modify time, we can also modify space. And in the spirit of this discussion, certainly we can recognize patterns.

Linking/Blending Mocap Datasets in a Horizontal Manner

To create a plausible or acceptable movement sequence without borrowing terminology such as ‘suspended disbelief’ as is found in theatre, film, and literature, one needs to be closely aware of gravity and support between the datasets being linked. Thus, for example if one dataset ends on the right foot with the body crouched forward, the ideal beginning of a linked dataset would be to have the body crouched forward, on the right foot, and facing the same direction.

One theory is of creating a motion library whereby certain sequences of mocap datasets can provide a set of elements that someone can put together to form new combinations. Ballet is often seen this way, where one movement may start from the 5th position and also end in the 5th position. So a sequence such as *chaussé*, *assemblé entornant*, *glissade*, *sissonne*, *tour en l'aire* could be reassembled in any combination (there would be $5 \times 4 \times 3 \times 2 = 120$ possibilities).

There are two possibilities for the nature of the datasets. One is that the mocap datasets can all be from the same mover but rearranged.

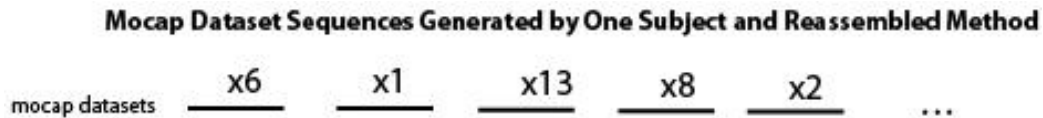


Figure 38. Horizontal sequencing of datasets of one subject.

They can also be culled from different motion producers/talents/subjects.

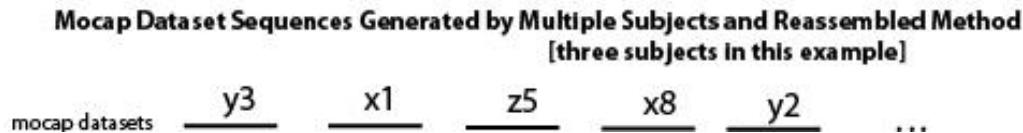


Figure 39. Horizontal sequencing of datasets of multiple subjects.

Blending Mocap Datasets in a Vertical Manner

Consider that you have mocap data in which you like what the legs are doing, but you don't like what the arms are doing; well you can put the legs of one sequence of datasets together with the arms of another sequence of datasets to produce a new dataset that was not originally produced in a biomechanical natural manner.

Similar to the conceptual aspect of blending in a horizontal manner, one can use datasets of the same motion creator, or, of different ones.

Moreover, one can use non-mocap data as part such vertical blending. A special case of this is using mocap data with distortion of figure.

A good thing about mocap data is that those systems that only report x,y,z data for joints (3 degrees of freedom) because they are passive (e.g. optical) can have that data analyzed to create rotational data (6 degrees of freedom).

What this means is that the digital figure does not need to have the same proportions as the talent providing the movement. In other words, someone aesthetically inclined working with mocap data does not need to view the x,y,z numbers of a sequence of datasets to be directly scalable. Rather, given the established joints of the model, the motion can be mapped not as absolutes, rather as relatives.

In *Mercury's Younger Brother*, the expressive idea is that each of us functions according to our 'natural gifts'. While Mercury as tradition and mythology has conveyed, received wings on his ankles to allow him to speedily go from one place to another, we all know that within a family (now, as sentient human beings), not everyone metaphorically receives wings. Sometimes the gifted one is the eldest, sometimes, a middle, sometimes, the youngest. The performance animation expresses a message about doing one's best regardless of the circumstances, and they might be a handicap. [16]

A more striking example of this technique is seen in *Armed with Reach*. I was thinking of empowerment of women (I have two beautiful daughters). I was thinking of a person being active and reaching out for what one desires, not being passive; so I mapped mocap data on a figure and made its arm grow at various moments.

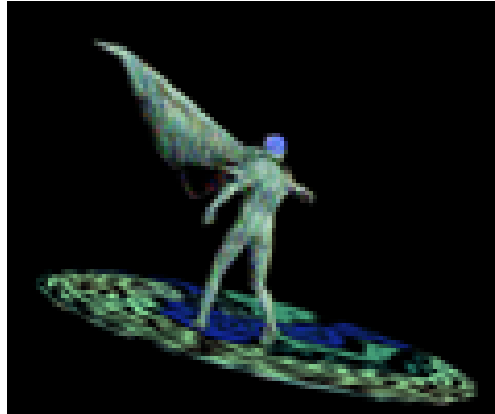


Figure 40. Mercury's Younger Brother (2002).

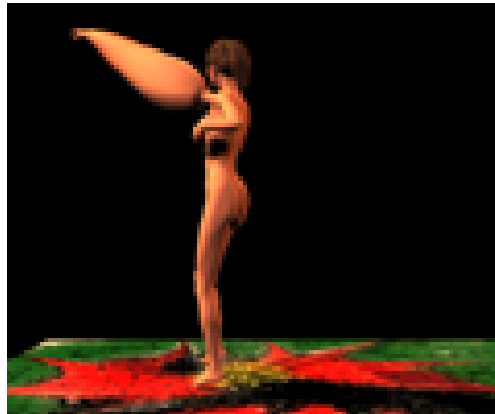


Figure 41. Armed With Reach (2002).

I normally use mocap data I created, with the exception of four pieces - *Ritual at the Well* (my movement data with that of members of my mocap class), *UnderTheSun,OverTheLand* (with movement by Tailfeathers), *Blue____onTheBlackSpan* (my movement data of the figures on the rock, with the jump and reaching movements of the stone figures by Scott Kovacs), and *Broken Egg* (with movement by unknowns, but freely available).

Cross-Mapping Mocap Data to Digital Joints/Bodies

While the normal method of using mocap datasets is a one-to-one mapping from the natural biomechanical joints to those of the digital model, for instance, mapping the mocap data of a right knee to the digital model right knee, one can assign, for instance the mocap right knee data to the digital model left elbow.

I did something like this in one segment of *Broken Egg*. [17]

It is appropriate to mention at this point that mocap data can be cross-mapped to non humanoid or non biped digital objects.



Figure 34. Broken Egg (2002).

Deterministic and Random Techniques of Ordering Datasets

At this point, the reader probably has a clear understanding of the complexity of using mocap datasets to create a memorable expression in the form of an animation. The two extremes of this process are whereby 1) a creator controls as much of the parameters and decision-making as possible and 2) a creator cedes control and accepts the consequences whereby the final product may have some chance, or random aspects to its composition.

When one collaborates, one cedes total control. In effect one is accepting other decision-making as an aspect that is part of the whole.

Yet, regarding movement, there are some ways for a creator to accept experiments that could be successful. For instance, some computer programs allow a movement creator to specify what movements will be blended, what range that blending can occur in, and the probability that such a blend should occur.

Return to Other Time-Based Arts and Their Methodologies

In *musique concrète* of a period fifty years ago or more, a creator takes physical segments of tape and reassembles them. “*Musique concrète* begins with raw sound material, which has been recorded on tape via a microphone. The identity of the sounds or sound objects is transformed by a variety of means and is recorded.” [18] Today, a movement creator/expressor/choreographer/assembler can, with mocap datasets, do similar transformations, as has been described and illustrated above.

By the use of the modifier *concrète*, the codifiers of the *musique concrète* believed in an importance of having objective sound data they felt existed naturally and could be captured through their technological intervention, and, then, through manipulation, be altered from its original state as part of human expression.

While *mouvement concrète* suggests backward thinking since it utilizes/recycles terminology, it is an apt way of viewing human organizational practices with natural movement recorded by electronic means. The struggle one has with recorded motion is

similar to that of recorded sound decades earlier. Both have data that is additive, and any manipulation of the source material has its effects expressed over time.

Primary, Secondary, Basic or Pure, or Applied Research

The ideas expressed in this article result from primary and basic research. I have always believed in the maxim “The Answers You Receive Depend on the Questions You Ask.” What is one person’s question might not be that of another. The research products (resulting animations) using mocap datasets are answers to my questions. And if the animations are shared in festivals and evoke thought or aesthetic appreciate in others, they are applied research.

CONCLUSION

Mocap datasets are being generated by many people with different applications. There are libraries of such datasets. Some people are going to play with datasets whether they be from libraries or are created by talent/movers they direct. Some people like to play, because they are curious. Some people understand, for instance in drawing or coloring, that their artistic representation is not a shared reality based on natural laws, rather it is a personal mapping of elements that really are shared, but are represented using symbolic or reductionist techniques. The same is true with motion. In my opinion, humans do motion best in reality. An animation of human movement can be seen as an imitation, or, if the movement is tweaked, a perception of reality that is felt or imagined, but not necessarily shared in objective time and space. That is all it can be, an imitation, or expression. In the digital representation, we use symbols. Symbols are reductionist by nature.

I have asked myself, why would I want to imitate reality when reality does what it does very well? I don’t want to imitate reality. For the most part, reality is banal. Let reality be reality. I want to exaggerate certain aspects of movement reality in the same manner a writer wants to find word symbols to create a picture in your mind about their story. Who can define what story is? It is not just plot. I propose that a concept similar to story exists in all serious mocap animations. I am not prepared to call story narrative and I use the word serious only as a conditional for those animations created with thought and awareness of a beginning, middle, and end, and the awareness of the rightful unfolding of new information. Maybe this is pretentious.

The general understanding of a good film is that if a section is boring, it can’t be boring for long. I watch my works and I wonder if they are boring to others. They are not for me. I see a development. Maybe it is the way I have framed the movement from the viewpoint of the camera combined with other changes (for example, the morphing of the body or the speed of revolution of a flattened spherical shape with bold textures).

Mapping objects that don’t have temporality is understandable to most people. Art practices often have such objects. They are there; there for a long time. They are tangible. They occupy both time and space. Mapping motion that does have temporality is, . . . well, less easy to seize upon in the mind regarding memory or imagination. It is, at the end - intangible. It is at one part of space at one moment of time. Then it is not there.

In this article, we have explored some methods by which mocap datasets can be manipulated. These techniques are based on experience. There are certainly others, but this survey can serve as a core, or good starting point for those wishing to explore mocap dataset manipulation.

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- [1] Barry Schrader. *Introduction to Electro-Acoustic Music*. Prentice-Hall, Inc., Englewood Cliffs, N.J. 1982 p.14.
- [2] Gongbing Shan, Peter Visentin, Tanya Harnett. "A Novel Use of 3D Motion Capture: Creating Conceptual Links between Technology and Representation of Human Gesture in the Visual Arts" *Leonardo* Vol 43 No 1 (Feb 2010) 34-42.
- [3] Alberto Menache. *Understanding Motion Capture for Computer Animation and Video Games*. Morgan Kaufmann Publishers San Francisco 2000.
- [4] To see *ThreeBlueRocks* [though small] in its entirety, go to <http://people.uleth.ca/~aw.smith/isabelle.html>. I have a theory regarding camera usage. While contemporary perceptions of camera cutting are based on works that require such cutting, for instance T.V. sitcoms and feature films, a non-narrative work featuring movement does not require cutting. It can have cutting, but does not require it - as there are no physical production limitations as in the real world. My personal viewpoint that has guided my decisions for a decade is that if the action/movement is interesting enough, one does not need to add excitement by camera movement.
- [5] To see the complete *Dialogos*, go to: <http://people.uleth.ca/~aw.smith/digitalChoreography.html>
- [6] To see samples of compression as demonstrated in *Glasshouse* and section 4 of *Journey*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>
- [7] To see a sample of amplification as demonstrated in *Ritual at the Well*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>
- [8] To see a sample of progression as demonstrated in *3 Marys, RGB*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>
- [9] Susan Kozel. *Closer Performance, technologies, phenomenology*. Cambridge, MA: The MIT Press, 2008.
- [10] To see a sample of reversal as demonstrated in the distant figure in *Virilian Hero Dance*, and for a superimposition of five figures [occupying simultaneous space] in *storyTeller*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>.
- [11] To see a sample of snipping to discontinuity as demonstrated in *3 Marys, RGB*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>.
- [12] To see a sample of snipping to sequencing non-mocap data with mocap data through keyframing as demonstrated in *Purity*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>
- [13] To see a sample of repurposing mocap datasets as demonstrated in *Broken Egg*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>
- [14] To see a sample of local gravity referents non-aligned with the world gravity referent as demonstrated in *Non-Plain Planes*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>.

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- [15] To see a sample of letting mocap datasets be layered in the same space as demonstrated in *Arcadian Women*, and as demonstrated in section 12 of *Journey*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>
 - [16] To see a sample of vertical layering of mocap datasets with non-mocap data in some joints as demonstrated in *Mercury's Younger Brother*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>
 - [17] To see a sample of crossmapping mocap data as demonstrated in *Broken Egg*, go to <http://www.youtube.com/watch?v=RjP7lb8yHgw>
 - [18] Jon. H. Appleton and Ronald C. Perera. *The Development and Practice of Electronic Music*. Englewood Cliffs, N.J.: Prentice-Hall, 1975. P 71.