Taekwondo training speeds up the development of balance and sensory functions in young adolescents

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Abstract

Objectives: This study aimed (1) to identify the developmental status of balance and sensory functions in young adolescents as compared to adults and, (2) to explore the effect of Taekwondo (TKD) training on the development of balance and sensory systems in young adolescents. *Design:* Cross-sectional controlled trial. *Methods:* Sixty-six participants including 42 adolescents (21 TKD practitioners, 21 non-TKD practitioners) and 24 adults were tested. The sway velocity of centre of gravity was recorded during standing on the non-dominant leg on a Smart Equitest ® system. The somatosensory, vestibular and visual ratios were also measured with the machine. *Results:* Adult participants swayed slower than both TKD and non-TKD adolescent groups during single leg stance with eyes open (p=0.007 and p<0.001, respectively). The TKD adolescent group, in turn, swayed slower than the non-TKD adolescent group (p<0.001). Adult participants had better visual ratio than both TKD and non-TKD adolescents (p=0.001 and p<0.001, respectively) while there was no difference between the TKD and non-TKD adolescents (p=0.164). For the vestibular ratio, there was no significant difference between adult participants and TKD adolescents (p=0.432). Adolescents who did not practice TKD showed significantly lower vestibular ratio than TKD adolescents and adults (p=0.003 and p<0.001, respectively). In addition, there was no significant difference in the somatosensory ratio among the 3 subject groups (p=0.711). *Conclusions:* Participation in TKD appears to speed up the development of postural control and vestibular function in adolescents. Clinicians might advocate TKD exercise as a therapeutic intervention for young people with balance or vestibular dysfunctions.

*Key Words***:** martial arts; postural control; maturation; sensory organization; stability

1. Introduction

Postural control relies on the central nervous system (CNS) to select and integrate sensory inputs from visual, somatosensory and vestibular systems and then generate appropriate motor outputs.[1] These three sensory systems develop at different rates in children and adolescents.[2,3] Regarding the development of somatosensory function, some studies reported that the somotosensory function matures by 9 to 12 years of age[4,5] while other studies found that maturation of the somatosensory function occurs much earlier at 3 to 4 years of age.[6-8]

For the visual function, the time of maturation also varies according to the literature. Cherng and colleagues found that children at 7 to 10 years old develop the same efficiency of using vision for standing balance as adult.[5,9] However, Hirabayashi and Iwasaki[6] and Cumberworth's research team[8] reported that visual function matures as late as 15 years old.

Although previous studies agreed that the vestibular function has the slowest speed of development among the three sensory systems for balance, the reported timing of maturation for this system varies. Shumway-Cook and Woollacott suggested that by the age of 7, children are able to balance efficiently with vestibular cues only.[10,11] However, some researchers reported that vestibular function would fully develop at the age of 15 to 16.[7,8,12] Therefore, the time of maturation of these three sensory systems for balance is still uncertain.

Apart from maturation of the sensory systems, the development of postural control is influenced by activity and experience.[11,13,14] Training in dynamic sports such as Judo and gymnastics has been reported to improve postural control of the young athletes.[15-17]

Taekwondo (TKD), besides being an official Olympic sport, is also one of the world's most popular sports among children and adolescents.[18] It is famous with its kicking techniques, in which unilateral stance stability is crucial and is a determining factor of success in competitions.[18] However, only few studies had investigated the effect of TKD training on balance control and most of them focused on the aged population.[19,20] Regarding the young TKD athletes, Sadowski reported that balance was amongst the most important 'coordination motor abilities' of elite level athletes[21] but the causal relationship between TKD training and balance performance was not explored. Thus the effect of TKD training on balance was not known.

In light of the increasing popularity of this sport and majority of the practitioners start training at a very young age,[18] there is a need to examine the impact of TKD training on balance development in young adolescents. This study aimed to: (1) identify the developmental status of balance and sensory functions in young adolescents as compared to adults, and (2) explore the effect of TKD training on balance and sensory development in young adolescents.

2. Methods

Sixty-six participants volunteered for this study and they were divided into three groups. Twenty-one were adolescent TKD practitioners (11 to 14 years old) who had practised TKD for 1 to 9 years with a minimum of 4 hours of training per week. Another 21 adolescents were non-TKD practitioners (11 to 14 years old) who had no previous experience in TKD or martial arts but were physically fit. The other 24 participants were healthy adults (18 to 23 years old) who had no previous experience in TKD or martial arts. An adult group was included in order to compare the developing balance functions in young adolescents to matured adults (objective 1). The exclusion criteria were the presence of vestibular or visual disorder, musculoskeletal or neurological disease, history of injury in the past 12 months requiring medical attention and regular training in sports other than TKD. The study was approved by the human subjects ethics review subcommittee of Hong Kong Polytechnic University. The procedures were fully explained to the participants and their guardians, and they all gave their written informed consent before testing. All procedures were performed in accordance with the Declaration of Helsinki.

Participants stood with bare foot on their non-dominant leg (dominant leg was defined as the one used to kick a ball) for 10 seconds on a Computerized Dynamic Posturography machine (Smart Equitest ® system, NeuroCom International Inc., OR, USA). During the unilateral stance test (UST), a standard posture was adopted with arms by the sides of trunk, eyes looking forward and the dominant leg flexed by 45° at the hip and knee so as to resemble the starting position of a front kick. The sway velocity of the center of gravity (COG) was recorded by the machine and 3 trials were performed with 10 seconds of rest in between.[22] The mean COG sway velocity across the 3 trials was used for analysis.

During the sensory organization test (SOT), participants stood bare foot on the platform of the same Computerized Dynamic Posturography machine and wore a security harness to prevent a fall. The feet placement was standardized according to the height of the participant. Moreover, participants were instructed to stand quietly with arms resting on both sides of their trunk and eyes looking forward. Participants were exposed to 6 different combinations of visual and support surface conditions during the test (Table 1). They were instructed to remain in an upright position as steadily as possible for 20 seconds in each trial. If the participant took a step or required assistance of the harness, the trial was rated as a fall. Each participant was tested for 3 times in each condition.

The machine detected the trajectory of the center of pressure (COP) of the participant which was then used to calculate the equilibrium score (ES).[1] Equilibrium score was defined as the non-dimensional percentage which compared the participant's peak amplitude of anterior-posterior (AP) sway to the theoretical limits of AP stability (12.5°). Although the actual theoretical limit of stability would be influenced by the individual's height and size of the base of support, the sway angle was used in the calculation. It represents an angle (8.5° anteriorly and 4.0° posteriorly regardless of body height) at which the person could lean in any direction before the centre of gravity would move beyond the point of falling.

The equilibrium score was calculated with the formula:

$$12.5° - ((\theta_{max} – \theta_{min})/12.5°) \times 100$$

Where θ_{max} is the greatest AP COG sway angle attained by the participant and θ_{min} is the lowest AP COG sway angle. An ES of 100 represented no sway (excellent balance control), whereas 0 indicated a sway that exceeded the limit of stability, resulting in a fall.[1] The mean ES of each testing condition across the 3 trials was calculated. Quotients of the ES scores in different conditions were then calculated to represent the somatosensory, visual and vestibular ratios. These ratios were used for analysis (Table 2).

The intraclass correlation coefficient ($ICC_{3,1}$) was calculated to assess the test-retest reliability of the UST and SOT. Each outcome measure was tested 3 times with 25 normal young participants who were not involved in the main study. The absolute values of COG sway velocity and SOT equilibrium scores for conditions 1 to 6 in the 3 trials were used to calculate the ICC values.

One-way ANOVA was used to compare the age, height and body weight among the three subject groups. Significant ANOVA results were further analyzed with post hoc tests to identify the pairs there were different. For between-group comparisons of the 4 outcomes of COG sway velocity, somatosensory ratio, visual ratio and vestibular ratio, one-way ANOVA was performed. Significant results were further analyzed with post hoc Bonferroni multiple comparisons. A significance level of 0.05 was adopted for all the statistical comparisons.

3. Results

The ICC value for the COG sway velocity was 0.77 which indicated a good reliability for the UST in adolescents. The ICC values for the equilibrium scores of SOT conditions 1 to 6 ranged from 0.50 to 0.77 which indicated moderate to good reliability for the SOT in adolescents.[23]

One-way ANOVA revealed significant differences between the adult participants and the 2 adolescent groups in age, height and weight, but no difference was found between the adolescent TKD practitioners and non-practitioners. The difference in height between the young and the adult participants did not affect comparison of the ES and the sensory ratios because the 'sway angle' was used in calculation. The difference in weight also has an insignificant role in postural control during unperturbed stance.[14]

Significant between-group differences in the visual ratio ($p<0.001$), vestibular ratio ($p<0.001$) and COG sway velocity ($p<0.001$) were found, but not in the somatosensory ratio ($p=0.711$) (Table 3). Post hoc analysis revealed that adult control participants swayed significantly slower than both TKD and non-TKD adolescents during single leg stance with eyes open (p=0.007 and p<0.001, respectively) whereas the TKD adolescents swayed slower than the non-TKD adolescents (p<0.001). The COG sway velocity in adolescent TKD practitioners was 57.8% higher than the adults while the COG sway velocity in non-TKD adolescents was 150% higher than the adults (Table 3).

For the three sensory ratios, adult participants had significantly better visual ratio than both TKD and non-TKD adolescents (p=0.001 and p<0.001, respectively) while there was no difference between the two adolescent groups (p=0.164) (Table 3). For the vestibular ratio, there was no difference between the adult participants and TKD adolescents (p=0.432). However, those non-TKD adolescents showed significantly lower vestibular ratio than TKD adolescents and adults (p=0.003 and p<0.001, respectively) (Table 3).

4. Discussion

The present study revealed that adolescents not involved in TKD training had most body sway in unilateral stance and attained significantly lower vestibular ratio than the adult participants. These agree with previous findings that development of the vestibular function and CNS integration are incomplete in children up to 14 or 15 years of age.[5,6,8]

The vestibular system is the most important and reliable sensor for postural control, especially in challenging conditions because this system measures accelerations of the head in relation to gravity rather than relying on external references for postural control.[1,6] This system also has a role in the vestibulo-ocular reflex (VOR) which stabilizes visual images on the retina during head and body movements.[24] Therefore, with an immature vestibular function in adolescents, it explains why the adolescents swayed more than adults in unilateral stance. We found that adolescents who practiced TKD had improved their vestibular function so that they had better stability in unilateral stance than their non-TKD counterparts. The frequent jumps and spinning kicks in TKD training might stimulate the development of vestibular system.[18] Our findings also revealed that the vestibular function in the TKD adolescents was as good as the adults. These findings support the notion that TKD training would speed up the development of vestibular system in adolescents so that the TKD practitioners out-performed their non-TKD counterparts in the vestibular function tests. With a well developed vestibular system, young TKD practitioners could maintain stability in challenging conditions such as performing spinning kicks. This would not only benefit them in scoring during competitions but also reduce their chance of injuries with falls during practice.

The contribution of vision to balance control is well documented.[1] This study revealed that non-TKD adolescents swayed fastest in UST among the three groups and attained significantly lower visual ratio than the adults. This concurs with previous studies that visual function develops slowly in children despite the fact that children prefer to rely on visual inputs more than the other sensory information in achieving postural equilibrium.[12] The visual function does not fully mature until 15 or 16 years of age.[6-8] This explains why non-TKD adolescents of 11 to 14 years old swayed more than the adults in unilateral stance. Although practicing TKD could improve unilateral stance postural control, these participants at their early teens had similar visual function as their non-TKD counterparts and they had not achieved the same visual function as adults. These findings imply that TKD training might not have a potent effect on the development of visual function for balance. The physiological maturation with age has a more profound effect instead.

The present study demonstrated that both TKD and non-TKD adolescents had similar somatosensory function as adults. This could be due to the fact that somatosensory function starts maturing at the age of 3 or 4 years and becomes comparable with adult very early on.[6-8] It seems that training in TKD may not further improve the somatosensory function in adolescents. This is contrary to many previous studies which reported that proprioception could be improved by sports training in young athletes.[17] The possible explanation of this discrepancy is that the somatosensory ratio, which compared SOT condition 2 to condition 1 (Table 2), quantified the extent of stability loss when the participants closed the eyes in standing. Since TKD training does not require the practitioners to balance with eyes closed, TKD participants had no advantage in this testing condition. In light of that, the somatosensory ratio might not be a valid reflection of the TKD participants' ability in using the somatosensory information for balance. Further study should measure the proprioceptive or tactile sensations directly as these have been reported to affect postural control.[25]

In summary, the present study revealed better vestibular function in the TKD adolescents than the non-TKD adolescent group and was comparable to the adults. These findings suggest that TKD training could hasten balance development in normal young persons. Thus, the use of TKD exercise as a potential therapeutic intervention for children with balance and vestibular dysfunctions warrants further investigation.

There were some limitations in this study that need to be considered when interpreting the findings. First, we used a cross-sectional study design (three groups with different ages and TKD experience). It is because previous studies had found that balance functions were different in different age groups[6,7,14] and no study has investigated the balance functions in young TKD practitioners. This is believed to be the first study attempting to explore the effect of TKD training on the maturation of balance systems in adolescents. However, the limitation with this study design is it is not clear whether the observed differences were due to TKD training or natural predispositions. This would best be tested with a longitudinal study. Second, the training experience varied from one to nine years in our TKD participants, this range is too wide for generalization of the training effect. Further study is needed to confirm the optimal TKD training duration in order to gain the physiological benefits. Finally, based on the Systems model of motor control, development of postural control is a result of interactions among multiple neural and mechanical components[2] but we have only investigated a part of the many components contributing to balance control. Additional research is needed to examine the other effects of TKD training such as on the development of muscle response synergies, muscle strength, joint range and body morphology.

5. Conclusion

Participation in TKD appears to speed up the development of unilateral stance postural control and vestibular function in adolescents of 11 to 14 years old. Clinicians may consider TKD exercise as a therapeutic intervention for children with balance and vestibular dysfunctions.

Practical Implications

- Balance systems are not fully matured in adolescents of 11 to 14 years old. This study provides a basis for normative postural stability data for healthy adolescents aged between 11 and 14 years.
- TKD training can speed up the development of balance in adolescents. Parents and clinicians may consider TKD exercise as a therapeutic intervention for children with balance dysfunction.
- The findings of the current study can be used for assessing TKD training effect, evaluation of TKD training progress and selection of talented TKD athletes.

Disclosures

No funding was provided for the preparation of paper and the authors have no conflicts of interest that are directly relevant to the content of this article.

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