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

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- 1 **Taekwondo training speeds up the development of balance and sensory functions in young**
- 2 **adolescents**
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4 **Abstract**

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

23

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

25 **1. Introduction**

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

32 For the visual function, the time of maturation also varies according to the literature. Cherng and
33 colleagues found that children at 7 to 10 years old develop the same efficiency of using vision for
34 standing balance as adult.^{5,9} However, Hirabayashi and Iwasaki⁶ and Cumberworth's research team⁸
35 reported that visual function matures as late as 15 years old.

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

42 Apart from maturation of the sensory systems, the development of postural control is influenced
43 by activity and experience.^{11,13,14} Training in dynamic sports such as Judo and gymnastics has been
44 reported to improve postural control of the young athletes.¹⁵⁻¹⁷

45 Taekwondo (TKD), besides being an official Olympic sport, is also one of the world's most
46 popular sports among children and adolescents.¹⁸ It is famous with its kicking techniques, in which
47 unilateral stance stability is crucial and is a determining factor of success in competitions.¹⁸ However,
48 only few studies had investigated the effect of TKD training on balance control and most of them focused
49 on the aged population.^{19,20} Regarding the young TKD athletes, Sadowski reported that balance was

50 amongst the most important ‘coordination motor abilities’ of elite level athletes²¹ but the causal
51 relationship between TKD training and balance performance was not explored. Thus the effect of TKD
52 training on balance was not known.

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

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59 **2. Methods**

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

72 Participants stood with bare foot on their non-dominant leg (dominant leg was defined as the one
73 used to kick a ball) for 10 seconds on a Computerized Dynamic Posturography machine (Smart Equitest
74 ® system, NeuroCom International Inc., OR, USA). During the unilateral stance test (UST), a standard

75 posture was adopted with arms by the sides of trunk, eyes looking forward and the dominant leg flexed by
76 45° at the hip and knee so as to resemble the starting position of a front kick. The sway velocity of the
77 center of gravity (COG) was recorded by the machine and 3 trials were performed with 10 seconds of rest
78 in between.²² The mean COG sway velocity across the 3 trials was used for analysis.

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

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

94 The equilibrium score was calculated with the formula:

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$$12.5^\circ - ((\theta_{\max} - \theta_{\min})/12.5^\circ) \times 100$$

96 Where θ_{\max} is the greatest AP COG sway angle attained by the participant and θ_{\min} is the lowest
97 AP COG sway angle. An ES of 100 represented no sway (excellent balance control), whereas 0 indicated
98 a sway that exceeded the limit of stability, resulting in a fall.¹ The mean ES of each testing condition

99 across the 3 trials was calculated. Quotients of the ES scores in different conditions were then calculated
100 to represent the somatosensory, visual and vestibular ratios. These ratios were used for analysis (Table 2).

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

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

111

112 **3. Results**

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

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

122 Significant between-group differences in the visual ratio ($p < 0.001$), vestibular ratio ($p < 0.001$) and
123 COG sway velocity ($p < 0.001$) were found, but not in the somatosensory ratio ($p = 0.711$) (Table 3). Post

124 hoc analysis revealed that adult control participants swayed significantly slower than both TKD and non-
125 TKD adolescents during single leg stance with eyes open ($p=0.007$ and $p<0.001$, respectively) whereas
126 the TKD adolescents swayed slower than the non-TKD adolescents ($p<0.001$). The COG sway velocity in
127 adolescent TKD practitioners was 57.8% higher than the adults while the COG sway velocity in non-TKD
128 adolescents was 150% higher than the adults (Table 3).

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

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136 **4. Discussion**

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

141 The vestibular system is the most important and reliable sensor for postural control, especially in
142 challenging conditions because this system measures accelerations of the head in relation to gravity rather
143 than relying on external references for postural control.^{1,6} This system also has a role in the vestibulo-
144 ocular reflex (VOR) which stabilizes visual images on the retina during head and body movements.²⁴
145 Therefore, with an immature vestibular function in adolescents, it explains why the adolescents swayed
146 more than adults in unilateral stance. We found that adolescents who practiced TKD had improved their
147 vestibular function so that they had better stability in unilateral stance than their non-TKD counterparts.
148 The frequent jumps and spinning kicks in TKD training might stimulate the development of vestibular

149 system.¹⁸ Our findings also revealed that the vestibular function in the TKD adolescents was as good as
150 the adults. These findings support the notion that TKD training would speed up the development of
151 vestibular system in adolescents so that the TKD practitioners out-performed their non-TKD counterparts
152 in the vestibular function tests. With a well developed vestibular system, young TKD practitioners could
153 maintain stability in challenging conditions such as performing spinning kicks. This would not only
154 benefit them in scoring during competitions but also reduce their chance of injuries with falls during
155 practice.

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

167 The present study demonstrated that both TKD and non-TKD adolescents had similar
168 somatosensory function as adults. This could be due to the fact that somatosensory function starts
169 maturing at the age of 3 or 4 years and becomes comparable with adult very early on.⁶⁻⁸ It seems that
170 training in TKD may not further improve the somatosensory function in adolescents. This is contrary to
171 many previous studies which reported that proprioception could be improved by sports training in young
172 athletes.¹⁷ The possible explanation of this discrepancy is that the somatosensory ratio, which compared
173 SOT condition 2 to condition 1 (Table 2), quantified the extent of stability loss when the participants

174 closed the eyes in standing. Since TKD training does not require the practitioners to balance with eyes
175 closed, TKD participants had no advantage in this testing condition. In light of that, the somatosensory
176 ratio might not be a valid reflection of the TKD participants' ability in using the somatosensory
177 information for balance. Further study should measure the proprioceptive or tactile sensations directly as
178 these have been reported to affect postural control.²⁵

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

184 There were some limitations in this study that need to be considered when interpreting the
185 findings. First, we used a cross-sectional study design (three groups with different ages and TKD
186 experience). It is because previous studies had found that balance functions were different in different age
187 groups^{6,7,14} and no study has investigated the balance functions in young TKD practitioners. This is
188 believed to be the first study attempting to explore the effect of TKD training on the maturation of
189 balance systems in adolescents. However, the limitation with this study design is it is not clear whether
190 the observed differences were due to TKD training or natural predispositions. This would best be tested
191 with a longitudinal study. Second, the training experience varied from one to nine years in our TKD
192 participants, this range is too wide for generalization of the training effect. Further study is needed to
193 confirm the optimal TKD training duration in order to gain the physiological benefits. Finally, based on
194 the Systems model of motor control, development of postural control is a result of interactions among
195 multiple neural and mechanical components² but we have only investigated a part of the many
196 components contributing to balance control. Additional research is needed to examine the other effects of
197 TKD training such as on the development of muscle response synergies, muscle strength, joint range and
198 body morphology.

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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

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