EFFECT OF TAEKWONDO TRAINING ON SENSORI-MOTOR PERFORMANCE AND POSTURAL CONTROL IN CHILDREN WITH AND WITHOUT DEVELOPMENTAL COORDINATION DISORDER

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A thesis submitted in partial fulfillment of the requirements for the degree of

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no materials previously published or written by others, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text. Any contribution made to the researches by others, with whom I have worked at The Hong Kong Polytechnic University, is explicitly acknowledged in the thesis.

I declare the intellectual content of this thesis is derived from discussions between me, Dr William Tsang, Professor Gabriel Ng, Dr Marco Pang and Dr Amy Fu. The data presented herein are the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.

I also declare that some of the data (48 children with DCD and 56 control subjects) in the first study "Sensory organization of balance control in children with developmental coordination disorder" were kindly provided by Dr Marco Pang and his student, Ms Velma Y.L. Lee. These data were previously incorporated into Ms Velma Y.L. Lee's Master of Science thesis, but her main focus was different from mine. Moreover, I added more subjects, obtained different findings and reached different conclusions.

Fong Siu Ming

December 2011

ABSTRACT

Developmental coordination disorder (DCD) is a common motor dysfunction, affecting approximately 6% of children at primary school age. A reported 73% to 87% of children with DCD exhibit balance problems. Suboptimal balance ability demonstrated in a child with DCD requires attention because any impairment in postural control may limit the child's participation in daily activities, increase the risk of falls and affect development of motor skills. Training in dynamic sports such as dancing is reported to improve postural control in young people. Taekwondo (TKD) is a popular sport famous for its fast kicking techniques. Practitioners are frequently required to stand and pivot on one foot. This manoeuvre is of interest as a potential therapeutic activity to improve balance control in children with DCD. However, the effects of TKD training on postural control have not been fully explored, particularly in children with DCD. Therefore, this thesis explores the effects of TKD training on postural control and sensori-motor performance in children with DCD.

Two cross-sectional studies (studies 1 and 2) were conducted to investigate and identify deficits in postural control status, i.e. (1) sensory organization, (2) motor strategy, and (3) standing postural control, in children with DCD. Three additional cross-sectional studies (studies 3 to 5) were then conducted to investigate the potential effects of TKD training in terms of (1) sensory organization, (2) knee joint proprioception, (3) knee muscle strength, and (4) unipedal stance stability, in typically developing adolescents. Finally, a

randomized controlled trial (study 6) was performed to verify the effects of specific TKD exercises on postural control and sensory organization in children with DCD.

Results from studies 1 and 2 revealed that children with DCD rely on somatosensory information for postural control as effectively as typically developing children ($p>0.05$). However, children with DCD were shown to be below their normal counterparts in their ability to integrate visual ($p<0.01$) and vestibular inputs ($p<0.01$), in their motor strategy used under conflicting sensory conditions ($p<0.05$), and in their static bipedal ($p<0.001$), unipedal ($p<0.01$) and functional standing balance ($p<0.001$). When the effects of short-term TKD training were investigated (studies 3 to 5), it was found that trainees were better able than their non-trained counterparts to integrate visual ($p<0.05$) and vestibular inputs ($p<0.05$) under conflicting sensory conditions and better able to control unipedal standing balance ($p<0.05$). Knee muscle strength and joint position sense in the TKD trainees were also found to be greater (effect sizes=0.58-0.88 between short-term TKD trainees and their non-trained counterparts) and more accurate ($p<0.01$), respectively. Results suggest that TKD may be appropriate for balance training in the DCD population. Finally, our main study (study 6, a randomized controlled trial) showed that three-month specific TKD intervention, aimed at improving sensory organization and balance control in children with DCD, yielded favourable results. This is, (1) somatosensory function in children with DCD was not influenced by TKD training ($p>0.05$); however, somatosensory function in children with DCD is normal; (2) TKD training improved visual

function for balance control in DCD-affected children ($p<0.01$), and the effect of training was more profound than the effect of physiological maturation; (3) after the TKD training, less standing sway occurred when only vestibular input was available in children with DCD ($p<0.01$) and the performance was comparable to that of children with normal motor development ($p>0.05$). TKD was therefore considered effective for vestibular training. In addition, (4) unilateral stance stability in children with DCD improved ($p<0.01$) and reached the status of typically developing children after training ($p>0.05$); and (5) although bipedal standing balance improved after TKD training in children with DCD ($p<0.01$), the effect of maturation was more profound than the training effect. Results indicate that clinicians can confidently suggest TKD exercise as a combined therapeutic-leisure activity to improve sensory organization and balance control in children with DCD.

PUBLICATIONS, CONFERENCE ABSTRACTS, AWARD, AND NEWSPAPER ARTICLE ARISING FROM OR RELATED TO THE THESIS

A. Refereed journal articles

1. Fong, S.S.M., & Ng, G.Y.F. (2011). Does Taekwondo training improve physical fitness? *Physical Therapy in Sport*, 12, 100-106. (This paper is not included in the thesis)
2. Fong, S.S.M., & Ng, G.Y.F. (2012). Taekwondo training improves sensory integration and standing balance in young adolescents. *Pediatric Exercise Science*, 24, 142-151. (Chapter 5)
3. Fong, S.S.M., & Ng, S.S.M. (2012). Can Taekwondo Footwear Affect Postural Stability in Young Adults? *Journal of the American Podiatric Medical Association*. In press. (This paper is not included in the thesis)
4. Fong, S.S.M., & Tsang, W.W.N. (2012). The relationship between Taekwondo training duration and lower limb muscle strength in adolescents. *Hong Kong Physiotherapy Journal*, 30, 25-28. (This paper is not included in the thesis)
5. Fong, S.S.M., Fu, S.N, & Ng, G.Y.F. (2012). Taekwondo training improves the development of balance and sensory functions in young adolescents. *Journal of Science and Medicine in Sport*, 15, 64-68. (Chapter 4)
6. Fong, S.S.M., Lee, V.Y.L., & Pang, M.Y.C. (2011). Sensory organization of balance control in children with developmental coordination disorder. *Research in Developmental Disabilities*, 32, 2376-2382. (Chapter 2)

7. Fong, S.S.M., Lee, V.Y.L., Chan, N.N.C., Chan, R.S.H., Chak, W.K., & Pang, M.Y.C. (2011). Motor ability and weight status are determinants of out-of-school activity participation for children with Developmental Coordination Disorder. *Research in Developmental Disabilities*, 32, 2614-2623. (Appendix X)
8. Fong, S. S. M., Tsang, W.W.N., & Ng, G.Y.F. Altered postural control strategies and sensory organization in children with developmental coordination disorder. *Human Movement Science* (2012), doi:10.1016/j.humov.2011.11.003 (Chapter 3)
9. Fong, S.S.M., Tsang, W.W.N., & Ng, G.Y.F. (2012). Taekwondo training improves balance and sensory organization in children with developmental coordination disorder: A randomized controlled trial. *Research in Developmental Disabilities,* 33, *85-95*. (Chapter 7)

B. Manuscripts (submitted/ under revision)

1. Fong, S.S.M., Cheung, C.K.Y., Ip, J.Y., Chiu, J.H.N., Lam, K.L.H., & W.W.N. Tsang. (2012, March) Sport-specific balance ability in Taekwondo practitioners. (Submitted) *Journal of Human Sport and Exercise.* (This paper is not included in the thesis)
2. Fong, S.S.M., Tsang, W.W.N., & Ng, G.Y.F. (2012, April) Lower limb joint sense, muscle strength and postural stability in adolescent Taekwondo practitioners. (Submitted) *Physical Therapy in Sport.* (Chapter 6)
3. Tsang, W.W.N., Guo, X., Fong, S.S.M., Mak, K.K., & Pang, M.Y.C. (2012,

April) Activity participation intensity, but not motor ability, is associated with skeletal development in pre-pubertal children with developmental coordination disorder. (Submitted) *Research in Developmental Disabilities*. (This paper is not included in the thesis)

C. Abstracts, conference presentations and awards

1. Fong, S.S.M., Pang, M.Y.C., Lee, V.Y.L., Chan, N.N.C., Chan, R.S.H., Chak, W.K., & Ng, G.Y.F. (2011). Motor ability and body fatness are determinants of extra-curricular activity participation in children with developmental coordination disorder. *Hong Kong Physiotherapy Journal*, 29, 94.
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14. Fong, S.M., & Tsang, W.N. (2012, July 23-25). Taekwondo training improves balance and sensory organization in children with developmental coordination disorder: A randomized controlled trial. Paper presented at *Third International Conference on Sport and Society*, Cambridge, UK.

D. Reports in newspapers and magazine

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7. Poor balance in children (平衡不好), *iKid magazine*, April 2012.

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PREFACE

Chapter 1 provides some background information and a general introduction to the present series of studies. Chapters 2 to 7 are either published papers (chapters 2, 4, 5 and 7), paper in press (chapters 3) or manuscript submitted/under revision (chapter 6). Full authorship and titles are given below. These papers have been reformatted so that consistency of the thesis format is maintained. This is seen particularly in the style used to cite references and in the order in which the studies are described and results presented (Abstract, Introduction, Methods, Results, Discussion and Conclusion). Moreover, relevant photos and figures have been added. The rationale of each study is presented at the beginning of each chapter and the relevance of each study (studies 1 to 5) as it pertains to the main study (study 6) is clarified at the end of each chapter (chapters 2 to 6). Chapter 8 summarizes the main conclusions of all the studies. The references have been compiled and are given at the end of the thesis in the Reference section.

REFERENCE LIST

Chapter 2 Fong, S.S.M., Lee, V.Y.L., & Pang, M.Y.C. (2011). Sensory organization of balance control in children with developmental coordination disorder. *Research in Developmental Disabilities*, 32, 2376-2382.

Chapter 3 Fong, S. S. M., Tsang, W.W.N., & Ng, G.Y.F. Altered postural control strategies and sensory organization in children with developmental coordination disorder. *Human Movement Science* (2012), doi:10.1016/j.humov.2011.11.003

Chapter 4 Fong, S.S.M., Fu, S.N., & Ng, G.Y.F. (2012). Taekwondo training improves the development of balance and sensory functions in young adolescents. *Journal of Science and Medicine in Sport,* 15, 64-68.

Chapter 5 Fong, S.S.M., & Ng, G.Y.F. (2012). Sensory integration and standing balance in adolescent taekwondo practitioners. *Pediatric Exercise Science,* 24, 142-151.

Chapter 6 Fong, S.S.M., Tsang, W.W.N., & Ng, G.Y.F. (2012, April) Lower limb joint sense, muscle strength and postural stability in adolescent Taekwondo practitioners. (Submitted) *Physical Therapy in Sport.*

Chapter 7 Fong, S.S.M., Tsang, W.W.N., & Ng, G.Y.F. (2012). Taekwondo training improves balance and sensory organization in children with developmental coordination disorder: A randomized controlled trial. *Research in Developmental Disabilities,* 33, *85-95*.

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LIST OF ABBREVIATIONS

°/s	=	Degree per second
Abd	=	Abdominal muscles
ADD	=	Attention deficit disorder
ADHD	=	Attention deficit-hyperactivity disorder
ANCOVA	=	Analysis of covariance
ANOVA	=	Analysis of variance
AP	=	Antero-posterior
BMI	=	Body mass index
BOS	=	Base of support
BOTMP	=	Bruininks-Oseretsky Test of Motor Impairment
CACs	=	Child assessment centres
CAPE	=	Children's Assessment of Participation and Enjoyment
CDP	=	Computerized dynamic posturography
CI	=	Confidence interval
cm	=	Centimeter
CNS	=	Central nervous system
COG	=	Center of gravity
COM	=	Center of mass
COP	=	Center of pressure
COP_{Tstab}	=	Onset of recovery
CTSIB	=	Clinical Test of Sensory Interaction and Balance
DCD	=	Developmental coordination disorder

DSM-IV-TR	=	Diagnostic and Statistical Manual of Mental Disorders 4th Edition
EMG	=	Electromyography
ES	=	Equilibrium score
Gast	=	Gastrocnemius muscle
Ham	=	Hamstrings
ICC	=	Intraclass correlation coefficient
ICF	=	International Classification of Functioning, Disability and Health
ITF	=	International Taekwon-Do Federation
kg	=	Kilogram
lb	=	Pound
LOS	=	Limit of stability
m	=	Meter
MANCOVA	=	Multivariate analysis of covariance
MANOVA	=	Multivariate analysis of variance
Max.	=	Maximum
MCT	=	Motor Control Test
MET	=	Metabolic equivalent
Movement ABC	=	Movement Assessment Battery for Children
Movement ABC-2	=	Movement Assessment Battery for Children - 2nd version
Nm	=	Newton meter
Para	=	Paraspinal muscles
P-CTSIB	=	Pediatric Clinical Test of Sensory Interaction and Balance

PRN	=	Postrotary nystagmus test
Quad	=	Quadriceps
RCT	=	Randomized controlled trial
RD	=	Reading disability
RM	=	Repetition maximum
SD	=	Standard deviation
SH_{max}	=	Greatest horizontal AP shear force in SOT
SH_{min}	=	Lowest horizontal AP shear force in SOT
SI	=	Sensory integration
SLI	=	Specific language impairment
SOT	=	Sensory Organization Test
SPSS	=	Statistical Package for the Social Sciences
SS	=	Strategy score
Tib	=	Tibialis anterior muscle
TKD	=	Taekwondo
UST	=	Unilateral Stance Test
VOR	=	Vestibulo-ocular reflex
WTF	=	World Taekwondo Federation
θ_{max}	=	Greatest AP COG sway angle attained by the participant in the SOT
θ_{min}	=	Lowest AP COG sway angle of the participant in the SOT

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CHAPTER 1: INTRODUCTION

This chapter provides background information for understanding the thesis and the six thesis studies. First, literature on postural control, developmental coordination disorder (DCD) and sport taekwondo (TKD) is reviewed. Second, the choice of research methodology is discussed. Finally, rationales and objectives of the thesis studies are explained.

1.1 Postural control

Postural control involves controlling the body's position in space for the purposes of stability and orientation. It is fundamental to all daily activities (Shumway-Cook & Woollacott, 2007). Impairments in postural control have a profound effect on the daily life of individuals. The consequences include loss of functional independence, increased risk of disability and falls etc. (Shumway-Cook & Woollacott, 2007).

1.1.1 Definitions

'Postural stability' or 'balance' is defined as the ability to control one's 'center of mass' (COM) in relation to the 'base of support' (BOS) (Shumway-Cook & Woollacott, 2007). 'Postural orientation' is defined as the ability to maintain an appropriate relationship between body segments, and between the body and environment, for a task (Horak & Macpherson, 1996). In some reports, the term ‘postural control’ is used interchangeably with ‘postural stability’ (Horak, 1987).

The ‘BOS’ is defined as the area of the body that is in contact with the support surface. The ‘COM’ is defined as the point at the center of the total body mass, which is determined by finding the weighted average of the COM of all body segments. The vertical projection of the COM becomes the ‘center of gravity’ (COG), which differs from the ‘center of pressure’ (COP), i.e. the center of the distribution of the total force applied to the supporting surface. The COP moves continuously around the COM to keep the COM within the BOS, for example, in quiet standing (Shumway-Cook & Woollacott, 2007).

1.1.2 Types of postural control

There are four basic types of postural control: static, reactive, anticipatory and adaptive. These are the foundations of functional balance necessary for many daily activities (Cech & Martin, 2002). The following sections (1.1.2.1 - 1.1.2.4) briefly describe these four types of postural control.

1.1.2.1 Static postural control

Static postural control is required for maintaining quiet postures such as standing. The BOS does not change. Although the term ‘static’ is used, quiet standing involves a small amount of spontaneous sway over the ankles (Shumway-Cook & Horak, 1989). When static balance is maintained in standing, the postural sway does not exceed the COM stability limits (i.e. boundaries of the BOS), and all forces acting on the body are balanced (Cech & Martin, 2002).

1.1.2.2 Reactive postural control

Reactive postural control, also known as feedback control, governs unexpected movement of the COM (e.g. as caused by an unexpected external perturbation) within or outside the BOS. Righting and equilibrium reactions are produced in response to weight shifts within the BOS. When the COM moves out of the BOS, additional automatic postural responses (e.g. step response, protective extension of the arms) occur (Cech & Martin, 2002; Shumway-Cook & Horak, 1989).

1.1.2.3 Anticipatory postural control

Anticipatory postural control refers to the postural response or readiness that is evoked in anticipation of a voluntary movement that is potentially destabilizing. There is a pre-selection of tuning of sensori-motor systems for the upcoming destabilizing events (central set). An example is contraction of para-spinal muscles before reaching, lifting or walking forward for the sake of maintaining stability during movement. Anticipatory postural adjustments require the nervous system to feed information forward to postural muscles to prepare for the movement. Experience and cognition are thus essential in acquiring this type of balance ability (Cech & Martin, 2002; Shumway-Cook & Horak, 1989).

Anticipatory postural adjustment serves three different purposes. First, it keeps postural disturbance at a minimum. Second, it prepares for movement, initiating gait, for example. Third, it assists movement in terms of force or velocity, when throwing a ball, for example (Cech & Martin, 2002).

1.1.2.4 Adaptive postural control

'Postural control under changing task and environmental conditions requires modification of motor strategies in response to new demands' (Shumway-Cook & Horak, 1989). This modification is known as adaptive postural control. For example, one would slow down and shorten one's steps when walking on a slippery surface. As in anticipatory postural control, cognition plays a significant role in adaptive postural control (Cech & Martin, 2002).

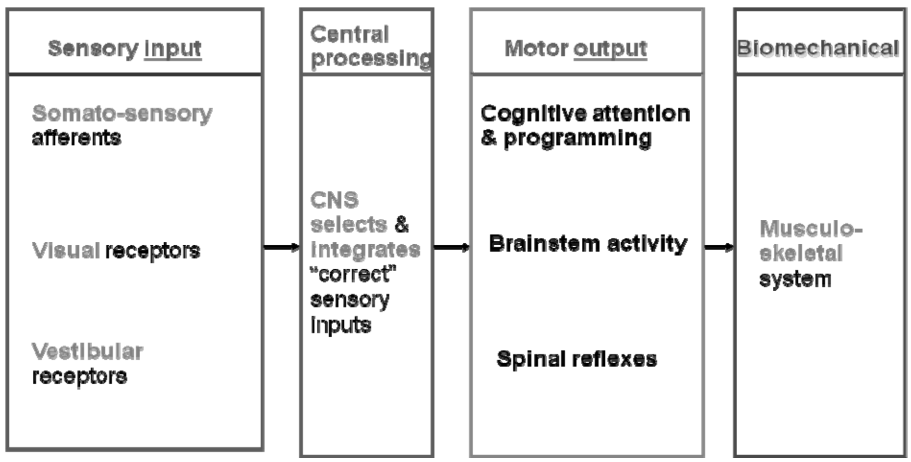
1.1.3 Components of postural control

All types of postural control require complex interaction of many bodily systems, as illustrated in Figure 1.1. According to the systems model, the specific organization of postural systems is determined by both the functional task and the environment in which the task is being performed (Horak, 1987; Horak, 1997; Nashner, 1997; Shumway-Cook & Woollacott, 2007). Disorder of any of these systems will influence the ability to balance in specific contexts. The following sections (1.1.3.1 – 1.1.3.4) briefly describe the different components of postural control: the (1) sensory, (2) central integration, (3) motor, and (4) biomechanical components.

1.1.3.1 Sensory components of postural control

Postural control relies on the central nervous system (CNS) to select and integrate sensory inputs from the somatosensory, visual and vestibular systems and then generate appropriate motor outputs (Nashner, 1997) (Figure 1.1). Each sensory system provides a different frame of reference for postural stability, as described below. All three types of sensory inputs are needed because when one or more of the sensory systems provide misleading or no information to the CNS, inputs from the other systems can compensate so that postural stability is maintained in different environmental conditions (Nashner, 1997).

The somatosensory system, including tactile receptors, deep pressure receptors, joint receptors and muscle proprioceptors, provides the CNS with information about the body’s position and motion with reference to the supporting surface. It also provides information about the relative position of different body segments and is the dominant source of sensory input for maintaining standing balance under normal (fixed) support surface conditions, even with eyes closed (Nashner, 1997; Shumway-Cook & Woollacott, 2007).



CNS: central nervous system

Fig. 1.1 The four components of postural control (Horak, 1987; Nashner, 1997)

The visual system reports information regarding the position and motion of the head with respect to the surroundings and provides a reference for verticality (Nashner, 1997). In addition, the visual system reports motion of the head; when the head moves forward, surrounding objects move in the opposite direction (Shumway-Cook & Woollacott, 2007). It plays a significant role in balance, especially when the support surface is unstable (Nashner, 1997; NeuroCom, 2008). Research shows that peripheral visual information is more important than foveal information for controlling posture (Paillard, 1987).

The vestibular system is the most reliable sensor, especially in challenging conditions (e.g. when both somatosensory and visual inputs are misleading or unavailable) because it does not rely on external references for postural control. Rather, it measures position and movement of the head in relation to inertial forces or gravity (Nashner, 1997; Shumway-Cook & Woollacott, 2007). The vestibular receptors in the semicircular canals and the otoliths are sensitive to angular and linear acceleration of the head, respectively (Horak & Macpherson, 1996). Apart from its role in balance, the vestibular system transmits information that triggers the vestibulo-ocular reflex (VOR), which is important for stabilizing visual images on the retina during head and body movements by rotating the eyes in the direction opposite to head movement (Tanguy, 2008).

1.1.3.2 Central integration of sensory information and neural systems for postural control

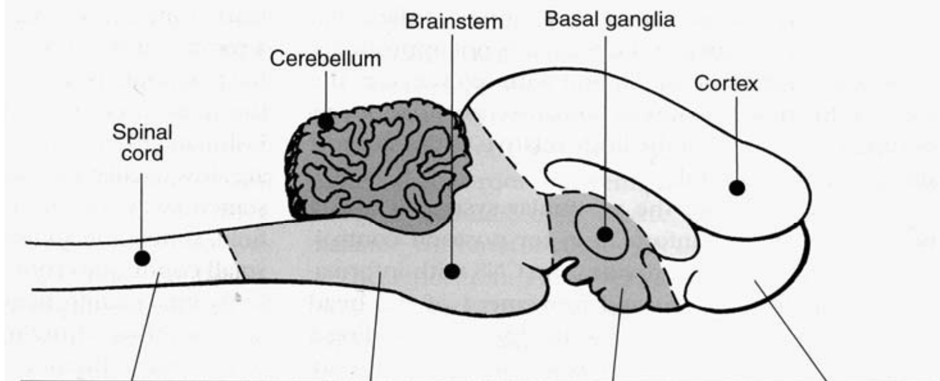
How does the CNS organize sensory information from the somatosensory, visual and vestibular systems for postural control? Studies suggest that when all three senses are present, they each contribute to postural control during quiet standing. However, the CNS may rely more heavily on somatosensory information for postural control than on visual or vestibular inputs in response to perturbation to stability (Shumway-Cook & Woollacott, 2007). When standing under conflicting sensory conditions in which there is disagreement among sensory inputs, the CNS modifies the weight, or importance, of a sensory input, depending on its relative accuracy as a sensory input for orientation (i.e. the CNS resolves sensory conflicts). For example, as vision becomes less reliable as an indicator of self-motion, visual input is weighted less heavily and somatosensory cues are weighted accordingly for postural control. This reweighting of sensory inputs to optimize stance in altered sensory environments is known as the sensory weighting hypothesis (Oie et al., 2002; Shumway-Cook & Woollacott, 2007). The relative weight given to a sense varies as a function of age, task and/or environment (Jeka & Lackner, 1994; Jeka & Lackner, 1995; Kuo et al., 1998; Nashner, 1976; Nashner, 1982).

What then are the neural structures that contribute to sensory organization and postural stability? Figure 1.2 summarizes the contributions of the brain and spinal cord to postural control.

1.1.3.3 Motor components of postural control

Postural stability requires not only integration and selection of reliable sensory information but also appropriate motor responses (Figure 1.1). The motor responses can be classified as (1) reflexive, (2) automatic and (3) voluntary postural movements (Nashner, 1997). Table 1.1 summarizes the characteristics of these three movement systems.

Of the three movement systems involved in balance, automatic postural movements are the earliest functionally effective responses helping to maintain stability when a standing individual's balance is perturbed. The automatic postural movements can be coordinated into three different strategies, i.e. ankle, hip and stepping strategies, to maintain antero-posterior (AP) stability in standing (Cherng et al., 2007; Nashner, 1997) (Figure 1.2).



Spinal preparation	Brainstem level	Basal ganglia/cerebellum	Intact system
Ground reaction forces for orientation present though diminished Tonically active extensor muscle for antigravity support for postural orientation No lateral stability Somatosensory contributions to postural control	Controls level of postural tone in combination with cerebellum Circuits for automatic postural synergies (hypothesized) Vestibular contributions to postural control	*Cerebellum* Control of adaptation — abilities to modify postural muscle amplitude in response to changing task and environmental conditions *Basal ganglia* Control of postural set—ability to quickly change muscle patterns in response to changing task and environmental conditions	Adaptable postural control system to meet the goals of stability and orientation in any environment Visual contribution to postural control

Fig. 1.2 Contributions of the neural systems to postural control

[Adapted from Shumway-Cook, A., & Woollacott, M.H. (2007). Development of postural control. In A. Shumway-Cook, & M.H. Woollacott (3rd ed.), *Motor control translating research into clinical practice* (pp. 175). Philadelphia: Lippincott Williams and Wilkins.]

Table 1.1 Characteristics of the three movement systems (Nashner, 1997)

	Movement system		
	Reflexive	**Automatic**	**Voluntary**
Mediating pathways	Spinal cord	Brain stem and subcortical	Brain stem and cortical
Mode of activation	External stimulus	External stimulus	Self-generated or external stimulus
Responses	Localized to point of stimulus, highly stereotyped	Coordinated among leg and trunk muscles, and stereotyped but adaptable	Unlimited variety
Role in postural control	Regulates muscle forces or stiffness	Coordinate movements across joints and muscles	Generates purposeful behaviors
Response times (muscle reflex latencies)	Fixed at 40 ms	Fixed at 100 ms	Varied, 150+ ms

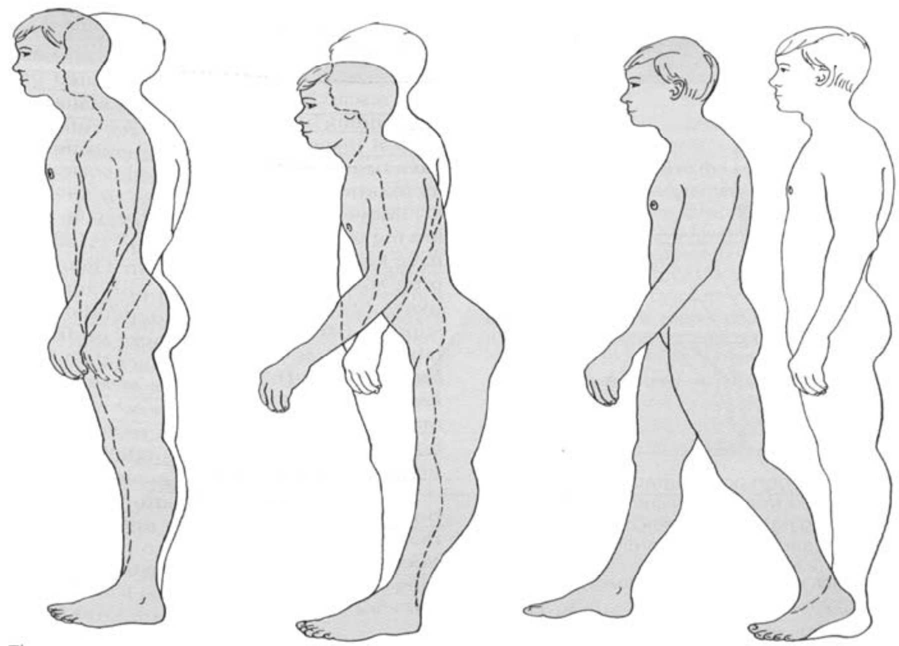
ms: millisecond

The ankle strategy shifts the COG while maintaining placement of the feet by rotating the body as an approximately rigid mass about the ankle joint (Figure 1.3). It appears to be used most commonly when the external perturbation is small and the support surface is firm. The hip strategy describes postural movements that are centered about the hip joints with opposing ankle joint rotations, as shown in Figure 1.3. The COG shifts in the direction opposite the hip joint because of the inertia of the trunk, generating an opposite horizontal shear reaction force against the support surface. The hip strategy is commonly used to restore equilibrium in response to larger and faster perturbations, or when the support surface is compliant or shorter than the feet. However, a combination of hip and ankle strategies is usually used when individuals respond to different kinds of perturbations. Sometimes, if the perturbation is too great and the above two strategies are not sufficient to restore balance, the stepping strategy (stumbling reaction) is used to realign the COM over the BOS to prevent a fall (Horak & Macpherson, 1996; Nashner, 1997; Shumway-Cook & Woollacott, 2007) (Figure 1.3) (Shumway-Cook & Woollacott, 2007).

The motor strategy selected for maintaining body balance depends on the individual's past experience. The pattern cannot be changed voluntarily by instruction alone, even if the individual is familiar with and motivated to change it. Moreover, the pattern of movements strongly influences the visual and vestibular inputs contributing to balance (i.e. sensori-motor interaction occurs) (Nashner, 1997).

1.1.3.4 Biomechanics of coordinated movement for postural control

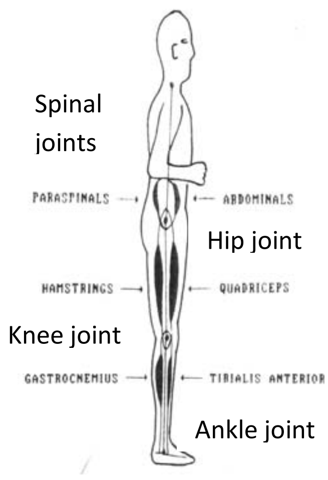
Postural movements involve the coordinated actions of many leg and trunk muscles that produce torque (Nashner, 1997). Adequate joint range, muscle strength and tone are prerequisites for movement against gravity and postural control (Cech & Martin, 2002; Horak, 1987). The major joints and muscles controlling the COG in the AP direction during static and perturbed stance (response to brief displacements of the supporting surface) are illustrated in Figure 1.4, whereas Figure 1.5 shows muscle torque data from a normal adult recovering balance after exposure to a backward platform perturbation. These are examples of the biomechanical components of postural control.



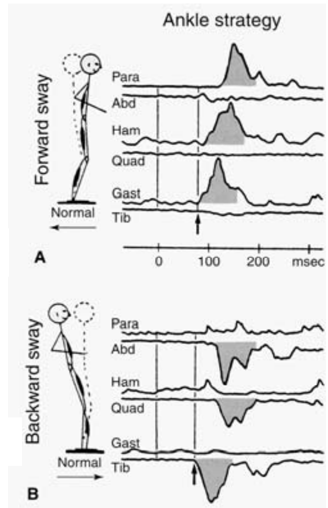
Ankle strategy Hip strategy Stepping strategy

Fig. 1.3 The three motor strategies used by normal adults to control upright body sway

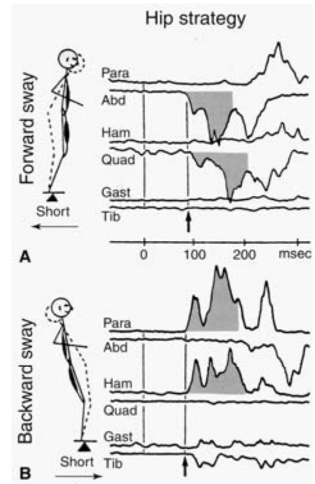
[Adapted from Shumway-Cook, A., & Horak, F.B. (1989). Vestibular rehabilitation: an exercise approach to managing symptoms of vestibular dysfunction. *Seminars in Hearing*, 10, 196-205.]



Major joint and muscle systems controlling COG movement during static standing (Nashner, 1997)



Muscle synergies (EMG signals) and joint motions associated with ankle strategy for controlling AP sway (Horak & Nashner, 1986)



Muscle synergies (EMG signals) and joint motions associated with hip strategy for controlling AP sway (Horak & Nashner, 1986)

Para: paraspinal muscles; Abd: abdominal muscles; Ham: hamstrings; Quad: quadriceps; Gast: gastrocnemius muscle; Tib: tibialis anterior muscle;

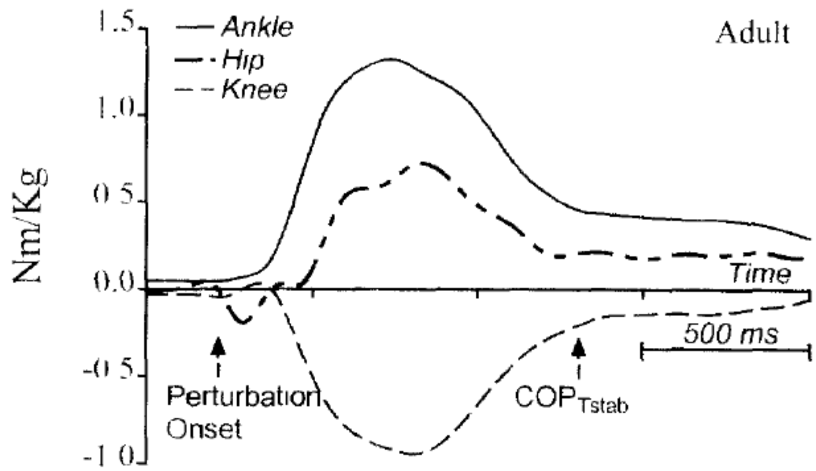
Normal: supporting surface is longer than the feet/ normal;

Short: supporting surface is shorter than the feet;

AP: Antero-posterior; EMG: Electromyography

Fig. 1.4 Major joint and muscle systems controlling movement of the body's COG during static standing and used to recover stability in the sagittal plane

[Adapted from Horak, F., & Nashner, L. (1986). Central programming of postural movements: adaptation to altered support surface configurations. *Journal of Neurophysiology*, 55, 1372. & Nashner, L.M. (1997). Computerized dynamic posturography. In G.P. Jacobson, C.W. Newman, & J.M. Kartush. *Handbook of balance function and testing* (pp. 270). St. Louis: Mosby Year book.]



COP_{Tstab}: onset of recovery

Fig. 1.5 Lower limb muscle torque data from an adult recovering balance after exposure to a backward platform perturbation. The ankle and hip torques were extensor (positive) and largely responsible for resisting gravity. Knee torque was flexor (negative) because it counterbalanced the extensor muscle torques generated about the ankle and hip

[Adapted from Roncesvalles, M.N.C., Woollacott, M.H., & Jensen, J.L. (2001). Development of lower extremity kinetics for balance control in infants and young children. *Journal of Motor Behavior*, 33(2), 180-192.]

1.2 Development of postural control in children and adolescents

The postural control functions and components summarized above (section 1.1) characterize mature adults. These balance systems and abilities develop in sequence and at different rates in children and adolescents. Indeed, the development of postural control is critical to the acquisition of many complex motor skills in children. Studies have found that postural control is essentially adult-like by age seven to ten years, when children have acquired most motor skills (Shumway-Cook & Woollacott, 2007). Development of the different aspects of postural control in children and adolescents is summarized below.

1.2.1 Development of different types of postural control

Regarding spontaneous sway in static standing, children sway more rapidly and in larger amplitudes than adults (Shumway-Cook & Woollacott, 2007). Sway velocity in quiet standing decreases to adult level by age nine to twelve years when standing with eyes opened and by 12 to 15 years when standing with eyes closed (Taguchi & Tada, 1988). This can be attributed to the fact that young children use a high-velocity balance strategy (i.e. large, fast corrections to the COP when they attempt to maintain the COM within the BOS) (Riach & Starkes, 1994), and they have a higher COM than adults, relative to their height (Lebiedowska & Syczewska, 2000).

For development of reactive postural control in standing, young children (15 months of age), in comparison to adults, show more variable and slower muscle responses to platform perturbation (Forssberg & Nashner, 1982). In addition, amplitudes of the muscle responses are larger and muscle reflex latencies are longer in children (1.5 to 3 years of age) than in adults (Shumway-Cook & Woollacott, 1985). Kinetic analysis also shows that young children (9 to 23 months of age) use multiple torque adjustments at the lower limb joints when recovering from balance threat; this is in contrast to adults who use rapid, large torques to regain balance control (Roncesvalles et al., 2001). All these factors may contribute to the inferior reactive balance control observed in children. Children's postural responses become comparable to adults' at seven to ten years of age (Shumway-Cook & Woollacott, 1985).

Anticipatory postural control in standing matures at a relatively young age (four to six years) (Nashner et al., 1983; Wollacott & Shumway-Cook, 1986) in comparison to static postural control (nine to twelve years of age) (Taguchi & Tada, 1988) or reactive postural control (seven to ten years of age) (Shumway-Cook & Woollacott, 1985). In standing, infants (ten months of age) are able to activate postural muscles in advance of arm movements, but the muscle activities are highly inconsistent. By 15 months of age, young children begin to show consistent anticipatory postural muscle activities in dynamic standing (Witherington et al., 2002).

1.2.2 Development of the sensory components and integration of postural control

Apart from the different types of postural control, sensory systems and sensory organization needed for balance control also develop at different rates in children and adolescents (Woollacott & Shumway-Cook, 1990; Woollacott & Shumway-Cook, 1994). Some studies have reported that somatosensory function matures by nine to twelve years of age (Cherng et al., 2001; Riach & Hayes, 1987), whereas other studies have found that maturation of somatosensory function occurs much earlier at three to four years of age (Cumberworth et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006).

The reported maturation times of visual function, also differ. Cherng and colleagues found that children (seven to ten years of age) use vision for standing balance with the same efficiency as adults (Cherng et al., 2001; Cherng et al., 2003). However, Hirabayashi and Iwasaki (1995) and Cumberworth et al. (2007) reported that visual function matures as late as 15 years of age.

Although previous studies agree that, of the three sensory functions involved in balance, vestibular function develops most slowly, the reported maturation times for this function differ. Shumway-Cook & Woollacott (1985 & 2007) suggested that by age seven, children are able to balance efficiently with vestibular cues only. However, some researchers have reported that vestibular function is not fully developed until age 15 to 16 (Cumberworth et al., 2007; Ionescu et al., 2006; Steindl et al., 2006). Thus, no consensus has been reached on the timing of maturation of these three sensory systems for postural control.

1.2.3 Development of the motor components of postural control

Postural stability in adults requires not only integration and selection of reliable sensory information but also appropriate motor responses, as noted in section 1.1.3.3. This is also true in children and adolescents. However, the motor responses for postural control develop at different rates in children. The ankle strategy develops properly (with a distal to proximal muscle activation pattern) at nine to eleven months when the infant begins to stand independently (Sveistrup & Woollacott, 1996; Woollacott & Sveistrup, 1992). The hip strategy (mature pattern with consistent active control) develops much later, between seven and ten years of age when the child starts to skip. Younger children demonstrate the ability to sway on the ankles and hips, but the patterns are immature (i.e. different sequence of muscle activation or inactivation of essential muscles) (Roncesvalles et al., 2003; Woollacott et al., 1998).

Development of the stepping strategy is not well described in the literature. However, toddlers can walk independently at around 11.5 months of age (Okamoto et al., 2003) and can walk with a more mature gait pattern at four to five years of age (Adolph et al., 2003). Thus, the stepping strategy might develop at around age one and might be more effective at around four to five years of age (Adolph et al., 2003). Indeed, Roncesvalles et al. (2000) report that the ability to take a corrective step to recover balance is not yet available in new standers and walkers (9 to 19 months of age). According to Roncesvalles et al. (2000), the stepping strategy begins to develop in infants (9 to 19 months of age) with one to three months of walking experience and is refined by six months of walking experience.

1.2.4 Development of the biomechanical components of postural control

Changes in biomechanics and body morphology during infancy and childhood also significantly affect postural stability. For example, the COM is relatively high in children (T12 level) versus adults (L5-S1 level). With their larger head and shorter height, children (younger than seven years), in comparison to adults, sway at a faster rate and closer to their LOS in static standing (Bradley & Westcott, 2006; Lebiedowska & Syczewska, 2000). Moreover, the change in alignment of the lower limbs may somehow affect postural stability: younger children (18 months of age) stand with genu varum, but three-year-old children stand with genu valgum. The legs do not straighten out until age six (Staheli, 1998).

Not all components of postural control develop at the same rate. Muscle strength was once suggested to be the component that develops most slowly and is thus a rate limiting factor for postural control. However, more recent study disputes this claim (Woollacott & Shumway-Cook, 1994). Further studies are needed to confirm whether this biomechanical component affects postural control.

1.2.5 Other factors affecting the development of postural control

According to the dynamic systems model, development of postural control results from the interaction of multiple systems including somatosensory, visual and vestibular systems; postural muscle response synergies; adaptive systems that modify sensori-motor systems to changes in task or environment; muscle strength; joint range of motion; and body morphology (Woollacott & Shumway-Cook, 1990). Practice and experience (i.e. environment and task demands) also shape the postural responses in developing individuals (Cech & Martin, 2002; Woollacott & Shumway-Cook, 1990).

Moreover, sex may affect the rate of development of the balance systems. Boys may lag behind somewhat in terms of developing static standing balance control (Nolan et al., 2005). One should take these potential confounding factors into account when assessing balance ability in children.

Figure 1.6 summarizes the emergence of adult levels of different aspects of postural control. The rate of development varies among the balance systems.

1.3 Assessment of postural control in children and adolescents

As early as 1851, Romberg (1853) used balance tests to assess static standing skills. Many tools have since been developed to describe and measure balance (Donahoe et al., 1994). Table 1.2 summarizes the common balance tests used by pediatric physical therapists.

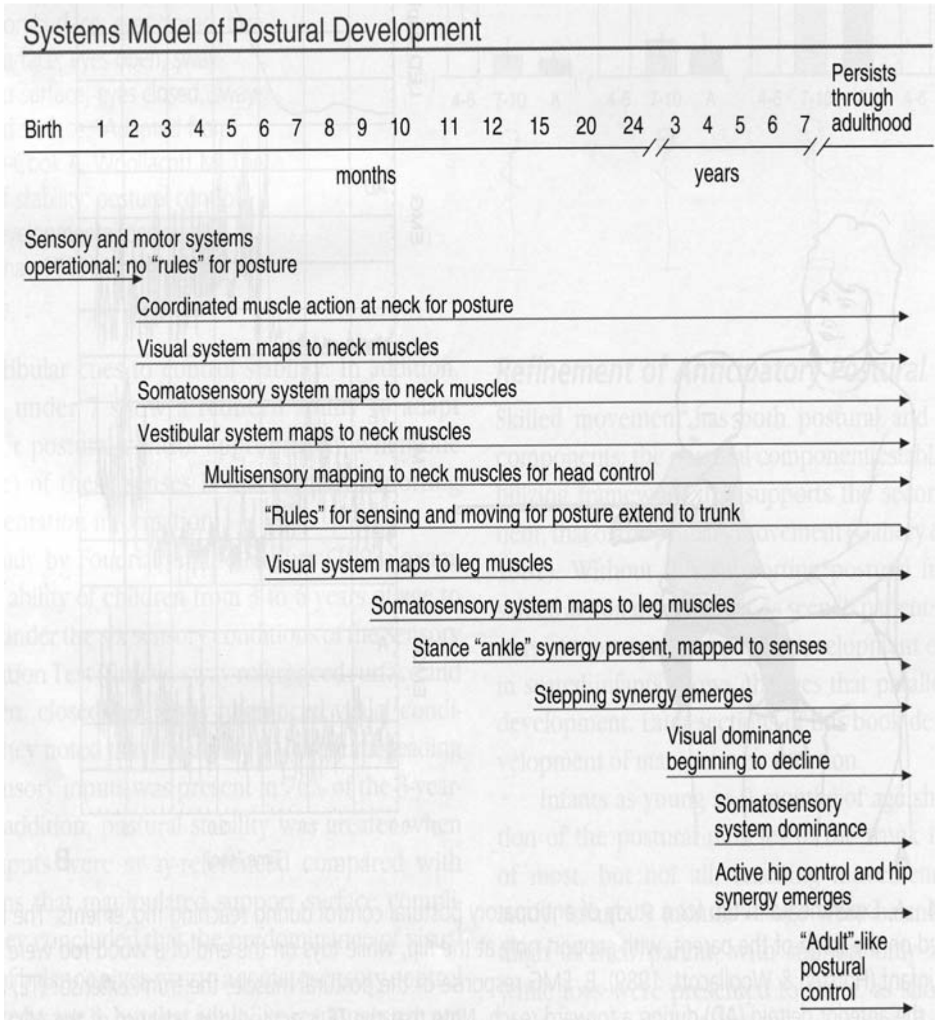


Fig. 1.6 Development of postural control systems (based on the systems model)

[Adapted from Shumway-Cook, A., & Woollacott, M.H. (2007). Development of postural control. In A. Shumway-Cook, & M.H. Woollacott (3rd ed.), *Motor control translating research into clinical practice* (pp. 208). Philadelphia: Lippincott Williams and Wilkins.]

Table 1.2 Common tests of postural stability in children and adolescents (Westcott et al., 1997)

Test	Outcome measures
• Computerized dynamic posturography (CDP) [e.g. Sensory Organization Test (SOT), Motor Control Test (MCT)] (Gagnon et al., 2006)	• COP sway by sensory conditions (equilibrium scores), sensory ratios, motor strategy scores, electromyography (EMG) timing, amplitude, sequence etc.
o Pediatric Clinical Test of Sensory Interaction for Balance (P-CTSIB) (Gagnon et al., 2006)	o Time/sway, sensory system scores, strategy used (ankle, hip, step or crouch)
• Romberg Test (Newton, 1989)	• Sway
o Tiltboard Test (Atwater et al., 1990)	o Tilt angle
• Standardized tests [e.g. Bruininks-Oseretsky Test of Motor Impairment (BOTMP), Movement Assessment Battery for Children (Movement ABC)] (Bruininks, 1978; Henderson et al., 2007)	• Motor skills performance including balance
o Functional Reach Test (Donahoe et al., 1994)	o Distance reached

The following balance and impairment tests were selected to measure the different aspects of postural control in children or adolescents in the thesis studies described herein. They are commonly used both clinically and for research purpose (to obtain accurate and objective outcome variables). A description of these assessments is presented below.

1.3.1 Sensory Organization Test (SOT)

Sensory organization refers to the ability of an individual to select information from among the three sensory systems and identify the most accurate input for maintaining postural stability. Sensory organization is commonly measured by the Smart Equitest® Computerized Dynamic Posturography machine (NeuroCom International Inc., Clackamas, OR, USA). During the SOT, postural sway is measured in response to various somatosensory and visual conditions. This permits systematic study of somatosensory, visual and vestibular inputs used for postural stability and orientation (Nashner, 1997; NeuroCom, 1992; NeuroCom, 2008). The individual stands on a computer-controlled movable force platform facing the center of a three-sided movable visual enclosure (Figure 1.7). The support surface and visual surroundings can be rotated in proportion to body sway, thus providing inaccurate somatosensory and visual inputs regarding orientation of the body's COM (Figure 1.8). Body (COP) sway is measured while the individual stands for 20 seconds under each of six sensory conditions (Figure 1.8):

(1) eyes opened, fixed support surface (all three sensory systems providing accurate information about body position);

(2) eyes closed, fixed support surface (only somatosensory and vestibular information are available);

(3) visual conflict, fixed support surface (sensory conflict due to inaccurate visual information but accurate somatosensory and vestibular information);

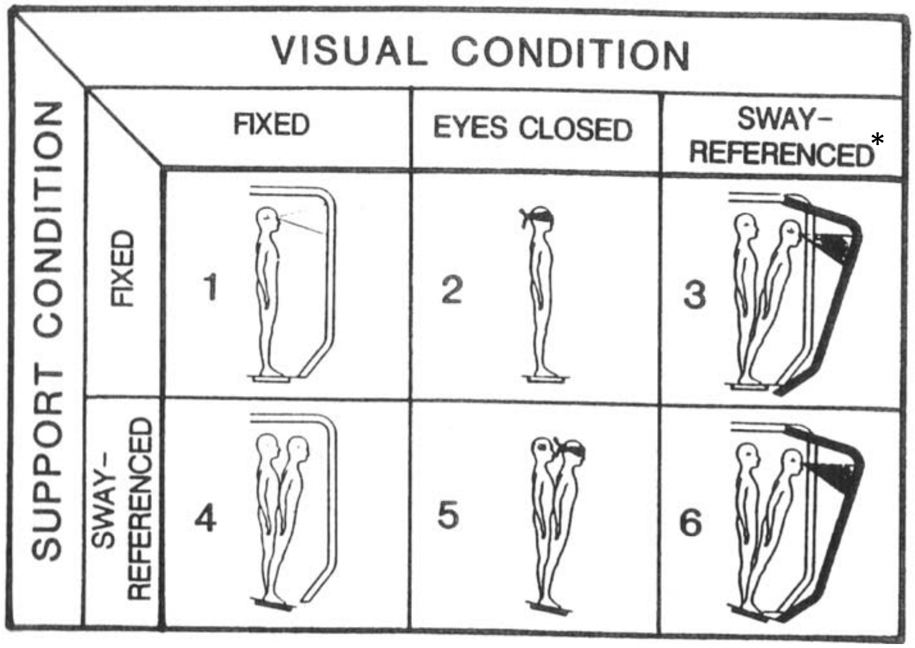
(4) eyes opened, somatosensory conflict (sensory conflict due to inaccurate somatosensation);

(5) eyes closed, somatosensory conflict (no vision and inaccurate somatosensation. Vestibular information must be used);

(6) visual conflict, somatosensory conflict (only vestibular system providing accurate information).

The complete testing protocol consists of eighteen 20-second trials, three consecutive trials for each of the six sensory conditions. The individual is instructed to ignore any surface or visual surround motion and remain upright and as steady as possible (Nashner, 1997; NeuroCom, 1992; NeuroCom, 2008).

Fig. 1.7 The individual being tested stands with bare foot on the platform of the Computerized Dynamic Posturography machine (Smart Equitest® system, NeuroCom International Inc., Clackamas, Oregon, USA) and wears a security harness to prevent falls (NeuroCom, 1992; NeuroCom, 2008)



*Sway-referenced condition: Tilting of the support surface and/ or the visual surround about an axis co-linear with the ankle joints to directly follow the patient's COG sway in the AP direction. Although the somatosensory and visual systems continue to provide information during sway-referenced conditions, these inputs contain no functionally useful information regarding orientation of the body COM relative to the vertical gravity line. Healthy individuals ignore sway-referenced sensory input that is functionally inaccurate and maintain balance using the other sensory inputs (Nashner, 1997).

Fig. 1.8 The six sensory conditions of the Sensory Organization Test

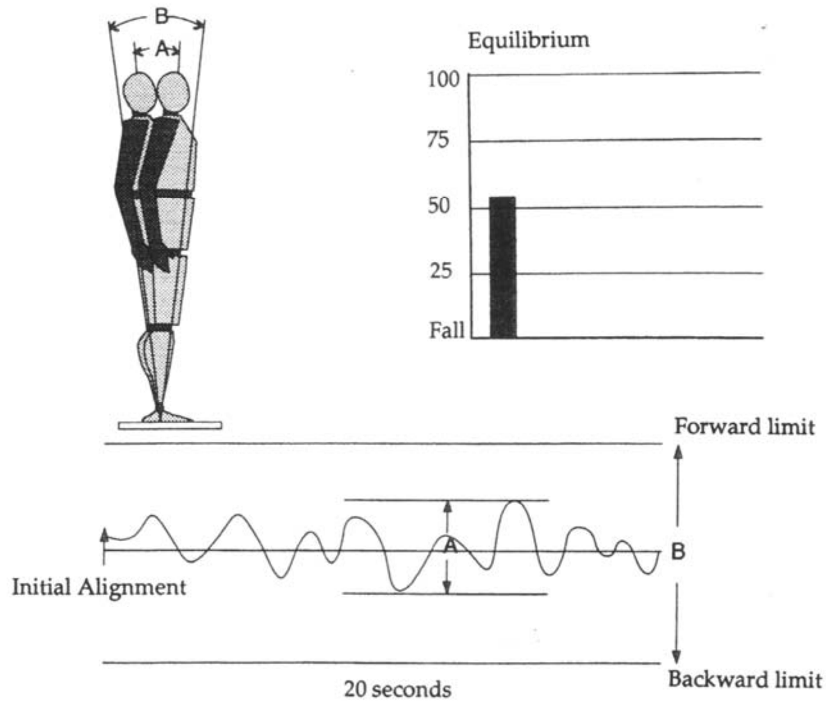
[Adapted from Nashner, L.M. (1997). Computerized dynamic posturography. In G.P. Jacobson, C.W. Newman, & J.M. Kartush. *Handbook of balance function and testing* (pp. 296). St. Louis: Mosby Year book.]

1.3.1.1 Equilibrium score

An equilibrium score (ES) is calculated for each trial, and a composite ES, which is the average of all eighteen equilibrium scores, is derived. The composite ES reflects the overall level of performance on the SOT. As shown in Figure 1.9, the ES is a non-dimensional percentage that compares the individual's peak amplitude of AP sway ('A' in Figure 1.9) to the theoretical AP limit of stability (LOS) ('B' in Figure 1.9, 8.5° anteriorly and 4.0° posteriorly = total 12.5°). The ES is calculated by the NeuroCom software according to the following formula:

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

where θ_{max} is the greatest AP COG sway angle attained by the individual, and θ_{min} is the lowest AP COG sway angle. An ES of 100 represents no sway (excellent balance control), whereas 0 indicates sway exceeding the LOS, resulting in a fall (Nashner, 1997; NeuroCom, 1992; NeuroCom, 2008).



A: Maximum AP sway angle of the individual being tested;

B: Theoretical LOS in the AP direction (12.5°);

COG: center of gravity;

ES: equilibrium score;

LOS: limit of stability

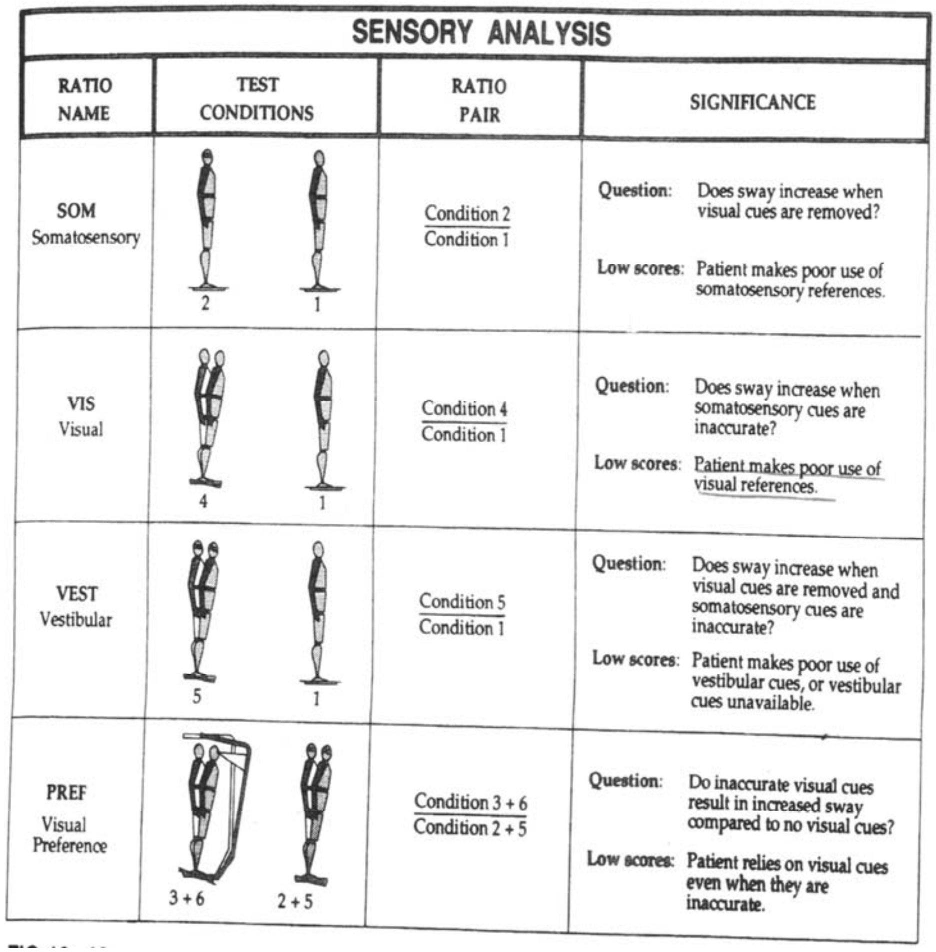
Fig. 1.9 Method for deriving the ES from the raw COP sway data of a 20-second-trial. As sway angle (A) increases from 0 toward the LOS (B), the ES decreases from 100 (i.e. perfect stability) toward 0 (i.e. loss of balance)

[Adapted from Nashner, L.M. (1997). Computerized dynamic posturography. In G.P. Jacobson, C.W. Newman, & J.M. Kartush. *Handbook of balance function and testing* (pp. 297). St. Louis: Mosby Year book.]

1.3.1.2 Sensory organization analysis

Three sensory ratios are commonly used to identify the contribution of each sensory system, namely the somatosensory, visual and vestibular inputs, to balance control. The somatosensory ratio, which compares the ES of condition 2 to that of condition 1, quantifies the extent of stability loss when the individual being tested closes the eyes. An atypically low ratio is interpreted as somatosensory input dysfunction; somatosensory input normally dominates the control of balance during stance on a fixed support surface. The visual ratio compares the ES of condition 4 to that of condition 1. It quantifies the extent of stability loss when the normally dominant somatosensory input is disrupted by sway-referencing of the support surface. A lower-than-normal ratio is interpreted as dysfunction of the visual sense of balance. The vestibular ratio comparing the ES of condition 5 to that of condition 1 reflects a relative reduction in stability when visual and somatosensory inputs are disrupted simultaneously. As with the other two sensory ratios, a lower-than-normal ratio is interpreted as dysfunction of the vestibular sense of balance (Nashner, 1997; NeuroCom, 1992; NeuroCom, 2008) (Figure 1.10).

The SOT also provides a visual preference ratio derived from the ES. This ratio compares the sum of condition 3 ES and condition 6 ES to the sum of condition 2 ES and condition 5 ES (Figure 1.10). It reflects the relative reduction in stability under sway-referenced visual condition versus the equivalent eyes-closed condition. A lower-than-normal ratio is interpreted as an abnormal preference for relying on vision (Nashner, 1997).



SENSORY ANALYSIS			
RATIO NAME	**TEST CONDITIONS**	**RATIO PAIR**	**SIGNIFICANCE**
SOM Somatosensory	2 1	Condition 2 / Condition 1	**Question:** Does sway increase when visual cues are removed? **Low scores:** Patient makes poor use of somatosensory references.
VIS Visual	4 1	Condition 4 / Condition 1	**Question:** Does sway increase when somatosensory cues are inaccurate? **Low scores:** Patient makes poor use of visual references.
VEST Vestibular	5 1	Condition 5 / Condition 1	**Question:** Does sway increase when visual cues are removed and somatosensory cues are inaccurate? **Low scores:** Patient makes poor use of vestibular cues, or vestibular cues unavailable.
PREF Visual Preference	3 + 6 2 + 5	Condition 3 + 6 / Condition 2 + 5	**Question:** Do inaccurate visual cues result in increased sway compared to no visual cues? **Low scores:** Patient relies on visual cues even when they are inaccurate.

Fig. 1.10 Sensory ratios and their functional meanings. A high score of close to 1 indicates that the participant has superior ability in using that particular sensory input for balance

[Adapted from Nashner, L.M. (1997). Computerized dynamic posturography. In G.P. Jacobson, C.W. Newman, & J.M. Kartush. *Handbook of balance function and testing* (pp. 301). St. Louis: Mosby Year book.]

1.3.1.3 Motor strategy analysis

The computerized dynamic posturography machine also detects shear forces in the AP direction. When the individual sways from the ankles, the associated low-frequency motions of the COG generate relatively little horizontal shear force against the supporting platform (force plate). In contrast, higher frequency hip and trunk movements generate small but rapid shifts in COG position and much larger horizontal forces against the force plate. The relative amounts of ankle and hip movements adopted by an individual are determined by comparing the peak-to-peak amplitude of the horizontal shear force to a theoretical limit for normal individuals of similar weight, giving rise to the motor strategy score. This strategy score (**SS**), like the ES, is calculated by the NeuroCom software. It quantifies the amount of ankle and hip movements the individual uses to maintain balance during each 20-second trial, according to the following formula:

$$\text{Strategy score} = [1 - (SH_{max} - SH_{min}) / 25] \times 100$$

In this formula, 25 is the difference (in lbs) measured between the greatest horizontal AP shear force (SH_{max}) and the lowest horizontal AP shear force (SH_{min}) generated by a group of normal individuals who used hip sway only when balancing on a narrow beam. The peak-to-peak horizontal AP shear force measured during the test interval is normalized to 25 lb of shear force. A strategy score approaching 100 indicates that the individual uses mainly the ankle strategy to maintain equilibrium, whereas a score near 0 reveals that the individual uses mainly the hip strategy. Scores between 0 and 100 represent a combination of these two strategies (Nashner, 1997; NeuroCom, 1992; NeuroCom, 2008).

Nowadays, the SOT is widely used to document developmental changes in sensory organization in children with and without disabilities (Nashner, 1997; Westcott et al., 1997). Results have been found to be reliable (Table 1.3) (Fong & Ng, 2012) and valid (good construct validity and moderate to good concurrent validity) (Westcott et al., 1997; Gagnon et al., 2006) in the pediatric population. Therefore, we incorporated the SOT in our studies. However, the SOT is not a direct measure of the individual sensory systems engaged in active postural control. Other tests such as the vestibular function test, neurotologic examination, postrotary nystagmus (PRN) test (Grove & Lazarus, 2007), and joint proprioceptive tests should be used to supplement and rule out individual sensory system problems.

Table 1.3 Test-retest reliability of sensory organization test and unilateral stance test in adolescents (Fong & Ng, 2012)

Testing conditions	$ICC_{3,1}$	95% CI	p value
Unilateral stance test COP sway velocity	0.77	0.56-0.89	<0.001
SOT Condition 1 ES	0.50	0.08-0.74	0.012
SOT Condition 2 ES	0.68	0.41-0.83	<0.001
SOT Condition 3 ES	0.55	0.18-0.77	0.004
SOT Condition 4 ES	0.64	0.35-0.82	<0.001
SOT Condition 5 ES	0.77	0.58-0.88	<0.001
SOT Condition 6 ES	0.60	0.27-0.79	0.001
SOT Condition 1 SS	0.32	-0.61-0.75	0.184
SOT Condition 2 SS	0.77	0.44-0.92	0.001
SOT Condition 3 SS	0.43	-0.37-0.79	0.104
SOT Condition 4 SS	0.06	-1.24-0.66	0.429
SOT Condition 5 SS	0.72	0.32-0.90	0.002
SOT Condition 6 SS	0.88	0.72-0.96	<0.001

1.3.2 Test of joint proprioception

Lower limb joint proprioception is a part of the somatosensory system that directly affects balance ability (Tsang & Hui-Chan, 2003 & 2004b). Therefore, lower limb joint proprioception was also assessed in our study. Common methods for testing joint proprioception include (1) testing the threshold for detecting joint movement, (2) joint position matching with the contralateral limb, and (3) limb segment repositioning, all of which can be tested in either a passive or an active mode, in non-weight- or weight-bearing positions (Tsang & Hui-Chan, 2004b). However, the passive mode with a non-weight-bearing position is preferred because it can minimize the motor contribution, which has been found to aid proprioceptive acuity (Ashton-Miller et al., 2001). The testing procedure is described in chapter 6 (study 5). The test-retest reliability was found to be good in adults in our previously reported study ($ICC_{3,3}$ 0.775; 95% CI: 0.638-0.866) (Fong & Ng, 2006) and the concurrent validity is found to be moderate (Grob et al., 2002).

1.3.3 Isokinetic muscle strength test

Apart from sensory organization and knee joint proprioception, knee muscle strength was also assessed in our study (study 5) because it is related to balance control in standing (Bressel et al., 2007; Horak, 2006; Tsang & Hui-Chan, 2004a; Tsang & Hui-Chan, 2004b). Muscle strength can be evaluated by many different methods such as isometric manual muscle testing, isotonic testing of repetition maximum (RM), field test (e.g. vertical jump) and isokinetic testing (Brown & Weir, 2001). Of these methods, isokinetic testing is the most reliable and accurate for documenting muscle strength and is thus widely used in research. The reliability of isokinetic measurement of muscle strength in children and adolescents has been studied extensively and found to be good to perfect (ICC ranged between 0.78 to 0.99 for quadriceps and hamstrings) (Gilliam & Vilanacci, 1979; Merlini et al., 1995; Molnar et al., 1979; Tabin et al., 1985; Weltman & Tippett, 1988).

A wide range of outcome variables is available for isokinetic data analysis. Of these, peak torque is particularly important for muscle strength analysis. Peak torque is defined as the product of mass, acceleration and lever arm length. It is the maximum torque produced anywhere in the range and is easily identified as the peak of the torque curve in the isokinetic report. It provides researchers with information regarding the greatest torque output of the limb tested, and it is an excellent indicator of the tested individual's maximum strength level. However, it does not take joint range into account (Brown & Weir, 2001; CSMI, 2005).

1.3.4 Movement Assessment Battery for Children-2

The Movement Assessment Battery for Children-2 (Movement ABC-2) is a standardized tool used to measure motor performance of children in three age ranges: 3 to 6 years, 7 to 10 years, and 11 to 16 years. The assessment consists of eight tasks that are divided into three domains: manual dexterity, aiming and catching, and balance. Test items in the balance domain, in particular, include both static and dynamic balance tasks such as single-leg standing, tandem walking and hopping (Table 1.4 & Appendix III). The raw score for each item is converted into the item standard score and then the domain component and standard scores. The balance domain standard score reflects the functional balance ability of the child (Henderson et al., 2007).

Movement ABC-2 has been shown to have good to perfect test-retest (ICC ranging from 0.73 to 0.80), inter-rater (ICC ranging from 0.95 to 1.00) reliability and criterion-related validity, and is commonly used to identify children with motor difficulties (e.g. DCD) (Henderson et al., 2007). Therefore, we incorporated Movement ABC-2 into one of our studies to measure the functional balance performance of children with DCD and correlated the results with the laboratory-based measurements. The percentile rank, which indicates the percentage of children in the standardization sample who obtained a score less than or equal to a given raw score, reflects whether the child being tested has motor problem or not (Henderson et al., 2007). A score at or below the 5th percentile indicates significant motor difficulty; a score between the 6th and 15th percentiles indicates borderline motor difficulty that requires monitoring; and a score at or above the 16th percentile is regarded as normal (Henderson et al., 2007).

1.3.5 Single-leg standing balance test

Apart from assessing the sensory components of balance (described in section 1.3.1), the Smart Equitest® Computerized Dynamic Posturography machine can also quantify the COP sway velocity in single-leg standing (with eyes opened or closed) accurately by a program known as the Unilateral Stance Test (UST) (NeuroCom, 2008). The ICC value for the UST COP sway velocity in adolescents (11 to 14 years of age) was found to be 0.77, indicating good reliability (Table 1.3) (Fong & Ng, 2012; Portney & Watkins, 2009). Moreover, the construct validity (known group validity) of UST on force platform was also found to be good in typically-developing children and children with hearing impairments (De Kegel et al., 2010). Therefore, it was adopted in our studies together with the Movement ABC-2 one-leg standing balance tests to assess the balance ability of children and adolescents objectively and functionally. The testing procedures are described in chapters 4 to 7 (studies 3 to 6).

Table 1.4 Movement ABC-2 balance tasks per age group (Henderson et al., 2007)

Age	**Balance tasks**
3-6 years	One-leg balance, walking heels raised, jumping on mats
7-10 years	One-leg balance on a board, waking heel-to-toe forwards, single-leg hopping on mats
11-16 years	Tandem stand balance on boards, walking toe-to-heel backwards, zig-zag hopping on mats

Remark: Photographs illustrating the individual test items and score calculations are presented in Appendix III.

1.4 Developmental coordination disorder (DCD)

1.4.1 Diagnostic criteria and prevalence of DCD

DCD is a fairly common disorder, affecting approximately 6% of primary school-aged children (five to eleven years old) (APA, 2000). Table 1.5 shows the diagnostic criteria for DCD as described in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) (APA, 2000). Common symptoms in children with DCD include marked delays in achieving motor milestones; clumsiness; and poor postural control, coordination and handwriting (APA, 2000; Cermak & Larkin, 2002). These motor impairments significantly interfere with the child's academic achievements and activities of daily living and cannot be explained by any medical or intellectual conditions (APA, 2000).

1.4.2 DCD subtypes and co-morbidities

To date, there is little agreement among studies on the proposed subtypes of DCD (Macnab et al., 2001). For example, Dewey & Kaplan (1994) used balance, bilateral coordination, upper limb coordination, transitive gestures and motor sequencing and found four subtypes of DCD. Miyahara (1994) using running speed, agility, balance, strength, upper limb speed and dexterity, also ending up with four subtypes but that differ from the subtypes reported by Dewey & Kaplan (1994). These differences in the establishment of DCD subtypes may be due to a number of factors such as sample differences and the presence of co-morbidities. The presence of co-morbid pathologies can result in different sensori-motor deficits and potentially confound the classification of DCD (Visser, 2003).

Research has shown that attention deficit disorder (ADD), attention deficit-hyperactivity disorder (ADHD), reading disability (RD) and specific language impairment (SLI) frequently co-occur with DCD (Dewey et al., 2000; Dewey et al., 2002; Gillberg, 1998; Gillberg & Kadesjo, 2000; Hill, 2001; Kadesjo & Gillberg, 1999; Kadesjo & Gillberg, 2001; Kaplan et al., 1997; Martini et al., 1999; Wilson & McKenzie, 1998). In a group of 115 children with DCD, only 53 ‘pure cases’ were identified, i.e. 53 children showed signs of DCD, RD or ADHD alone. Among the 62 ‘comorbid cases’ identified, 23 children had difficulty in all sensori-motor areas measured (Kaplan et al., 1998). To conclude, DCD is a heterogeneous disorder characterized by a variety of sensori-motor deficits that cause difficulty in classifying the disorder into subtypes.

Table 1.5 Diagnostic criteria for DCD (DSM-IV) (APA, 2000)

A. Performance in daily activities that require motor coordination is substantially below that expected given the person's chronological age and measured intelligence. This may be manifested by marked delays in achieving motor milestones (e.g. walking, crawling and sitting), dropping things, "clumsiness", poor performance in sports or poor handwriting.
B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living.
C. The disturbance is not due to a general medical condition (e.g. cerebral palsy, hemiplegia, or muscular dystrophy) and does not meet criteria for a pervasive developmental disorder.
D. If mental retardation is present, the motor difficulties are in excess of those usually associated with it.

1.4.3 Etiology and pathophysiology of DCD

The etiology of DCD is still unclear (Cermak & Larkin, 2002). Some studies showed that DCD may be associated with minimal brain damage during the prenatal, perinatal or postnatal periods. Indeed, recent neuro-imaging study demonstrated that activity in the left posterior parietal cortex was lower in boys with DCD when they were asked to track a horizontally moving target by manipulating a joystick (Kashiwagi et al., 2009). Since parietal cortex integrates multimodal sensory information relevant to motor control, dysfunction can cause visual-motor deficits (Kashiwagi et al., 2009). Other neurological deficits demonstrated in children with DCD include disrupted cerebello-cerebral networks that may affect visuo-spatial cognition (Marien et al., 2010); non-specific ventricular dilatation and cortical sulcal prominence that may lead to poor visual-motor integration (Knuckey et al., 1983); poor cerebellar and basal ganglia functioning that may cause motor dysfunction (Ivry, 2003; Marien et al., 2010; Groenewegen, 2003; Zwicker et al., 2009), and have problems in generating and applying forces in a coordinated way (Shumway-Cook & Woollacott, 2007).

1.4.4 Risk factors associated with DCD

Previous studies show that DCD may be associated with perinatal complications such as jaundice, low birth weights, and prematurity (Johnston, et al., 1987). Besides, heredity predisposition (e.g. Fatty acid conversion problem) (Stordy, 2000) and impoverished environment that leads to less movement experiences could also predispose young children to have DCD

(Cermak and Larkin, 2002). Therefore, adequate movement experiences and exercises are crucial.

1.5 Postural control and sensori-motor deficits in children with DCD

Previous studies reported balance problems in 73% to 87% of children with DCD (Macnab et al., 2001). The suboptimal balance ability (e.g. poor static and dynamic balance, below normal unipedal and bipedal standing balance) observed in these children (Cherng et al., 2007; Engel-Yeger & Kasis, 2010; Geuze, 2003; Geuze, 2005; Grove & Lazarus, 2007; Inder & Sullivan, 2005; Jarus et al., 2011; Li et al., 2011; Tsai et al., 2009; Wann et al., 1998) is important and needs to be tackled because any impairment in postural control may limit a child's activities and participation, increase the risk of falls and injuries and affect motor skill development (Grove & Lazarus, 2007). To date, a few studies have examined the relation of sensory organization to balance function in children with DCD (Cherng et al., 2007; Deconinck et al., 2007; Grove & Lazarus, 2007; Inder & Sullivan, 2005; Przysucha & Taylor, 2004). Inder & Sullivan (2005), using computerized platform posturography, first reported widespread impairment in sensory organization (somatosensory, visual and vestibular ratios were below normal) in four children with DCD. Grove & Lazarus (2007) replicated Inder & Sullivan (2005)'s testing methods in a larger sample (16 and 14 children in the DCD and control groups, respectively) and found that the ability to utilize vestibular information for balance was insufficient (significantly lower vestibular ratio) in children with DCD. Somatosensory and visual inputs were, therefore, re-weighted more heavily for postural control. This finding is in some contrast to that of Wann et al. (1998), who reported that children with DCD rely on vision in the maintenance of posture, like children at four or five years of age, and they have difficulty in re-weighting sensory information in response to environmental demands (Deconinck et al., 2007). Recently, Cherng et al. (2007), using the modified Clinical Test of Sensory Interaction and Balance, found no difference in the three sensory ratios between children with (n=20) and without DCD (n=20).

The sensory organization deficits that contribute to balance problems in children with DCD remain elusive. Conflicting results of the aforementioned studies may be due to small sample sizes, use of different age groups and different testing instruments across studies. To more accurately characterize the relation between sensory organization and balance control in children with DCD, it will thus be important to use standardized tools and evaluate larger samples of children in specific age ranges in future studies.

Apart from sensory organization ability, kinesthetic proprioceptive input is important to postural control because it provides continuous feedback about static posture and superimposed movements of the body (Laszlo, 1990). Because children with DCD have deficits in kinesthetic perception and cross-modal (e.g. visual-kinesthetic) integration (Piek & Coleman-Carman, 1995; Piek & Dyck, 2004), it is reasonable to postulate that postural stability is poorer in such children than in children with normal development.

Postural stability requires not only reliable sensory information but also appropriate motor responses to realign the COG within the BOS (Cherng et al., 2007). It is well known that motor control strategies for regulating muscle activity are less uniform in children with DCD than in children showing the normal developmental milestones (Cermak & Larkin, 2002). To date, no study has investigated the motor control strategies, including the hip strategy and ankle strategy, used to maintain stance by children with DCD.

Apart from the sensory contributions and motor responses, lower limb muscle strength is important for postural stability (Bressel et al., 2007; Horak, 2006). Evidence suggests that children with DCD have lower power and peak torque in the knee flexors and extensors but a higher level of quadriceps and hamstring co-activation during isometric knee flexion and isokinetic knee extension (Raynor, 2001). However, how these strength and power deficits relate to balance control in children with DCD remains unknown.

1.6 Impact of motor and balance deficits in children with DCD

According to the International Classification of Functioning, Disability and Health (ICF) model, participation in everyday activities and a variety of life situations is integral to normal child development and positively influences health, quality of life and future life outcomes (Mandich et al., 2003; WHO, 2001). However, DCD often restricts a child's ability to participate in typical activities of daily living due, for example, to balance difficulties, motor deficits and overweight (Fong et al., 2011a & 2011b; Jarus et al., 2011). Reduced activity, in turn, may further increase body fat, decrease motor proficiency and increase the risk of coronary vascular disease, thus triggering a vicious cycle of inactivity and deteriorating health (Faught et al., 2005; Fong et al., 2011b; Fong et al., 2011a; Mandich et al., 2003). Interventions should aim to prevent the vicious cycle of activity avoidance, poor motor performance and physical fitness, and decreased participation in all activities. Interventions for children with poor motor ability and poor physical fitness should be made available in the community and after-school facilities along with more opportunities to participate in a variety of activities (Fong et al., 2011a & 2011b).

1.7 Prognosis of DCD

Previous research suggests two developmental paths for children with DCD: ‘persistence of perceptual motor problems’ and ‘catching up with the norm’ at adolescence (Cantell et al., 2003). Some children outgrow their motor problems, either with or without intervention, whereas many others continue to show poor motor skills throughout adolescence and even into adulthood (Cantell et al., 1994; Cantell et al., 2003; Geuze & Borger, 1993; Visser, 2003; Visser et al., 1998). In reviewing the literature, it becomes clear that a greater number of studies suggest that children do not outgrow clumsiness and that, without intervention, physical coordination will not improve (Coleman et al., 2001; Losse et al., 1991; Schoemaker et al., 2001; Smyth, 1992; Sugden & Chambers, 1998). Losse et al. (1991), for example, examined 17 children at six years of age and re-examined them at age 16. The children with motor difficulties at age six continued to exhibit problems at age 16. A very important clinical implication arises from these studies: early intervention aimed at improving motor proficiency, including postural control, are critical in children with DCD. In other words, intervention should begin at a young age.

1.8 Intervention for children with DCD

Current interventions for children with DCD include bottom-up and top-down approaches. Bottom-up approaches aim at changing underlying impairments (e.g. decreased proprioception, balance or muscle strength) that contribute to poor motor performance. These traditional therapies are based on the neuro-maturational and hierarchical theories, which advocate that remediation of underlying deficits results in improved function (Gentile, 1992). Targeting these impairments is thought to facilitate the integration of sensory information in the cortical regions of the brain and to produce a more organized body schema (Willoughby & Polatajko, 1995). Bottom-up approaches include sensory integration, process-oriented treatment, perceptual motor training and a combination of these interventions (Mandich et al., 2001). These treatment approaches have been criticized for lacking empirical evidence to support them (Wilson, 2005).

In contrast to the traditional bottom-up approaches, top-down approaches aim to improve cognitive or problem-solving skills as strategies to overcome movement difficulties (Hillier et al., 2010). These approaches are derived from modern theories proposing that both internal (i.e. motor planning) and external factors (i.e. environment, specific task) can influence a child's motor development (Barnhart et al., 2003). Examples of top-down approaches include task-specific interventions and cognitive approaches (Mandich et al., 2001). These approaches appear promising. However, the quality and quantity of studies into their effects on children with DCD are limited (Hillier, 2007).

1.9 Sports activities for children with DCD

Apart from the therapeutic interventions, sports activities can serve as complementary treatment for children with DCD in the attempt to improve motor proficiency and balance performance. Indeed, a survey has shown that it is quite common for physiotherapists to recommend that children with motor dysfunction participate in sports activities (Westcott et al., 1998). Aquatic exercise (Hillier et al., 2010), trampoline exercise (Mitsiou et al., 2011) and table tennis (Tsai, 2009) are reported to be beneficial (e.g. improve motor performance and neuromuscular coordination) in children with DCD. These activities involve both afferent inputs and repetitive problem-solving tasks. That is, they fall into both bottom-up and top-down intervention approaches (Hillier et al., 2010).

1.10 Sports training and postural control

It is well reported that sports training induces the development of specific postural control or sensory strategies in athletes (Aalto et al., 1990; Alpini et al., 2008; Aydin et al., 2002; Asseman et al., 2004; Bressel et al., 2007; Bringoux et al., 2000; Golomer et al., 1999a & 1999b; Herpin et al., 2010; Lephart et al., 1996; Nagy et al., 2004; Perrin et al., 2002; Perrot et al., 1998a & 1998b). The choice of an appropriate sensory cue for balance is influenced by prior motor experiences (Mesure et al., 1997). Generally, novices rely heavily on visual inputs to balance and to learn new motor skills.

As movements and postural control become more automatic, there is a decrease in the relative importance of visual inputs for postural control and an increase in the reliance on somatosensory inputs (Lee & Lishman, 1975).

Sensory organization and balance ability, in particular, are highly sport-specific. Sportsmen can select the most appropriate sensory information from the three sensory systems in order to regulate posture and to meet the requirements of the sport. For example, gymnasts and dancers use somatosensory inputs more than they use otholitic or visual cues for perception of body orientation and balance (Aydin et al., 2002; Bringoux et al., 2000; Golomer et al., 1999a; Lephart et al., 1996). Judoists, golfers and tai chi practitioners rely heavily on proprioceptive senses to adjust their posture and to maintain balance during competitions and practice (Fong & Ng, 2006; Perrin et al., 2002; Perrot et al., 1998a & 1998b; Tsang & Hui-Chan, 2004b). Trained ironman triathlon athletes, in comparison to active, untrained non-athletes, have better static postural control and are less dependent on vision (Nagy et al., 2004). Shooters and fencers use proprioceptive or vestibular cues more than visual cues to stabilize posture, and they save the visual sense to focus on sports-related events (Aalto et al., 1990; Herpin et al., 2010). Synchronized ice skaters depend on the vestibular system to fine tune body posture (Alpini et al., 2008).

What are the possible mechanisms underlying these sport-specific balance abilities? Del Percio et al. (2007) studied the neuro-physiological mechanisms underlying the superior standing balance of elite karate athletes. They suggested that practicing rapid leg attacks with the use of a mobile visuo-spatial target trains the athletes to perform the highly demanding task of visual-somatosensory-vestibular integration. They also suggested that the cerebral mechanisms for balance (e.g. integrating and switching between visual, somatosensory and vestibular inputs) might become more effective with prolonged training, which correlates with decreased body sway in standing. Furthermore, Perrin et al. (1998) proposed that combat sports training improves adaptive postural control through the use of knowledge acquired in training. From the biomechanical standpoint, athletes might learn correct lower limb and spinal alignments during practice of techniques that aid in postural stability (Violan et al., 1997). These factors might explain the superior and specific balance ability of sportsmen.

1.11 Taekwondo – a popular sport

Taekwondo, a Korean word meaning the art of kicking and punching, is a martial art that originated in Korea to equip armies and individual warriors with combat skills. After the Korean War, this martial art was taken from Korea to other countries. Since the late 1950s, TKD has been transformed from a traditional combat skill to a modern sport practiced all over the world. It became an Olympic sport in the year 2000 (Pieter & Heijmans, 2000) and is now one of the world's most popular martial sports in terms of the number of practitioners (Park et al., 1989). According to the 2009 figures of World Taekwondo Federation (WTF) and International Taekwon-Do Federation (ITF), which are the world's two largest TKD organizations, there are over 80 million people worldwide practising TKD in some 182 countries (ITF, 1994;

WTF, 2009). At present, TKD is practiced in two forms. The more traditional form, under the aegis of the ITF, puts emphasis on combat fighting and various crushing and defensive techniques, whereas a more modern form, under the WTF, places emphasis on sport performance and competition (Heller et al., 1998).

The training regime in TKD is systematic, long-term and progressive (Pieter & Heijmans, 2000) and generally involves the basic skills, forms or patterns, sparring and breaking techniques. Basic techniques such as punching, kicking and blocking are performed individually in stationary positions or with body movements in formal stances (Park et al., 1989; Toskovic et al., 2004). Table 1.6 summarizes the essentials of TKD training. The belt color or the ranking system represents the training experience and fighting proficiency of the TKD practitioners. Practitioners have to pass several belt promotion tests (yellow belt, yellow belt with green strip, green belt, green belt with blue strip, blue belt, blue belt with red strip, red belt, and red belt with black strip) before they can earn the black belt. It usually takes several years for a TKD beginner (white belt) to become an advanced practitioner (black belt) (ITF, 1994; Park et al., 1989; WTF, 2009).

Despite its combative nature, TKD is relatively safe because protective gear is mandatory and practitioners must follow strict rules during competitions (Pieter, 2005). According to Pieter (2005), the incidence of concussion ranged from 5% to 8.8% of all injuries in young male TKD practitioners and 8.1% to 9.6% in young female TKD practitioners. These injury rates were slightly higher than that in judo and karate practitioners.

However, the incidence of more serious injuries such as joint dislocation in young TKD practitioners was far lower than in young practitioners of other martial arts (Pieter, 2005).

Table 1.6 Essentials of WTF TKD training (Park et al., 1989)

Basic techniques	Forms (Poomse in Korean)	Sparring techniques
• Stances (e.g. ready stance, horseback riding stance, walking stance, twist stance, kicking stance) • Blocks (e.g. rising block, down block, inner and outer arm blocks, X block, knife-hand block) • Strikes (e.g. straight punch, reverse punch, knife-hand strike) • Kicks (e.g. front kick, side kick, roundhouse kick, rising kick, axe kick, spinning back kick and hook kick, jump kick) • Stepping techniques (footwork)	• Taegeuk forms 1 to 8 and techniques (colored belt patterns) • Koryo, Keumgang, Taebaek, Pyongwon, Sipjin, Jitae, Chonkwon, Hansu, Ilyeo (black belt patterns)	• Various attack and counter-attack techniques (e.g. kick and block drills) • Self-defense techniques

1.12 TKD training and postural control

TKD is renowned for its swift kicking techniques, and there are many forms that require one-leg stance (Lee, 1996; Pieter & Heijmans, 2000). Therefore, stability in unilateral stance is crucial for TKD practitioners. Postural control is a known determining factor for athletes' performance in competitions (Adlerton et al., 2003; Pieter, 2009), but there have been very few studies investigating the effect of TKD training on balance control. Brudnak and colleagues (2002) were the first group to report a beneficial effect of TKD training on single-leg standing balance in the elderly. They found an improvement in standing balance time on each leg after 17 weeks of TKD training. However, the major limitation of their study was lack of a control group; all control participants dropped out after the study started. Later, Cromwell et al. (2007) studied the effect of TKD training on balance and walking ability in older adults and found more significant improvements in terms of multi-directional reaching ability, gait stability and walking velocity in participants after 11 weeks of training than in participants that did not receive any training. They concluded that TKD is effective for improving balance and walking ability in community-dwelling elderly.

Sadowski (2005) reported balance as one of the dominant 'coordination motor abilities' of young elite-level TKD athletes, but any causal relation between TKD training and balance performance was not explored. Recently, Suzana & Pieter (2009) compared the standing balance performance of adult and teenage TKD practitioners and found that the teenagers maintained standing balance for an average of two seconds longer than adult control participants. However, none of these studies on young TKD athletes compared the balance performance of TKD athletes with that of non-athletes. Therefore, the association between TKD training and balance is not known.

Our research group first found that young participants with low-level TKD training demonstrate better balance performance than untrained participants. We postulated that TKD practitioners rely more on the somatosensory and vestibular inputs to maintain standing and landing balance control, particularly when visual input is absent (Leong et al., 2011). This study deepens our understanding of the balance performance and sensory organization strategy of TKD practitioners. However, postural stability requires many resources from different body systems. In addition to the sensory contributions of the somatosensory, visual and vestibular systems, motor responses and lower limb muscle strength are important for postural stability (Bressel et al., 2007; Horak, 2006). To date, some reported data support improvement in lower limb muscle strength by TKD training (Fong & Ng, 2011; Pieter et al., 1989; Fong & Tsang, 2012), but no study has linked up TKD training with balance performance. Further study is needed to explore the effects of TKD training on sensori-motor performance and balance in young people before clinicians can confidently suggest TKD training as an alternative therapy for children and adolescents with balance difficulties (e.g. children with DCD).

This thesis describes six studies conducted to investigate the effect of taekwondo training on postural control in children with and without DCD. The rationales and objectives of each study are summarized below, and the six studies, together with their relevance in terms of the main thesis question, are presented in chapters 2 to 7. We expect the results of our studies can contribute to the design of an effective balance training program for children with DCD.

1.13 Rationale, hypotheses and objectives of the six studies

Studies 1 to 2 investigate the sensori-motor and balance problems in children with DCD while studies 3 to 5 attempt to explore the beneficial effects of TKD training in the area of improving balance performance. These studies provide the background knowledge for the main study (study 6): 'TKD training improves balance and sensory organization in children with DCD: a randomized controlled trial' (Figure 1.11).

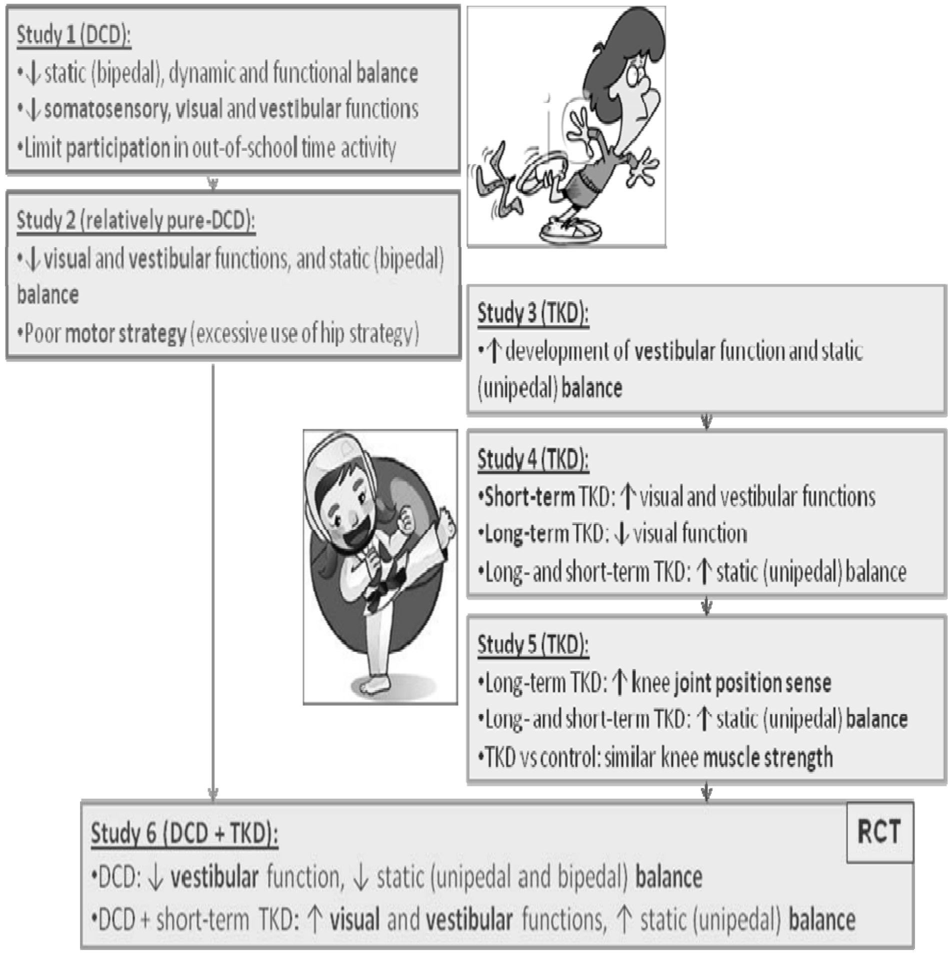


Fig. 1.11 Flowchart showing the relations of the six thesis studies

1.13.1 Study 1: Sensory organization of balance control in children with DCD

Rationale: DCD is a fairly common disorder, affecting approximately 6% of primary school-aged children (APA, 2000). Balance dysfunction is one of the most common impairments observed in this group (Macnab et al., 2001). The ability to maintain balance requires optimal reception, processing and integration of sensory information from different systems (i.e. the somatosensory, visual and vestibular systems) (Nashner, 1997). Several studies have examined sensory contributions to postural control deficits in children with DCD, but conclusions remain elusive due to the use of different testing instruments and the relatively small sample sizes (Cherng et al., 2007; Grove & Lazarus, 2007; Inder & Sullivan, 2005). It is important to use a large sample and standardized tools to more accurately reflect the difference in sensory organization of balance control between children with and without DCD.

Suboptimal balance performance in children with DCD is an important issue that needs to be addressed in both clinical practice and research, as any bodily impairment, including impaired postural control, may limit participation in activities, according to the International Classification of Functioning, Disability and Health model (Grove & Lazarus, 2007; WHO, 2001). Although many daily activities require good postural control, no study has explored the relations between functional balance performance, sensory organization ability and activity participation in children with DCD.

Hypothesis 1: Children with DCD have extensive sensory organization and postural control deficits.

Hypothesis 2: Poor postural control might be associated with decreased activity participation in children with DCD.

Objective 1: To compare the functional balance performance, sensory organization of standing balance control and out-of-school time activity participation between children with and without DCD.

Objective 2: To examine association between different aspects of postural control and activity participation among children with DCD.

The study "Sensory organization of balance control in children with DCD" is presented in Chapter 2.

1.13.2 Study 2: Altered postural control strategies and sensory organization in children with DCD (but without autistic disorder or ADHD)

Rationale: In study 1, we found in a large sample that children with DCD had significantly lower SOT-derived equilibrium scores and sensory ratios than typically developing children (81 children with DCD and 67 typically developing children). However, our findings in study 1 reflect only the postural and sensory organization ability in children (aged six to twelve years) with DCD and co-morbidities (e.g. ADHD). Because the presence of co-morbidities may significantly influence the nature and severity of sensori-motor deficits (Shum & Pang, 2009), it is important to use a relatively homogenous sample and a narrow age range to confirm the balance and sensory organization performance in children with DCD.

Moreover, postural stability requires not only reliable sensory information but also appropriate motor responses to realign the COG within the BOS (Cherng et al., 2007). It is well known that motor control strategies for regulating muscle activity are less uniform in children with DCD than in children showing the normal developmental milestones (Cermak & Larkin, 2002). To date, no study has investigated the motor control strategies, including the hip strategy and ankle strategy, used to maintain stance by children with DCD and limited co-morbidities.

Hypothesis 1:# Children with DCD and limited co-morbidities also have extensive sensory organization and postural control deficits.

Hypothesis 2:#Postural control strategies used by children with DCD might be different from that used by normal children.

Objective 1: To compare the standing balance ability of children with and without DCD.

Objective 2: To investigate postural sway when children with and without DCD rely on somatosensory, visual and vestibular inputs.

Objective 3: To compare the motor control strategies used by children with and without DCD.

The study "Altered postural control strategies and sensory organization in children with DCD" is presented in Chapter 3.

1.13.3 Study 3: TKD training speeds up the development of balance and sensory organization in young adolescents

Rationale: It is well known that sports training can improve sensori-motor elements and efficiency of postural control (Anderson & Behm, 2005; Mesure et al., 1997). Previous studies have shown that experienced dancers, gymnasts and soccer players, in comparison to non-sportsmen, have superior static and dynamic balance ability (Davlin, 2004; Golomer et al., 1999a & 1999b; Paillard et al., 2006). However, it seems that non of these sports can remediate the balance and sensory problems found in children with DCD (i.e. visual and vestibular deficits) (studies 1 and 2). We intended to identify a sport activity which is multi-dimensional and can facilitate the development of postural control, visual and vestibular functions in this particular group of children.

TKD is an Olympic sport and is a popular martial art among children and adolescents (Park et al., 1989). It is a kind of physical (renowned for its swift kicking techniques) and spiritual training (can improve self-esteem and induce positive mood state) (multi-dimensional exercise) (Finkenberg, 1990; Toskovic, 2001). TKD practitioners have many opportunities to stand on one leg during training and sparring (Pieter & Heijmans, 2000). Indeed, postural control is a determining factor for success in competitions (Pieter, 2009; Adlerton et al., 2003). Previous studies have shown that TKD training may have positive effects on balance control in the elderly (Brudnak et al., 2002; Cromwell et al., 2007) and in adult populations (Leong et al., 2011). Therefore, we hypothesized that TKD training would also hasten the development of balance and sensory organization ability in normal children/ young adolescents with immature balance systems (studies 3 to 5) as well as in children with DCD (study 6). We pilot tested the potential benefits of TKD in young adolescents with normal development in studies 3 to 5 before we implement TKD training in children with DCD (study 6).

Hypothesis 1:#The 3 sensory functions for balance control develop at different rates in young adolescents.

Hypothesis 2:#TKD-adolescents might have relatively matured balance ability and sensory organization than non-TKD-trained adolescents.

Objective 1: To identify the developmental status of balance and sensory organization in young adolescents as compared to that in adults.

Objective 2: To explore the balance performance and sensory development among adolescent TKD practitioners, non-TKD practitioners and matured adults.

The study "TKD training speeds up the development of balance and sensory organization in young adolescents" is presented in Chapter 4.

1.13.4 Study 4: Sensory organization and standing balance in adolescent TKD practitioners of different training levels

Rationale: In study 3, we found that young adolescents practicing TKD had better single-leg standing balance and that they relied more than non-TKD adolescents on the contribution of vestibular input to balance (ability comparable to that of adults). TKD training appears to speed up the development of postural control. However, participants in study 3 had trained in TKD for one to nine years. From the clinical perspective, it is unrealistic to prescribe long-term (e.g. nine years) balance exercises for children/ adolescents with and without normal development. Therefore, in study 4, we aimed to differentiate long- and short-term potential training effects of TKD in young adolescents with normal motor development.

Hypothesis 1:# Sensory organization and balance ability might be comparable between short-term and long-term TKD practitioners.

Hypothesis 2:#Both short- and long-term TKD practitioners might be better than non-trained adolescents in terms of balance control and sensory organization.

Objective 1: To compare the single-leg standing balance performance of adolescent TKD practitioners at different levels of expertise with that of non-practitioners.

Objective 2: To compare the sensory organization ability of adolescents with long-term TKD training, of adolescents with short-term TKD training, and of adolescents without TKD training.

The study "Sensory organization and standing balance in adolescent TKD practitioners of different training levels" is presented in Chapter 5.

1.13.5 Study 5: Lower limb joint sense, muscle strength and postural stability in adolescent TKD practitioners (of different training levels)

Rationale: As a continuation of study 4, we explored the potential benefits of long-term and short-term TKD training in adolescents with normal motor development. It is well documented that postural stability requires contributions from multiple systems (Nashner, 1997). Apart from sensory contributions from the somatosensory, visual and vestibular systems (addressed in study 4), motor responses and lower limb muscle strength are important factors that affect postural stability in athletes (Bressel et al., 2007; Horak, 2006). Increased knee muscle strength is known to be associated with better postural control in elderly tai chi practitioners (Tsang & Hui-Chan, 2005). To date, some studies support improvement in lower limb muscle strength by TKD training (Pieter et al., 1989; Fong & Tsang, 2012), but no study has linked up TKD training and lower limb muscle strength with balance performance in young TKD practitioners.

In addition, lower limb joint proprioception is known to play a key role in maintaining normal body posture (Gardner et al., 2000), and lower limb joint proprioception can be strengthened by sports training, such as judo, golf or tai chi (Fong & Ng, 2006; Perrot et al., 1998a & 1998b; Tsang & Hui-Chan, 2004b). Our previous study hinted that TKD practitioners sway significantly less than healthy non-athletically-trained individuals when they have to rely more on somatosensory input for maintaining balance (Leong et al., 2011). Therefore, it is logical to hypothesize that lower limb joint proprioception would also improve with TKD training.

Hypothesis 1:#Knee joint proprioception, muscle strength and postural control might be better in both long- and short-term TKD practitioners when compared to control-adolescents.

Hypothesis 2:#The improved knee joint proprioception and muscle strength might be associated with the better balance ability in TKD practitioners.

Objective 1: To compare the knee joint proprioceptive sense of adolescent TKD practitioners at different levels of expertise with that of adolescent non-TKD practitioners.

Objective 2: To compare the lower limb muscle strength of adolescent TKD practitioners at different levels of expertise with that of adolescent non-TKD practitioners.

Objective 3: To compare the single-leg standing balance performance of adolescent TKD practitioners at different levels of expertise with that of adolescent non-TKD practitioners.

Objective 4: To explore the relations between knee joint proprioception, muscle strength and balance performance in TKD practitioners.

The study "Lower limb joint sense, muscle strength and postural stability in adolescent TKD practitioners" is presented in <u>Chapter 6</u>.

1.13.6 Study 6 (main study): TKD training improves balance and sensory organization in children with DCD: a randomized controlled trial

Rationale: In studies 1 and 2, we confirmed that children with DCD have impaired postural control and sensory organization ability (exceptionally low SOT visual and vestibular ratio scores). Children with DCD participated in fewer activities, and their balance deficits accounted for 10.9% of the variance in activity participation (study 1). To prevent a vicious cycle of activity avoidance, poor balance performance and decreased participation in all activities, a multi-dimensional activity that can facilitate the development of postural control is deemed appropriate.

In studies 3 to 5, we found that TKD training might speed up the development of single-leg standing balance and vestibular function for postural control in normal young adolescents. Short-term TKD practitioners might rely more heavily on visual and vestibular inputs to maintain standing balance, whereas long-term TKD practitioners might have better knee joint position sense associated with their better unilateral stance balance performance.

From the above-described five studies, it seems that short-term TKD training might be suitable for children with DCD to improve their single-leg standing balance and sensory organization ability (e.g. reliance on visual and vestibular inputs to maintain balance). However, all five studies were cross-sectional in design; a prospective randomized controlled trial (RCT) is needed to establish a causal relation between TKD training and balance performance in children with DCD.

This study is the first to investigate the effect of short-term intensive TKD training on sensory organization and balance control in children with DCD. The hypothesis and objectives of the study were as follows:

Hypothesis 1:# A relatively short period of TKD training could improve sensory organization (especially visual and vestibular functions) and postural control (especially in unilateral stance) in children with DCD.

Objective 1: To investigate the effect of short-term (three months) intensive TKD training on the balance performance and sensory organization of children with DCD.

Objective 2: To identify the developmental status of balance and sensory organization of children with DCD, both with and without TKD training, as compared to that of children with normal motor development.

The study "TKD training improves balance and sensory organization in children with DCD: a randomized controlled trial" is presented in Chapter 7.

RESEARCHES ON

DEVELOPMENTAL COORDINATION DISORDER

CHAPTER 2 (STUDY 1): SENSORY ORGANIZATION OF BALANCE CONTROL IN CHILDREN WITH DEVELOPMENTAL COORDINATION DISORDER

Publication:

- Fong, S.S.M., Lee, V.Y.L., & Pang, M.Y.C. (2011a). Sensory organization of balance control in children with developmental coordination disorder. *Research in Developmental Disabilities*, 32, 2376-2382.

Conference abstract:

- Fong, S.S.M., Tsang, W.W.N., Lee, V.Y.L., & Pang, M.Y.C. (2011, October 25-27). Balance ability in children with developmental coordination disorder and relationship to activity participation. Paper presented at *International Conference on Global Health and Public Health Education*, Hong Kong.

2.1 Rationale of study 1

Developmental coordination disorder (DCD) is a fairly common disorder, affecting approximately 6% of primary school-aged children (APA, 2000). Balance dysfunction is one of the most common impairments observed in this group (Macnab et al., 2001). Suboptimal balance performance in children with DCD is an important issue that needs to be addressed in both clinical practice and research, as any bodily impairment, including impaired postural control, may limit participation in activities, according to the International Classification of Functioning, Disability and Health model (Grove & Lazarus, 2007; WHO, 2001). Although many daily activities require good postural control, no study has explored the relations between functional balance performance, sensory organization ability and activity participation in children with DCD. Therefore, in study 1, the sensori-motor and balance problems in DCD-affected children were first explored, and the association between postural control and participation diversity among children with DCD was also examined. The findings in this study can facilitate the development of a balance training program for this group of children (study 6).

2.2 Abstract

Objectives: (1) To compare functional balance performance and sensory organization of postural control between children with and without Developmental Coordination Disorder (DCD), and (2) to determine the association between postural control and participation diversity among children with DCD.

Methods: We recruited 81 children with DCD and 67 typically developing children. Participation patterns were evaluated using the Children Assessment of Participation and Enjoyment (CAPE) assessment. Balance was evaluated with the Sensory Organization Test (SOT) and the Movement Assessment Battery for Children-2 (Movement ABC-2). Analysis of variance was used to compare outcome variables between the two groups. Multiple regression analysis was performed to examine the relationship between participation diversity and balance performance in children with DCD.

Results: The DCD group had significantly lower Movement ABC-2 balance scores, SOT-derived equilibrium scores, and all three sensory ratios than the control group ($p<0.05$). However, only the Movement ABC-2 balance score was significantly associated with participation diversity in children with DCD. After accounting for the effects of age and sex, Movement ABC-2 balance score remained significantly associated with participation diversity, explaining 10.9% of the variance ($F_{change1,77}=9.494$, $p=0.003$).

Conclusions: Children with DCD demonstrate deficits in sensory organization of balance control. This suboptimal balance ability contributes to limited participation in activities.

Keywords: Clumsy children, activity, postural control, rehabilitation

2.3 Introduction

Developmental coordination disorder is a relatively common motor disorder, affecting 6% of children (APA, 2000). Balance dysfunction is one of the most common sensori-motor impairments observed among children with DCD. Indeed, it has been reported that 73% to 87% of children with DCD have balance problems (Macnab et al., 2001). The ability to maintain balance requires optimal reception, processing, and integration of sensory information from different systems (i.e. somatosensory, visual, and vestibular systems).

Several studies have investigated sensory contributions to postural control deficits in children with DCD, and results have been inconsistent (Cherng et al., 2007; Grove & Lazarus, 2007; Inder & Sullivan, 2005). Using the EquiTest Sensory Organization Test, Grove & Lazarus (2007) evaluated 16 children with DCD and 14 typically developing children and found that the ability to use vestibular feedback for postural control was impaired in children with DCD; somatosensory and visual inputs were therefore weighted more heavily for postural control. In contrast, Cherng et al. (2007) used the modified Clinical Test of Sensory Interaction and Balance (CTSIB) and found that sensory ratio scores, which indicate the ability to use information from the somatosensory, visual, and vestibular systems to maintain balance, was not significantly different between children with DCD (n=20) and their typically developing peers (n=20). These conflicting results may be due to small sample sizes and different testing instruments used across studies. To more accurately characterize the relationship between sensory organization and balance control in children with DCD, it is thus important to use standardized tools and evaluate larger samples.

The suboptimal balance performance demonstrated in children with DCD (Inder & Sullivan, 2005) needs to be addressed in both clinical practice and research, as any bodily impairments, including postural control, may limit activity participation, according to the International Classification of Functioning, Disability and Health model (Grove & Lazarus, 2007; WHO, 2001). Although many daily activities require good postural control (e.g. attending school and playing sports), few studies have explored the relationships among functional balance, sensory organization, and activity participation in children with DCD. Inder & Sullivan (2005) provided the first glimpse into the relationship between motor performance and participation in a sample of four children with DCD, and speculated that poor functional balance may influence activity participation patterns in these children. However, due to the small sample size, no conclusion about the relationship between balance performance and activity participation could be drawn.

The objectives of this study were (1) to compare the functional balance performance, sensory organization of standing balance control between children with DCD and their typically developing peers, and (2) to determine the relationships among different aspects of postural control with activity participation diversity among children with DCD.

2.4 Methods

2.4.1 Study design

This was a cross-sectional, exploratory study.

2.4.2 Participants

Sample size calculations were based on a statistical power of 0.80 and an alpha level of 0.05 (two-tailed). Grove & Lazarus (2007) previously reported SOT composite equilibrium scores of 63.9% (14.1%) and 72.4% (11.7%) for the DCD group (n=16) and control group (n=14) respectively, which translates into a medium to large effect size (0.66). Based on this study, the minimum sample size needed to detect a significant between-group difference in outcomes (objective 1) is 38 for each group (children with DCD and control) (Portney & Watkins, 2009). Regarding the regression analysis (objective 2), Jarus et al. (2011) reported that the Movement Assessment Battery for Children-2 (Movement ABC-2) percentile score had fair to good correlation with various activity participation scores (r=0.29–0.64) among children with DCD. Therefore, with three predictors and an effect size of 0.20 (medium to large), a minimum sample size of 59 children with DCD would be required for multiple regression analysis (Portney & Watkins, 2009).

Participants with DCD were recruited from a local Child Assessment Centre and hospital by convenience sampling. Inclusion criteria were: (1) formal diagnosis of DCD according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) (APA, 2000); (2) age six to twelve years; (3) study in a regular education framework; and (4) no intellectual impairment.

Exclusion criteria were: (1) formal diagnosis of emotional, neurological, or other movement disorders; or (2) significant musculoskeletal or cardiopulmonary conditions that may influence motor performance. For the control group, children with normal development were recruited from the community on a volunteer basis using the same inclusion and exclusion criteria stated above, except that they did not have any history of DCD.

2.4.3 Procedures

The study was approved by the human subjects ethics review subcommittee of the Hong Kong Polytechnic University and by the Hospital Authority (Appendix IV). After explaining the study to each participant and their guardian, written informed consent was obtained. Data were collected by two experienced pediatric physiotherapists. All procedures were conducted in accordance with the Declaration of Helsinki.

2.4.4 Demographic information

Basic demographic information was obtained by interviewing the children and their guardians.

2.4.5 Sensory organization of balance control

The SOT, which has demonstrated good reliability and validity, is used to evaluate the sensory organization of balance control in our participants (Di Fabio & Foudriat, 1996; NeuroCom, 2008). During the test, participants stood with bare foot on the platform of the computerized dynamic posturography machine (Smart EquiTest® system, NeuroCom International Inc., Oregon, USA), wearing a security harness to prevent falls. They were instructed to stand quietly with arms resting on both sides of the trunk (Figure 2.1). Participants were exposed to six different combinations of visual and support surface conditions, in the order specified by the manufacturer's protocol (Table 2.1) (NeuroCom, 2008). Each participant was tested three times under each condition.

The device detected the center of pressure (COP) trajectory of the participant, which was used to calculate the equilibrium score (ES). ES was defined as a dimensionless score (percentage) representing the participant's peak amplitude of antero-posterior (AP) sway relative to the theoretical limits of AP stability. An ES of 100 represented no sway, whereas 0 indicated a sway exceeding the limit of stability, resulting in a fall (Nashner, 1997; NeuroCom, 2008).

After obtaining the ES under all six conditions, the mean ES under each testing condition was calculated and used to calculate the somatosensory, visual, and vestibular ratios (Table 2.1). A high sensory ratio of close to 1 indicated a superior ability to use that particular sensory input to maintain balance (Nashner, 1997). The composite ES was generated, taking into account the mean ES attained under the six testing conditions (NeuroCom, 2008).

Table 2.1 The six testing conditions of the Sensory Organization Test and the sensory ratio analysis

SOT	Description
Testing condition	
1	Eyes open, fixed support
2	Eyes closed, fixed support
3	Sway-referenced[a] vision, fixed support
4	Eyes open, sway-referenced[a] support
5	Eyes closed, sway-referenced[a] support
6	Sway-referenced[a] vision and support
Sensory ratios	
Somatosensory	The ability of the child to utilize somatosensory information to maintain balance (ES condition 2/1).
Visual	The ability of the child to utilize visual information to maintain balance (ES condition 4/1).
Vestibular	The ability of the child to utilize vestibular information to maintain balance (ES condition 5/1).

[a]Sway-referenced refers to tilting of the support surface and/or the visual surround about an axis colinear with the ankle joints to directly follow the antero-posterior sway of the participant's center of gravity (NeuroCom, 2008).

Fig. 2.1 Sensory Organization Test standardized posture

2.4.6 Functional balance

The Movement ABC-2 was used to measure functional balance. It is a standardized tool for measuring motor performance in 3- to 16-year-old children that consists of eight tasks for each of the three age ranges. The eight tasks are divided into three domains: manual dexterity, aiming and catching, and balance. Test items in the balance domain include static and dynamic balance tasks (single-leg standing, tandem walking, hopping etc.). The raw score of each item was converted into the item standard score and domain standard score. The balance domain standard score was the only score used for analysis (Henderson et al., 2007). The test-retest reliability, inter-rater reliability, and criterion-related validity of Movement ABC-2 have been established (Henderson et al., 2007).

2.4.7 Out-of-school time activity participation

The Children's Assessment of Participation and Enjoyment (CAPE) was used to assess participation in out-of-school time activities (Table 2.2). The description of scores within each participation dimension of the CAPE was listed in Table 2.3 and Appendix I. CAPE is a reliable and valid self-report measure of participation in outside school activities for children and youth (6 to 21 years old) (Imms, 2008; King et al., 2004). Telephone or face-to-face interviews were conducted with participants and their guardians to complete the CAPE assessment. The total activity diversity and intensity scores were used for analysis (Table 2.3).

Table 2.2 Activities assessed by CAPE (King et al., 2004)

Recreational (n=12)	Physical (n=13)	Social (n=10)	Skill-based (n=10)	Self-improvement (n=10)
1. Doing puzzles	1. Doing martial arts	1. Talking on the phone	1. Swimming	1. Writing letters
2. Playing board or card games	2. Racing or track and field	2. Going to a party	2. Doing gymnastics	2. Writing a story
3. Doing crafts, drawing or coloring	3. Doing team sports	3. Hanging out	3. Horseback riding	3. Getting extra help for schoolwork from a tutor
4. Collecting things	4. Participating in school clubs	4. Visiting	4. Learning to sing (choir or individual lessons)	4. Doing a religious activity
5. Playing computer or video games	5. Bicycling, in-line skating or skateboarding	5. Entertaining others	5. Taking art lessons	5. Going to the public library
6. Playing with pets	6. Doing water sports	6. Going to the movies	6. Learning to dance	6. Reading
7. Doing pretend or imaginary play	7. Doing snow sports	7. Going to a live event	7. Playing a musical instrument	7. Doing volunteer work
8. Playing with things or toys	8. Playing games	8. Going on a full-day outing	8. Taking music lessons	8. Doing a chore
9. Going for a walk or a hike	9. Gardening	9. Listening to music	9. Participating in community organizations	9. Doing homework
10. Playing on equipment	10. Fishing	10. Making food	10. Dancing	10. Shopping
11. Watching TV or a rented movie	11. Doing individual physical activities			
12. Taking care of a pet	12. Playing non-team sports			
	13. Doing a paid job			

Table 2.3 Description of scores within each participation dimension (King et al., 2004)

	CAPE dimensions	
	Diversity	**Intensity**
Raw data	Yes/no response to whether an activity was done within past 4 months	Frequency scores: 1 = Once/4 months 2 = Twice/4 months 3 = Once/month 4 = 2-3 times/month 5= Once/week 6 = 2-3 times/week 7 = Once/day
Score	Number of activities in which the child participates.	Sum of frequency score divided by total number of items in scale of interest.
Score range	Overall: 0-55 Formal: 0-15 Informal: 0-40 Recreational: 0-12 Physical: 0-13 Social: 0-10 Skill-based: 0-10 Self-improvement: 0-10	0-7

2.4.8 Statistical analysis

Descriptive statistics were used to describe all the relevant variables. The normality of the data was ascertained with the Kolmogorov-Smirnov test. Continuous and categorical demographic variables were compared by independent t-test and chi-square test.

To compare the Movement ABC-2 balance domain standard scores, SOT-derived ES and sensory ratios, and CAPE-derived participation scores between groups, multivariate analysis of covariance (MANCOVA) was performed with body mass index (BMI) as the covariate. The Bonferroni adjustment was carried out to reduce the risk of type I error due to multiple comparisons. Effect sizes (indicated by partial eta-square) were computed for between-group comparisons. By convention, small, medium, and large effect sizes were defined as partial eta-square values of 0.01, 0.06, and 0.14, respectively (Portney & Watkins, 2009).

Pearson's correlation coefficients (for continuous variables) or Spearman's rho (for ordinal variables) were used to examine the bivariate association of balance scores (Movement ABC-2 balance domain standard score and SOT composite ES and sensory ratios) with the CAPE total activity scores (diversity and intensity scores) and other relevant variables (e.g. age) among children with DCD. Next, multiple regression analyses were performed to determine which balance parameters were the strongest determinants of the CAPE total diversity and intensity score. Selection of the predictors for regression analysis was based on physiological relevance and results of the bivariate correlation analysis. Age and sex were first entered into the regression model, because these factors may influence activity participation (Bult et al., 2011). The relevant balance parameter (e.g. Movement ABC-2 balance domain standard score) was then entered into the regression model. To avoid multicollinearity, the degree of association among the predictor variables was also assessed. Data were analyzed with SPSS 17.0 (SPSS Inc., Chicago, IL, USA), and a significance level of 0.05 was adopted for all statistical tests (two-tailed).

2.5 Results

2.5.1 Demographic characteristics

Basic demographic characteristics of the DCD group (n=81) and the control group (n=67) are outlined in Table 2.4. No significant difference in age, boy-to-girl ratio, height, or weight was observed between groups in all measured variables except BMI ($p<0.05$).

2.5.2 Sensory organization and balance performance

Children with DCD had significantly lower Movement ABC-2 balance domain standard scores (7.23±3.09) than the control group (10.70±2.53). In addition, the SOT-derived ES for all six test conditions, composite ES, and all three sensory ratio scores were significantly lower among children in the DCD group ($p<0.05$) (Table 2.5).

Table 2.4 Demographic characteristics of the participants

	DCD group (n=81) Mean±SD	Control group (n=67) Mean±SD	p value
Age, year	8.07±1.49	8.25±1.60	0.481
Sex, n	63 males & 18 females	48 males & 19 females	0.391
Height, cm	130.53±11.87	129.87±10.41	0.720
Weight, kg	33.09±11.55	30.33±8.69	0.109
BMI, kg/m^2	18.85±3.72	17.65±2.97	0.035*
Co-morbidity			
Attention deficit hyperactivity disorder	9	0	
Attention deficit disorder	9	0	
Dyslexia	9	0	
Asperger syndrome	5	0	
Autism spectrum disorder	1	0	

*p<0.05

2.5.3 Relationships among balance performance, sensory organization and participation pattern in children with DCD

Children with DCD showed significantly lower CAPE total activity diversity and intensity scores than the control group (Table 2.5, the detailed participation pattern is listed in Appendix II). A fair correlation ($r=0.318$, $p<0.01$) was found between Movement ABC-2 balance domain standard score and CAPE total diversity score in children with DCD. No correlation was found between SOT-derived measures and CAPE-derived scores ($p>0.05$) (Table 2.6).

2.5.4 Determinants of diversity of activity participation in children with DCD

The results of multiple regression analysis showed that, after accounting for age and sex, the Movement ABC-2 balance score remained independently associated with activity participation diversity ($F_{change1,77}=9.494$, $p=0.003$), explaining 10.9% of the variance in the total CAPE diversity score. As a number of children in our DCD group had co-morbidities (Table 2.4), sensitivity analyses were carried out by analyzing only DCD children without co-morbidities, with similar results (Tables 2.7 – 2.10).

Table 2.5 Comparison of balance ability and participation patterns

	DCD group (n=81) Mean±SD	Control group (n=67) Mean±SD	p value	Effect size (η^2_p)
Movement ABC-2				
Balance standard score	7.23±3.09	10.70±2.53	<0.001***	0.295
Sensory Organization Test				
Equilibrium score				
Composite	55.88±13.75	65.04±10.08	<0.001***	0.127
Condition 1	85.55±6.96	89.83±4.22	<0.001***	0.119
Condition 2	80.37±10.43	87.21±5.44	<0.001***	0.151
Condition 3	78.19±14.74	86.65±8.18	<0.001***	0.121
Condition 4	56.69±22.14	68.08±15.47	0.001***	0.081
Condition 5	37.28±18.28	45.11±17.27	0.010**	0.045
Condition 6	32.71±21.49	44.21±18.03	0.001***	0.070
Sensory ratio score				
Somatosensory ratio	0.94±0.10	0.97±0.04	0.022*	0.036
Visual ratio	0.66±0.24	0.76±0.16	0.005**	0.053
Vestibular ratio	0.43±0.21	0.50±0.19	0.049*	0.027
CAPE Total activities				
Diversity score	23.40±6.74	27.94±4.99	<0.001***	0.082
Intensity score	1.97±0.52	2.43±0.48	<0.001***	0.131

*p<0.05

**p<0.01

***p<0.001

Table 2.6 Correlations between demographic characteristics, balance ability and CAPE activity participation diversity and intensity in children with DCD

	Total activities	
	Diversity score	**Intensity score**
Age	0.012	-0.037
Sex	15.837	60.268
Height	<0.001	-0.023
Weight	0.015	0.036
Movement ABC-2 balance domain standard score	0.318**	0.178
SOT composite score	0.042	-0.060
SOT somatosensory ratio	-0.058	-0.003
SOT visual ratio	0.097	-0.032
SOT vestibular ratio	0.079	-0.019

*p<0.05

**p<0.01

2.6 Discussion

2.6.1 Sensory organization and balance control in children with and without DCD

This study revealed that children with DCD had poorer static and dynamic balance performance than typically developing children, as evidenced by their lower Movement ABC-2 balance domain standard score and lower SOT ES. Among the three sensory systems, the visual system appears to be the most critical, as the visual ratio showed the greatest between-group difference (effect size=0.053), compared with the somatosensory ratio (effect size=0.036) and vestibular ratio (effect size=0.027) (Table 2.5). These findings are consistent with previous studies that reported that static postural sway was more severe (Cherng et al., 2007; Grove & Lazarus, 2007; Inder & Sullivan, 2005) and dynamic balance (e.g. postural muscle activation during dynamic reaching) was altered in children with DCD (Johnston et al., 2002).

Postural control requires the ability to integrate and appropriately select visual, somatosensory, and vestibular inputs to generate coordinated motor actions (Nashner, 1997). Visual-spatial processing, visual perception, and visual-kinesthetic integration are prerequisites for successful maintenance of postural stability and coordinated movements, but they are usually impaired in children with DCD (Cermak & Larkin, 2002; Wilson & McKenzie, 1998). Difficulty in processing visual information has been found in children with DCD; this results in poor eye–hand coordination (Cermak & Larkin, 2002) and poor visually guided matching of limb orientation (Mon-Williams et al., 1999). In the context of balance, we found that children with DCD were less able to use visual information to maintain static posture, as reflected by their significantly lower visual ratio score. Indeed, this impaired ability to use visual information to maintain balance was reported by Inder & Sullivan (2005) and Wann et al. (1998), who found that some children with DCD exhibited postural control problems and tended to use visual information in a manner similar to that of nursery school children (Wann et al., 1998).

Recent neuroimaging studies have provided insight into why children with DCD have difficulty maintaining balance when forced to rely on visual input. Kashiwagi et al. (2009) showed reduced activity in the left posterior parietal cortex of the brain in boys with DCD. The parietal cortex integrates multimodal sensory information relevant to motor control; its dysfunction can cause visual-motor deficits that result in poor balance (Kashiwagi et al., 2009). In addition, Knuckey et al. (1983) reported abnormalities including nonspecific ventricular dilatation and cortical sulcal prominence in clumsy children, suggesting poor visual-motor integration. This may be another cause underlying the visual-balance problem associated with DCD.

Kinesthetic proprioceptive input provides continuous feedback about static posture and superimposed movements of the body and is therefore also important for postural control (Laszlo, 1990). As children with DCD have deficits in kinesthetic perception and cross-modal integration (e.g. visual-kinesthetic) (Piek

& Coleman-Carman, 1995; Piek & Dyck, 2004), it is reasonable that this group of children were less able to use somatosensory feedback for postural stability. Consistent with our finding, Inder & Sullivan (2005) reported that three of the four children with DCD in their study had a lower somatosensory ratio than the norm. In contrast, Grove & Lazarus (2007) reported similar somatosensory ratios in the SOT for the DCD group (n=16) and control group (n=14) groups. This finding could be attributed to low statistical power because of their relatively small sample size. Moreover, the boy to girl ratio differed between the DCD and comparison groups, which may have confounded the results (Grove & Lazarus, 2007).

Among the three sensory systems, vestibular system is the most important and reliable sensor for postural control because it measures acceleration of the head relative to gravity (Nashner, 1997). A normal functioning vestibular system is critical for balance control, particularly in challenging postural conditions. We found that children with DCD were less able to use vestibular information to maintain balance, as reflected by their significantly lower vestibular ratio (14% lower; small to medium effect size of 0.027). This is consistent with previous studies reporting that vestibular function may be impaired in children with DCD (Grove & Lazarus, 2007; Inder & Sullivan, 2005). Inder & Sullivan (2005) reported that the mean vestibular score of children with DCD aged six to twelve years was lower than that of typically developing children aged three to four years (Hirabayashi & Iwasaki, 1995; Inder & Sullivan, 2005). We found a smaller discrepancy in vestibular scores between children with DCD and the norm

(Hirabayashi & Iwasaki, 1995), and it was the least affected sensory system, as reflected by the smallest between-group difference and smallest effect size (Table 2.5). One possible explanation for this finding is that the vestibular system develops more slowly than the other sensory systems in typically developing children; it is not fully mature even at the age of 14 to 15 years (Ferber-Viart et al., 2007). Because the children in our study were younger than 13 years, those in the control group may not have had optimal vestibular function. Thus, the between-group difference in vestibular function may have been less apparent.

Only one previous study (Cherng et al., 2007) reported no deficits in all three sensory ratios in children with DCD. Although they found lower sensory ratios in children with DCD than controls, these differences were not significant. The research group suggested that poor balance (increased COP sway area) in children with DCD might be due to a general deficit in sensory organization rather than problems in individual sensory systems. The difference in results may be attributable to several factors. Their sample size was smaller (each group, n=20) and the participants were younger (four to six years old) compared with our study (DCD group, n=81; control group, n=67; six to twelve years old). The assessment method also differed. The standardized computerized dynamic posturography device used in our study creates conditions of conflicting sensory inputs through the sway-referenced support and surround, whereas the modified CTSIB used in their study provides only compliant support without the sway-referenced function (Grove & Lazarus, 2007; Inder & Sullivan, 2005; Nashner, 1997). In addition, their participants swayed in different directions to produce the COP sway area. In our study, we calculated the equilibrium score, which is a dimensionless number (percentage) that represented the participant's peak amplitude of AP sway relative to the theoretical limits of AP stability (12.5°) (Nashner, 1997).

2.6.2 Participation patterns and determinants of participation diversity in children with DCD

Our results agree with findings from previous studies (Jarus et al., 2011), which showed that children with DCD participated in fewer activities (less diverse) and less intensely than their typically developing peers. However, this study provides the first evidence that decreased diversity of activity participation is independently associated with poor functional balance, as measured by Movement ABC-2, accounting for 10.9% of the observed variance. This contribution is considerable, considering that participation itself is multidimensional and is influenced by many factors (e.g. cognitive ability and communication skills) (Bult et al., 2011). In contrast, we found no correlation between SOT-derived balance scores and CAPE diversity score. One potential explanation for this finding is that SOT measures only static standing balance, whereas most out-of-school time activities measured by CAPE (e.g. playing non-team sports, going for a walk or hike, learning to dance) involve both static and dynamic balance in various postures, which could be better captured by the Movement ABC-2 functional balance tests.

Our results confirmed the speculation that poor balance performances may affect activity participation diversity in children with DCD (Inder & Sullivan, 2005). A previous study reported that very poor performance on balance tasks was related to nonparticipation in active and social activities such as football (Smyth & Anderson, 2001). This could be due to anxiety regarding the motor challenges posed by social engagement (Bar-Haim & Bart, 2006).

2.6.3 Clinical implication

Our results have important clinical and research implications. As children with DCD demonstrate significant deficits in balance ability and sensory organization of balance control, interventions to enhance balance should be an important component of the clinical management of this condition. A balance training program should be multidimensional and designed to (1) improve both static and functional balance, (2) improve sensory organization ability, and (3) avoid a vicious cycle of activity avoidance, poor functional balance performance, and decreased participation in all activities (Barnhart et al., 2003). The results of this study also provide the basis of future research to investigate the clinical efficacy of balance training programs on improving balance ability, sensory organization, and activity participation for children with DCD.

2.6.4 Limitations and consideration for future studies

Some limitations of this study need to be considered. First, this was a cross-sectional study and causality could not be established. Second, our regression model accounted for only 10.9% of the variance in activity participation diversity. Further studies are needed to determine the relative contributions of balance ability and other factors (personal, familial, and environmental) to activity participation diversity (Jarus et al., 2011).

2.7 Conclusions

Children with DCD demonstrate deficits in balance control and sensory organization. This suboptimal balance ability is independently associated with limited participation in activities.

2.8 Annex (Study 1)

- All participants in study 1 were included by pediatric physiotherapists. They participated in the study voluntarily.

- Children were not matched between the two groups for age and sex because we intended to maximize the number of participants. Independent t-test and chi-square test shows that age and sex were comparable between the two groups ($p>0.05$).

- The test-retest reliability of SOT in adolescents was listed in Table 1.3.

- Learning effect during the SOT was reported in adults only. The effect plateaus at the 4th trial (Wrisley et al., 2007). Therefore, familiarization trials were allowed in our studies.

- Validity of Equitest CDP:

    - Mostly widely used commercial device to measure postural stability in adults and children (Barin, 1992; Liao et al., 2001).

    - Good construct validity – known groups' method. Significant differences in postural sway under different sensory conditions between typically developing children and children with disabilities (e.g. Cerebral Palsy, Down syndrome, learning disability, epilepsy, hearing impairment) (1.5 to 10 years old) were found (Westcott et al., 1997).

- Good criterion-related validity - concurrent validity (PCTSIB holding time and SOT stability score in 16 healthy children) (Gagnon et al., 2006).

- Good to perfect inter-rater reliability of Movement ABC-2 balance tests - ICC 0.95-1 (Henderson et al., 2007).

- Good test-retest reliability of Movement ABC-2 balance tests - ICC 0.73-0.80 (Henderson et al., 2007).

- Validity of Movement ABC-2 (Henderson et al., 2007):

Criterion-related validity - correlate Movement ABC-2 test scores with other motor tests' scores (in typically developing children):	Pearson r
MABC-2 total impairment score <-> BOTMP composite score	0.53 (moderate)
MABC-2 total test score <-> PDMS-2 total score	0.76 (good)

  - Good content validity (content coverage and relevance). It was judged by experts qualitatively (Henderson et al., 2007).

  - Good face validity. It was commented by professionals from different disciplines (Henderson et al., 2007).

- Moderate to good test-retest reliability of CAPE diversity and intensity scores – ICC 0.72-0.75 (King et al., 2004).

- Good validity of CAPE (King et al., 2004):
  - Expert review.
  - Correlations (Pearson r) among CAPE intensity scores (n=427).

	Overall participation
Formal activities	0.64
Informal activities	0.96
Recreational activities	0.72
Physical activities	0.71
Social activities	0.68
Skill-based activities	0.60
Self-improvement activities	0.64

- An outliner is defined as a value whose distance from the nearest quartile is greater than 1.5 times the interquartile range. Outliers pull the mean in their direction (Portney & Watkins, 2009). Therefore, before conducting the statistical analysis, all outliers were removed.
- Results demonstrated that children with DCD had higher BMI than typically developing children. Therefore, BMI was treated as a covariate in the subsequent data analysis. Moreover, how BMI/ weight status affects activity participation in children with DCD was explained in detailed in Fong et al. (2011b) (Appendix X).

- Additional results:

Table 2.7 Demographic characteristics of the participants (including children with DCD & with no known co-morbidities)

	DCD group (n=81) Mean±SD	Pure-DCD group (n=48) Mean±SD	Control group (n=67) Mean±SD	p value (% DCD & control groups)	p value (% pure-DCD & control groups)
Age, year	8.07±1.49	8.02±1.33	8.25±1.60	0.481	0.411
Sex, n	63 males & 18 females	37 males & 11 females	48 males & 19 females	0.391	0.512
Height, cm	130.53±11.87	130.34±11.06	129.87±10.41	0.720	0.813
Weight, kg	33.09±11.55	33.06±10.64	30.33±8.69	0.109	0.133
BMI, kg/m^2	18.85±3.72	18.97±3.23	17.65±2.97	0.035*	0.025*
Co-morbidity:					
Attention deficit hyperactivity disorder	9	0	0		
Attention deficit disorder	9	0	0		
Dyslexia	9	0	0		
Asperger syndrome	5	0	0		
Autism spectrum disorder	1	0	0		

*p<0.05

Table 2.8 Comparison of balance ability and participation pattern (including children with DCD & with no known co-morbidities)

	DCD group (n=81) Mean±SD	Pure-DCD group (n=48) Mean±SD	Control group (n=67) Mean±SD	p value (% DCD & control groups)	p value (% pure-DCD & control groups)	Effect size (η^2_p) (% DCD & control groups)	Effect size (η^2_p) (% pure-DCD & control groups)
				Similar			
Movement ABC-2							
Balance standard score	7.23±3.09	7.31±2.86	10.70±2.53	<0.001 ***	<0.001 ***	0.295	0.263
Sensory Organization Test							
Equilibrium score							
Composite	55.88±13.75	56.83±11.48	65.04±10.08	<0.001 ***	<0.001 ***	0.127	0.145
Condition 1	85.55±6.96	87.45±4.96	89.83±4.22	<0.001 ***	0.004**	0.119	0.072
Condition 2	80.37±10.43	81.15±8.85	87.21±5.44	<0.001 ***	<0.001 ***	0.151	0.163
Condition 3	78.19±14.74	80.00±10.36	86.65±8.18	<0.001 ***	<0.001 ***	0.121	0.112
Condition 4	56.69±22.14	57.87±20.62	68.08±15.47	0.001 ***	0.001 ***	0.081	0.094
Condition 5	37.28±18.28	37.25±16.03	45.11±17.27	0.010**	0.007**	0.045	0.063
Condition 6	32.71±21.49	33.38±21.90	44.21±18.03	0.001 ***	0.004**	0.070	0.074
Sensory ratio score							
Somatosensory ratio	0.94±0.10	0.93±0.07	0.97±0.04	0.022*	<0.001 ***	0.036	0.132
Visual ratio	0.66±0.24	0.66±0.22	0.76±0.16	0.005**	0.003**	0.053	0.075
Vestibular ratio	0.43±0.21	0.43±0.18	0.50±0.19	0.049*	0.019*	0.027	0.048
CAPE Total activities							
Diversity score	23.40±6.74	22.92±5.50	27.94±4.99	<0.001 ***	<0.001 ***	0.082	0.176
Intensity score	108.37± 28.67	105.15± 22.45	133.76± 26.61	<0.001 ***	<0.001 ***	0.131	0.236

*p<0.05; **p<0.01; ***p<0.001

Table 2.9 Correlation between demographic characteristics, balance ability and CAPE activity participation diversity and intensity in children with DCD & with no known co-morbidities

	CAPE total activities	
	Diversity score	**Intensity score**
Age	0.038	0.037
Gender	-0.039	-0.082
Height	0.055	0.093
Weight	-0.008	0.089
Movement ABC-2 balance domain standard score	0.289*	0.055
SOT composite score	0.056	-0.074
SOT somatosensory ratio	0.134	0.093
SOT visual ratio	0.060	-0.062
SOT vestibular ratio	0.006	-0.114

*p<0.05; **p<0.01 (two-tailed)

Table 2.10 Multiple regression analysis for determining diversity of participation in children with DCD & with no known co-morbidities (n=48)

Independent variables	R^2 change	Unstandardized Regression Coefficient (B)	95% Confidence interval	Standardized Regression Coefficient (β)	p value
Age (year)		0.324	-0.893, 1.541	0.078	0.595
Sex (boys=1, girls=2)	0.004	-1.176	-4.957, 2.604	-0.091	0.534
Movement ABC-2 balance standard score	0.094	0.600	0.035, 1.165	0.312	0.038*

*p<0.05

Table 2.11 Multiple regression analysis for determining MABC-2 balance standard score in children with DCD (with co-morbidities; n=81)

Independent variables	R^2 change	Unstandardized Regression Coefficient (B)	95% Confidence interval	Standardized Regression Coefficient (β)	p value
Age (year)		-0.413	-0.847, 0.022	-0.199	0.062
Sex (boys=1, girls=2)	0.005	0.622	-0.927, 2.170	0.084	0.426
CAPE diversity score	0.105	0.149	0.053, 0.245	0.325	0.003**

*p<0.05; **p<0.01

Poor functional balance in children with DCD is also independently associated with the decreased in diversity of activity participation, accounting for 10.5% of the observed variance.

Table 2.12 Comparison of balance ability and participation pattern (boys and girls)

	DCD group (Mean±SD)			Control group (Mean±SD)			p value (η^2_p)		
	All (n=81)	Boys (n=63)	Girls (n=18)	All (n=67)	Boys (n=48)	Girls (n=19)	All	Boys	Girls
Movement ABC-2									
Balance standard score	7.23±3.09	7.23±2.87	7.61±3.60	10.70±2.53	10.46±2.64	11.32±2.16	<0.001 *** (0.295)	<0.001 *** (0.238)	0.001 *** (0.296)
Sensory Organization Test									
Equilibrium score									
Composite	55.88±13.75	54.23±14.23	61.56±10.38	65.04±10.08	64.40±9.79	66.68±10.88	<0.001 *** (0.127)	<0.001 *** (0.179)	0.396 (0.043)
Condition 1	85.55±6.96	84.74±7.35	88.37±4.52	89.83±4.22	89.33±4.52	91.09±3.11	<0.001 *** (0.119)	<0.001 *** (0.142)	0.105 (0.102)
Condition 2	80.37±10.43	79.12±11.32	84.70±4.42	87.21±5.44	86.94±4.91	87.91±6.69	<0.001 *** (0.151)	<0.001 *** (0.194)	0.249 (0.064)
Condition 3	78.19±14.74	77.09±14.70	81.96±14.66	86.65±8.18	86.13±8.89	87.97±6.08	<0.001 *** (0.121)	<0.001 *** (0.147)	0.315 (0.054)
Condition 4	56.69±22.14	54.48±23.09	64.30±16.93	68.08±15.47	66.60±14.84	71.81±16.78	0.001 *** (0.081)	0.001 *** (0.106)	0.361 (0.047)
Condition 5	37.28±18.28	36.20±18.69	40.98±16.75	45.11±17.27	43.33±17.26	49.61±16.92	0.010 ** (0.045)	0.014* (0.055)	0.422 (0.040)
Condition 6	32.71±21.49	30.54±20.92	40.17±22.35	44.21±18.03	44.90±17.86	42.47±18.83	0.001 *** (0.070)	<0.001 *** (0.133)	0.796 (0.011)
Sensory ratio score									
Somato-sensory ratio	0.94±0.10	0.94±0.11	0.96±0.06	0.97±0.04	0.97±0.04	0.96±0.05	0.022* (0.036)	0.017* (0.052)	0.894 (0.005)
Visual ratio	0.66±0.24	0.64±0.25	0.73±0.21	0.76±0.16	0.74±0.16	0.79±0.18	0.005 ** (0.053)	0.003** (0.077)	0.593 (0.025)
Vestibular ratio	0.43±0.21	0.42±0.21	0.47±0.19	0.50±0.19	0.48±0.19	0.54±0.18	0.049* (0.027)	0.054 (0.034)	0.585 (0.025)

*p<0.05; **p<0.01; ***p<0.001

Table 2.13 Correlation between demographic characteristics, balance ability and CAPE activity participation diversity and intensity in children with DCD (boys and girls)

	CAPE total activities	
	Diversity score (male/female)	**Intensity score (male/female)**
Age	0.012/0.018	-0.020/-0.116
Height	0.024/-0.140	-0.018/-0.084
Weight	0.024/-0.026	0.018/0.104
Movement ABC-2 balance domain standard score	0.315*/0.372	0.207/0.105
SOT composite score	0.083/-0.109	0.012/-0.403
SOT somatosensory ratio	-0.057/-0.019	0.019/-0.139
SOT visual ratio	0.148/-0.103	0.033/-0.312
SOT vestibular ratio	0.137/-0.170	0.070/-0.425

*p<0.05

Table 2.14 Multiple regression analysis for determining diversity of participation in BOYS with DCD (with co-morbidities; n=63)

Independent variables	R^2 change	Unstandardized Regression Coefficient (B)	95% Confidence interval	Standardized Regression Coefficient (β)	p value
Age (year)		0.203	-1.424, 1.830	0.044	0.804
BMI (kg/m^2)	0.001	0.065	-0.695, 0.824	0.030	0.865
Movement ABC-2 balance standard score	0.102	0.777	0.178, 1.376	0.325	0.012*

*p<0.05

2.9 Relevance to the main study (study 6)

- This study provides a very strong 0.64background to substantiate the need of designing a specific balance training program for children with DCD.
- We found children with DCD demonstrate significant deficits in balance ability and sensory organization of balance control**.**
- The decreased in diversity of activity participation reported by this group of children is independently associated with poor functional balance, accounting for 10.9% (quite significant value because participation itself is multi-dimensional) of the observed variance.
- A ‘multidimensional balance training program’ designed to (1) improve both static and functional balance, (2) improve sensory organization ability, and (3) avoid a vicious cycle of activity avoidance, poor functional balance performance, and decreased participation in all activities, is essential.
- This ‘multidimensional balance training program’ could probably be ‘taekwondo’ (TKD) because it involves many single leg standing and spinning movements that may enhance balance and sensory organization (will be substantiated in studies 3 to 5). In addition, the nature and ranking system of taekwondo may motivate and attract children to participate in this sport. Thus, preventing a vicious cycle of activity avoidance, poor functional balance performance, and decreased participation in all activities. This hypothesis will be tested in the main study.

CHAPTER 3 (STUDY 2): ALTERED POSTURAL CONTROL STRATEGIES AND SENSORY ORGANIZATION IN CHILDREN WITH DEVELOPMENTAL COORDINATION DISORDER (BUT WITHOUT AUTISTIC DISORDER OR ADHD)

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3.1 Rationale of study 2

In study 1, we found in a large sample that children with DCD had significantly lower SOT-derived equilibrium scores and sensory ratios than typically developing children (81 children with DCD and 67 typically developing children). However, our findings in study 1 reflect only the postural and sensory organization ability in children (aged six to twelve years) with DCD and co-morbidities (e.g. ADHD). Because the presence of co-morbidities may significantly influence the nature and severity of sensori-motor deficits (Shum & Pang, 2009), it is important to use a relatively homogenous sample and a narrower age range to confirm the balance and sensory organization performance in children with DCD.

Moreover, postural stability requires not only reliable sensory information but also appropriate motor responses to realign the COG within the BOS (Cherng et al., 2007). It is well known that motor control strategies for regulating muscle activity are less uniform in children with DCD than in children showing the normal developmental milestones (Cermak & Larkin, 2002). To date, no study has investigated the motor control strategies, including the hip strategy and ankle strategy, used to maintain stance by children with DCD and limited co-morbidities. Therefore, we would further explore the sensori-motor and balance deficits in children with DCD in study 2. The final goal is to develop a specific balance exercise for this particular group of children (study 6).

3.2 Abstract

Objectives: The postural control of children with and without developmental coordination disorder (DCD) was compared under conditions of reduced or conflicting sensory input.

Methods: Twenty-two children with DCD (16 males and 6 females; mean age 7 years 6 months, SD 1 year 5 months) and 19 children with normal motor development were tested (13 males and 6 females; mean age 6 years 11 months, SD 1 year 1 month). Standing balance, sensory organization and motor control strategy were evaluated using the Sensory Organization Test.

Results: The results reveal that children with DCD had lower SOT composite equilibrium scores ($p<0.001$), visual ratios ($p=0.005$) and vestibular ratios ($p=0.002$) than normal children in the control group. No significant between-group difference in their average somatosensory ratio was observed. Additionally, children with DCD had lower SOT motor strategy scores (swayed more on their hips) than the normal children when forced to depend on vestibular cues alone to balance ($p<0.05$).

Conclusions: We conclude that children with DCD had deficits in standing balance control in conditions that included reduced or conflicting sensory signals. The visual and vestibular systems tended to be more involved in contributing to the balance deficits than the somatosensory system. Moreover, children with DCD tended to use hip strategy excessively when forced to rely primarily on vestibular signals to maintain postural stability.

Keywords: Balance deficits, clumsy children, sensory organization, movement strategy

3.3 Introduction

Developmental coordination disorder (DCD) is a fairly common disorder, affecting approximately 6% of children of primary school age (APA, 2000). Common symptoms include marked delays in achieving motor milestones, clumsiness, poor balance, poor coordination and poor handwriting (APA, 2000; Cermak & Larkin, 2002). These motor impairments significantly interfere with the child's academic achievements and activities of daily living and cannot be explained by any other medical or intellectual condition (APA, 2000). Previous studies have reported that 73% to 87% of children with DCD have balance problems (Macnab et al., 2001). Their suboptimal balance is important and needs to be tackled, because any impairment in postural control may limit the children's activity and participation, increase the risk of falling and injury, and affect their motor skills development (Fong et al., 2011a; Grove & Lazarus, 2007).

Postural control requires the ability to integrate inputs from the somatosensory, visual and vestibular systems and to select and utilize the integrated sensory signals in generating coordinated motor actions to maintain body equilibrium (Nashner, 1997). A few studies have examined sensory organization for balance control in children with DCD but the results have been inconsistent (Cherng et al., 2007; Grove & Lazarus, 2007; Inder & Sullivan, 2005; Przysucha & Taylor, 2004). For example, Inder & Sullivan (2005) first reported wide-spread impairment in sensory organization in four children with DCD using computerized platform posturography. Their somatosensory, visual and vestibular ratios were all below the norm. Grove & Lazarus (2007) replicated Inder &

Sullivan's testing methods with a larger sample (16 and 14 children in the DCD and control groups, respectively) and found that the ability to utilize vestibular information for balance was ineffective (significantly lower vestibular ratio) in children with DCD. Somatosensory and visual inputs were therefore weighted more heavily in postural control. Later, Cherng's group used the modified Clinical Test of Sensory Interaction and Balance and found that there was no difference in the three sensory ratios between children with and without DCD (Cherng et al., 2007). So the sensory organization deficits that contribute to the balance problems of children with DCD remain elusive. Moreover, these findings only reflect their postural performance of the DCD participants with co-morbidities such as attention deficit hyperactivity disorder (ADHD). Since co-morbidities may significantly influence the nature and severity of sensori-motor deficits (Pitcher et al., 2002; Shum & Pang, 2009), it is important to use a relatively homogenous group of children when studying DCD.

Postural stability not only requires reliable sensory information, but also appropriate motor responses to position the center of gravity (COG) within the base of support (BOS) (Cherng et al., 2007). The motor responses can be coordinated into hip and ankle strategies which maintain antero-posterior (AP) stability in fixed stance (Cherng et al., 2007; Nashner, 1997). The ankle strategy shifts the centre of gravity while maintaining foot placement by rotating the body as an approximately rigid mass about the ankle joint. It appears to be used most commonly when the external perturbation is small and the support surface is firm (Horak & Macpherson, 1996; Nashner, 1997). Hip strategies involve postural movements centered about the hip joints with opposing ankle joint rotations. The COG shifts in the direction opposite to the hip joint because of the inertia of the trunk, generating an opposite horizontal shear reaction force against the support surface. Hip strategies are commonly used to restore equilibrium in response to larger and faster perturbations, or when the support surface is compliant or shorter than the feet (Horak & Macpherson, 1996; Nashner, 1997). Normal individuals typically use combinations of these two strategies to maintain standing balance when the feet are stabilized (Horak & Macpherson, 1996; Nashner, 1997; Shumway-Cook & Woollacott, 2007).

In children with DCD it is well known that motor control strategies for regulating muscle activity are less uniform and consistent than in children following the normal developmental milestones (Huh et al., 1998; Williams, 2002). For example, Johnston et al. (2002) reported that the timing and pattern of postural muscle activation used to maintain posture were altered during goal directed reaching in children with DCD. This echoes Williams (2002), who reported that the normal distal-to-proximal muscle activation sequence in perturbed standing was substituted by a proximal-to-distal pattern of activation. Moreover, Geuze (2003) found that children with DCD and balance problems showed more co-activation of the leg muscles when standing on their non-preferred leg. All these neuromuscular deficits may affect the motor strategies such children use for postural control. However, no study has investigated their motor control strategies, including their hip and ankle strategies, in detail. Studying the motor strategies used for balance is important from a diagnostic perspective because any change in body posture will alter the type of sensory feedback available and will thus further influence postural stability (e.g. changing the head position during postural corrections may alter the visual and vestibular feedbacks for balance control) (Black et al., 1988; Horak et al., 1990).

The objectives of the present study were (1) to compare the standing balance ability of children with and without DCD, (2) to investigate the postural sway when children rely on somatosensory, visual and vestibular inputs, and (3) to compare the motor control strategies used by children with and without DCD.

3.4 Methods

3.4.1 Study design

This was a cross-sectional study.

3.4.2 Participants

Twenty-two children with DCD but with no indications of autistic disorder or ADHD were recruited from a local child assessment centre which provides assessment service for children. A formal diagnosis of DCD was made by an interdisciplinary team according to the DCD criteria of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) (APA, 2000). To warrant a diagnosis of DCD the child had to demonstrate motor coordination substantially below normal for their age (i.e. a gross motor composite score ≤42 as measured by the Bruininks-Oseretsky Test of Motor Proficiency) (Bruininks, 1978) which interfered with the child’s activities of daily living and academic performance.

Each child also underwent a neurological screening performed by a pediatrician to rule out other causes of motor deficits. In addition, each child was required to have normal intelligence (Hung & Pang, 2010; Shum & Pang, 2009).

Children who had recently been diagnosed with DCD were then screened by the primary investigator to determine whether the following criteria were fulfilled: (1) aged between six and nine years, and (2) studying in a regular education framework without demonstrating significant physical or psychosocial disability. Children were excluded if they had any of the following: (1) a history of any neurological condition; (2) any other movement disorder; (3) a vision, hearing or vestibular function deficit: (4) a formal diagnosis of autistic disorder or ADHD; or (4) significant musculoskeletal or cardiopulmonary conditions that might influence balance performance.

Nineteen children with normal development were recruited from the community as control participants. They had to fulfill the same inclusion and exclusion criteria set for the DCD group, except that they had no history of DCD.

3.4.3 Procedures and measures

Ethical approval was obtained from the human subjects ethics review subcommittee of the Hong Kong Polytechnic University (Appendix IV). The study was explained to each child and at least one parent, and written informed consent was obtained from the parent. A medical history and information on exercise habits were obtained by interviewing the parent and child. Each child’s physical activity level was estimated by asking the parents about the type of extracurricular physical activity that the child had most actively engaged in during a typical week within the past year. This factor was considered because previous research has shown that physical training can improve motor skills in children with DCD (Hung & Pang, 2010). The physical activity level, in metabolic equivalent (MET) hours per week, was calculated based on the exercise intensity, duration, frequency and the assigned MET value of the activity according to the Compendium of Energy Expenditures for Youth (Ridley et al., 2008).

All of the data was collected by an experienced pediatric physical therapist. The procedures were conducted in accordance with the Declaration of Helsinki. Postural sway was assessed in bipedal stance under normal, reduced or conflicting sensory conditions using the Sensory Organization Test (SOT) (NeuroCom, 2008). The SOT is commonly used to evaluate a participant's ability to make effective use of somatosensory, visual and vestibular inputs and filter out inappropriate sensory information in maintaining balance. It also provides information on the degree of ankle and hip movement under different sensory conditions (NeuroCom, 2008; Nashner, 1997). The results with children have been found to be reliable and valid (Di Fabio & Foundriat, 1996; Fong et al., 2011a).

During the test, the child stood barefoot on the platform of a computerized dynamic posturography machine (Smart Equitest, NeuroCom International Inc., Clackamas OR, USA) and wore a security harness to prevent falling. Each participant was instructed to stand quietly with both arms resting by the sides of the trunk and eyes looking forward. The child was then exposed to six different combinations of visual and support surface conditions in sequence according to the protocol suggested by the manufacturer of the posturograph (NeuroCom, 2008). Condition 1 was designed to provide accurate somatosensory, visual and vestibular inputs; conditions 2 and 3 provided only accurate somatosensory and vestibular inputs. In these three conditions, the child stood on a fixed platform first with their eyes open, then with their eyes closed, and then with their eyes open in a sway-referenced visual surround. In conditions 4 (provided accurate visual and vestibular inputs), 5 and 6 (provided accurate vestibular input only), the child stood on a sway-referenced platform under the same three visual conditions (Table 3.1). Sway-referencing involved tilting the support surface and/or the visual surround about an axis co-linear with the ankle joints to directly follow the AP sway of the child's centre of gravity (NeuroCom, 2008). Each participant was tested three times in each condition.

The machine captured the trajectory of the center of pressure (COP) on the platform, which was then used to calculate an equilibrium score (ES) defined as the non-dimensional percentage that compared the participant's peak amplitude of AP sway to the theoretical limits of AP stability (12.5°). The theoretical limit of stability was influenced by the individual's height and size of the supporting base. It represented an angle (8.5° anteriorly and 4.0° posteriorly) 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 by the machine's software with the formula

$$12.5° - [(\theta_{max} - \theta_{min})/12.5°] \times 100,$$

where θ_{max} is the largest AP COG sway angle attained by the participant and θ_{min} is the smallest. An ES of 100 represented no sway whereas a score of 0 indicated a sway exceeding the limit of stability which without the restraint would have required the child to move his or her foot or would have resulted in a fall (Nashner, 1997; NeuroCom, 2008).

After obtaining the three ESs in each of the six conditions, the mean ES in each condition was calculated for each child, and these averaged scores were used to calculate the somatosensory, visual and vestibular ratios (Table 3.2). These three sensory ratios were then used to represent the contribution of each sensory system, namely somatosensory, visual and vestibular inputs to balance control. High sensory ratio (close to 1) reflected the participant had superior ability in using that particular sensory input for balance (Nashner, 1997). A composite ES was also generated by the machine's software taking into account the ES attained in all the six testing conditions (NeuroCom, 2008). The composite ESs, mean ESs for the six sensory conditions and the three sensory ratios were used in the analysis.

Table 3.1 Testing conditions of the Sensory Organization Test

Condition	Description	Accurate sensory signals available
1	Eyes open, fixed support	Somatosensory, visual, vestibular
2	Eyes closed, fixed support	Somatosensory, vestibular
3	Sway-referenced[a] vision, fixed support	Somatosensory, vestibular
4	Eyes open, sway-referenced[a] support	Visual, vestibular
5	Eyes closed, sway-referenced[a] support	Vestibular
6	Sway-referenced[a] vision and sway-referenced[a] support	Vestibular

[a]Sway-referenced – tilting of the support surface and/or the visual surround about an axis co-linear with the ankle joints to directly follow the anterior-posterior sway of the participant's centre of gravity (NeuroCom, 2008)

Table 3.2 Sensory ratio analysis

Sensory ratio[a]	Description	Computation
Somatosensory	The ability of the child to use somatosensory information for maintaining balance.	ES of Condition 2 / ES of Condition 1
Visual	The ability of the child to use visual information for maintaining balance.	ES of Condition 4 / ES of Condition 1
Vestibular	The ability of the child to use vestibular information for maintaining balance.	ES of Condition 5 / ES of Condition 1

[a]The sensory ratios were generated by the Smart Equitest ® system; computational formulas are shown in the text (NeuroCom, 2008)

The posturograph also detected shear forces in the AP direction and produced a motor strategy score. That score, like the ES, was calculated by the machine's software. It quantifies the amount of ankle and hip movement used in maintaining balance during each 20-second trial according to the formula

$$\text{Strategy score} = [1 - (SH_{max} - SH_{min}) / 25] \times 100.$$

In this formula, SH_{max} is the greatest horizontal AP shear force observed and SH_{min} is the lowest. Their difference was normalised to 25lb of shear force because 25lb is the average difference measured with a group of normal participants who use hip sway only to balance on a narrow beam. A strategy score approaching 100 indicated that the child predominantly used an ankle strategy to maintain equilibrium, while a score near 0 revealed that the child predominantly used a hip strategy. Scores between 0 and 100 represented a combination of the two strategies (NeuroCom, 2008). A strategy score was obtained for each trial in each testing condition and the mean score across three trials was calculated. The means in SOT conditions 1 to 6 were used for analysis.

3.4.4 Statistical analysis

Descriptive statistics were calculated for each variable. The normality of data was checked using Kolmogorov-Smirnov tests. Independent t-tests were used to compare age, height, weight, and physical activity level between the DCD and control groups. A χ^2 test was used for the boy/girl ratio comparison between the two groups. Multivariate analysis of variance (MANOVA) was performed to compare the equilibrium scores (conditions 1 to 6 of the SOT), the sensory ratios (somatosensory, visual and vestibular) and the motor strategy scores (conditions 1 to 6 of the SOT) between the two groups. If significant differences were found in the overall multivariate tests, a follow-up univariate test was conducted for each of the measures. Where the assumptions of MANOVA were not met, independent t-tests were used instead. Independent t-tests were also performed to compare the composite ESs of the two groups. A significance level of 0.05 was adopted for all the statistical tests (two-tailed).

3.5 Results

3.5.1 Demographic characteristics

The characteristics of the DCD and control groups are presented in Table 3.3. The two groups of children were comparable in terms of age, sex, physical activity level and other demographic variables.

Table 3.3 Characteristics of participants

	DCD group (n=22)	Control group (n=19)	p value
Mean age±SD, years and months	7 years 6 months± 1 year 5 months	6 years 11 months± 1 year 1 month	0.137
Sex, n	16 males & 6 females	13 males & 6 females	0.763
Mean height±SD, cm	124.8±10.4	121.3±11.9	0.309
Mean weight±SD, kg	27.4±8.4	29.3±12.6	0.600
Type of physical activity			
Swimming, n	6	6	
Basketball, n	2	0	
Soccer, n	1	1	
Roller skating, n	0	3	
Table tennis, n	1	1	
Riding a bicycle, n	1	0	
Badminton, n	1	1	
Athletics (track & field), n	0	1	
Golf, n	0	1	
Running, n	0	1	
Gymnastics, n	0	1	
None, n	12	7	
Physical activity level±SD, MET hours per week	2.3±3.1	3.7±3.7	0.193

3.5.2 Standing balance in different sensory conditions

The composite equilibrium score which indicates the overall balance ability in all six conditions was 24.2% lower in the DCD group than in the control group ($p<0.001$). MANOVA revealed an overall difference in equilibrium scores (condition 1 to 6 of the SOT) between the two groups (Wilks' $\lambda=3.749$, $p=0.006$). When each individual primary outcome was considered, the between-group difference remained significant for all ESs except in condition 1 of the SOT ($p=0.143$). The between group ES difference in condition 3 was close to significance ($p=0.051$) (Table 3.4). The ESs in the other conditions were lower in the DCD group than in the control group by 11.9% in condition 2 ($p=0.001$), 29.8% in condition 4 ($p=0.003$), 47.7% in condition 5 ($p=0.001$), and 48.6% in condition 6 ($p=0.012$). The DCD group children had poorer standing balance than those in the control group, particularly when standing in reduced or conflicting sensory conditions (Table 3.4).

3.5.3 Contribution from the three sensory systems to standing balance

MANOVA also revealed an overall difference in the sensory ratios between the two groups (Wilks' $\lambda=5.454$, $p=0.003$). The visual and vestibular ratios were lower in the DCD group than the control group by 27.1% ($p=0.005$) and 46.8% ($p=0.002$), respectively. However, the somatosensory ratio showed no significant difference between the groups ($p=0.115$).

3.5.4 Motor strategies used in different sensory conditions

MANOVA was not used to assess the strategy scores because the covariance matrices of the dependent variables were not equal between the two groups. Independent t-tests revealed no significant differences in the two groups' motor strategy scores in conditions 1 ($p=0.537$), 2 ($p=0.149$), 3 ($p=0.527$) or 4 ($p=0.094$) of the SOT. The strategy scores were significantly lower in the DCD group than in the control group in conditions 5 ($p=0.015$) and 6 ($p=0.018$) only (Table 3.4). Children with DCD employed the hip strategy more when they had to rely on vestibular inputs to maintain their standing balance.

Table 3.4 Results from the Sensory Organization Test

	DCD group (n=22)	Control group (n=19)	p value
Equilibrium score±SD			
Condition 1	82.4±12.9	87.2±5.4	0.143
Condition 2	73.6±11.5	83.5±5.5	0.001***
Condition 3	71.3±16.1	79.4±7.6	0.051
Condition 4	43.0±20.2	61.2±16.6	0.003**
Condition 5	21.2±17.0	40.6±19.2	0.001***
Condition 6	14.6±15.8	28.4±17.6	0.012*
Composite ES±SD	43.3±12.8	57.1±9.6	<0.001***
Sensory ratio analysis±SD			
Somatosensory ratio	0.91±0.14	0.96±0.56	0.115
Visual ratio	0.51±0.22	0.70±0.18	0.005**
Vestibular ratio	0.25±0.18	0.47±0.22	0.002**
Strategy score±SD			
Condition 1	96.6±12.4	98.4±4.1	0.537
Condition 2	97.1±5.3	99.0±2.1	0.149
Condition 3	95.9±10.2	97.5±4.5	0.527
Condition 4	77.4±13.3	83.5±8.2	0.094
Condition 5	58.3±14.3	71.8±19.3	0.015*
Condition 6	47.4±30.6	66.9±16.7	0.018*

* p<0.05

**p<0.01

***p<0.001

3.6 Discussion

Children with DCD (but without autistic disorder or ADHD) have poorer balance than normal children that is evidenced by their lower composite ES scores in the SOT. Their standing balance control was similar to that of the normal control group in less challenging situation (condition 1 of the SOT) when information from all three sensory systems was available and correct. However, they swayed significantly more than their normally developing counterparts in conditions 2 through 6 in which their somatosensory and/or visual inputs were distorted or absent.

3.6.1 Somatosensory input for postural control among children with DCD

These results demonstrate that without vision, children with DCD swayed on average more than the control group but the between-group difference in ES was relatively small when the somatosensory input was correct. With error in the visual signal (SOT condition 3), there was similar postural sway in both groups. These findings, together with the lack of a group effect in the somatosensory ratio, suggest that children with DCD use somatosensory information for postural control as effectively as children with normal development. Somatosensory function normally matures at three to four years old (Steindl et al., 2006) and is not affected by DCD, as these results demonstrate. So children with DCD partially compensate their balance problem by relying on somatosensory input. This is in agreement with Grove & Lazarus (2007) and Przysucha & Taylor (2004) who reported that somatosensory feedback is re-weighted more heavily for postural control in children with DCD.

3.6.2 Visual input for postural control among children with DCD

Visual-spatial processing and visual-kinesthetic integration are prerequisites for successful maintenance of stability, but they are usually impaired in children with DCD (Wilson & McKenzie, 1998). SOT visual ratio deficits have previously been reported for children with DCD (Inder & Sullivan, 2005) and confirmed in the present study. We also found that children with DCD (without autistic disorder or ADHD) swayed significantly more when they relied on the visual information to balance (i.e. condition 4 of the SOT). Recent neuro-imaging studies shows that activity in the left posterior parietal cortex is lower in boys with DCD (Kashiwagi et al., 2009). The parietal cortex integrates multimodal sensory information relevant to motor control, and its dysfunction can cause visual-motor deficits (Kashiwagi et al., 2009). In addition, Marien and his colleagues have pointed out that clumsy children may have disrupted cerebello-cerebral networks that may affect visuo-spatial cognition (Marien et al., 2010). These recent neuro-imaging findings may explain why children with DCD have difficulty maintaining balance when forced to rely on visual input.

Interestingly, Grove & Lazarus (2007) did not find any significant deficit in using visual inputs for postural control in children with DCD. This may be due to the fact that they studied a relatively heterogeneous sample and a large age range from six to twelve years old. Normally, visual function matures at seven to ten (Cherng et al., 2003). It is possible that some older children with DCD might have developed a mature visual system for balance, or their visual-motor integration may have improved due to the plasticity of the developing brain (Marien et al., 2010). The participants in our study were relatively homogenous and they had a narrow age range of between six and nine years old. It is reasonable to speculate that children with DCD who are younger than ten years old may have delayed development of their visual function for postural control.

3.6.3 Vestibular input for postural control among children with DCD

The vestibular system is the most important and reliable sensor for postural control because it measures any acceleration of the head in relation to gravity during stance (Nashner, 1997). This system also transmits information that triggers the vestibulo-ocular reflex (VOR) that stabilizes visual images on the retina during head and body movements (Tanguy et al., 2008). A normally functioning vestibular system is thus critical in balance control, particularly in challenging conditions.

In this study, we found that children with DCD swayed significantly more when they had to rely on vestibular information alone to maintain their balance, as reflected by their significantly lower vestibular ratios and ES scores in SOT conditions 5 and 6. This partially concurs with the findings of Grove & Lazarus (2007) who reported that seven out of 16 children with DCD (no information about co-morbidity) demonstrated impaired postural stability under SOT conditions 5 and 6 in which vestibular feedback was the sole accurate source of orienting feedback for postural control. However, since the SOT is not a direct measure of how the complex vestibular system contributes to active postural control, further research is needed to confirm and localize the vestibular dysfunction in this group of children using vestibular function tests and neurotologic examination etc. (Grove & Lazarus, 2007; Black, 2001).

3.6.4 Postural control strategies among children with DCD

This has been the first study to investigate the motor strategies used by children with DCD to control their standing posture. It is well known that the ankle strategy is the first pattern for controlling upright body sway and that individual tends to shift to the hip strategy in more unstable conditions (Nashner, 1997). Analysis of the strategy scores generated in this study reveals that children with DCD shifted from ankle to hip strategies in a similar manner to normally developing children when the challenge to balance increased across the six conditions of the SOT. When standing under less challenging conditions (conditions 2 to 4), the movement strategies adopted by the DCD group to maintain balance did not differ from those of the control group even though the children with DCD swayed more (attained lower composite scores) than the normal controls. However, children with DCD had difficulty adjusting their postural strategy in conditions in which they needed to rely more on vestibular input for balance control (SOT conditions 5 and 6). The DCD group responded by using comparatively more of the hip strategy rather than the ankle strategy. These findings reflect the fact that children with DCD do not fully adapt to their poor postural control, particularly in environments where they must depend on vestibular signals. They are unable to account for the restricted and/or distorted visual and somatosensory inputs and maintain postural stability. Over-reliance on the hip strategy by these children might not be effective when balancing on unstable surfaces, and it would increase their energy consumption for postural control and increase the risk of falling (Ray et al., 2008).

The neuro-physiological explanations of the poor balance strategies in children with DCD have become clearer in recent years. A number of neuro-imaging studies have suggested that poor cerebellar and basal ganglia functioning could be the major causes of motor dysfunction in this group of children (Ivry, 2003; Groenewegen, 2003; Marien et al., 2010; Zwicker et al., 2009). The function of the cerebellum in postural control is to modulate the amplitude of postural muscle contractions in response to changing environmental conditions, while the basal ganglia control the swift adjustment of muscle tension. If these structures are compromised, children have problems generating and applying forces in a coordinated way to control the body's position in space (Shumway-Cook & Woollacott, 2007).

Previous studies have also suggested that neuromuscular deficits in children with DCD may contribute to their altered balance strategies (Huh et al., 1998; Johnston et al., 2002; Raynor, 2001; Smits-Engelsman et al., 2008). Their motor impairments typically include lower maximal knee muscle strength and power, increased knee flexor and extensor co-activation (Raynor, 2001); less steady force production (Smits-Engelsman et al., 2008); inconsistent and less efficient motor-control strategies to execute movements (Huh et al., 1998); inconsistent timing of postural muscle activation (Johnston et al., 2002; Williams, 2002); proximal to distal muscle activation patterns; and increased and prolonged activation or co-contraction of the ankle muscles in standing (Geuze, 2003; Williams & Castro, 1997). These may partly explain the ineffective motor strategies demonstrated by our DCD group in more challenging environments.

Another interesting finding of this study is that although the children with DCD had lower composite scores (they swayed more) in condition 4 of the SOT where somatosensory information was distorted, they used a good mix of hip and ankle strategies to balance that was similar to that of their normal peers. This is different from the observations of Horak and his colleagues (1990), who found that somatosensory loss could result in increased reliance on the hip strategy in standing, even in conditions in which a pure ankle strategy should have been more effective. In their study, somatosensory loss was induced by ischemic disruption of somatosensory inputs from the feet, while in our study the children stood on a sway-referenced support surface that provided inaccurate somatosensory information only. The tactile and proprioceptive receptors in the soles and feet were intact, and nerve conduction was not affected in our children with DCD. This may explain the discrepancy between our observations and those of Horak's group (1990). Moreover, Horak's participants were healthy normal adults who received anaesthesia of both feet and both ankles during the study. The participants might not have been able to adapt to this somatosensory loss condition immediately during the test. Our participants were children born with DCD who might have learned to compensate for their motor disabilities.

3.6.5 Clinical implications

Balance dysfunction has an important impact on activity, particularly in situations that demand good balance such as walking on uneven terrain (Grove & Lazarus, 2007). Sensory deficits coupled with the ineffective motor control strategies used in certain sensory deprived conditions by children with DCD may predispose them to falls and injuries in their daily activities. Therefore, physical rehabilitation programs for children with DCD (Pless & Carlsson, 2000) should include individualized postural control training emphasizing the use of visual and vestibular inputs as well as appropriate use of ankle and hip strategies.

3.6.6 Limitations and consideration for future studies

The results of this study raise the question as to whether the greater use of hip strategy in conditions 5 and 6 of the SOT is a cause (i.e. over-reliance on hip strategy to balance) or a consequence (i.e. respond with the hip strategy when unstable) of postural instability among children with DCD. It was beyond the scope of this study to examine this issue, so further research is needed. Greater reliance on the hip strategy should in any case lead to more falls, particularly when standing on unstable surfaces, and is a cause for concern (Ray et al., 2008). Further study might fruitfully examine more directly the relationship between fall risk and postural control strategies in children with DCD.

This study has definitely confirmed that children with DCD sway significantly more under reduced or conflicting sensory conditions. However the underlying mechanism of these balance deficits is not yet confirmed, because postural control involves complex sensori-motor systems (Nashner, 1997). Children with DCD may have many other motor deficits which cause their increased postural sway, particularly under challenging conditions. More studies of their motor abilities and postural control are warranted. Future studies might attempt to differentiate the motor and balance deficits of children with different DCD subtypes or with different co-morbid psychiatric conditions (Macnab et al., 2001). Although we tried to select a 'pure' DCD group for this study, it cannot be ruled out that other co-morbid conditions such as dyslexia could have contaminated our results. Care is therefore called for in generalizing the study's findings.

Finally, more studies under dynamic conditions are called for to determine if this would further expose children with DCD to falls. How balance deficits affect activity and participation in daily living has also not yet been examined, and this important area awaits further research.

3.7 Conclusions

Children with DCD swayed more when they were compelled to rely on visual and/or vestibular inputs to maintain standing posture. They tended to use hip strategy excessively when relied on vestibular signals to balance. Training programs should therefore target on sensori-motor deficits in order to improve postural control in this patient population.

3.8 Annex (Study 2)

- Data was collected by an experienced pediatric physical therapist and the therapist was not blinded to the child's condition. However, all testing procedures are standardized and data was obtained by using the Equitest machine.

- Precision and accuracy of the evaluation device used in this study are presented in section 2.8 and Table 1.3.

- All participants completed the six SOT testing conditions and there was no drop out. If the child fell or touched the visual surround for support, that trial was marked as "FALL" and then progressed to other trials. If the child suddenly moved (not due to postural instability), that trial was repeated.

- The testing sequence was not randomized, starting from the least challenging condition to the most challenging condition. The testing effect was minimized by providing familiarization trials to the participants.

- Sample size calculation was based on a statistical power of 0.80 and an alpha level of 0.05 (two-tailed). In study 1 (Fong et al., 2011a), we found that MABC-2 balance standard scores of 7.31±2.86 and 10.70±2.53 for the relatively pure-DCD group (n=48) and control group (n=67) respectively, which translates into a large effect size (1.26). Based on this study, the minimum sample size needed to detect a significant between-group difference in all outcomes is 12 for each group (children with DCD and control) (Portney & Watkins, 2009).

- Additional results:

Table 3.5 Results from the SOT (95% CI is presented)

	DCD group (n=22)		Control group (n=19)		p value	Effect size
Equilibrium score	**Mean ± SD**	**95% CI**	**Mean ± SD**	**95% CI**		
• **Condition 1**	82.4 ± 12.9	78.05-86.80	87.2 ± 5.4	82.47-91.88	0.143	0.054
• **Condition 2**	73.6 ± 11.5	69.62-77.59	83.5 ± 5.5	79.24-87.82	0.001*	0.231
• **Condition 3**	71.3 ± 16.1	65.70-76.82	79.4 ± 7.6	73.41-85.37	0.051	0.094
• **Condition 4**	43.0 ± 20.2	34.94-50.97	61.2 ± 16.6	52.57-69.82	0.003*	0.201
• **Condition 5**	21.2 ± 17.0	13.44-29.02	40.6 ± 19.2	32.20-48.96	0.001*	0.231
• **Condition 6**	14.6 ± 15.8	7.40-21.78	28.4 ± 17.6	20.67-36.14	0.012*	0.152
Composite ES	43.3 ± 12.8	38.34-48.20	57.1 ± 9.6	51.80-62.41	<0.001*	0.277
Sensory ratio analysis						
• **Somatosensory ratio**	0.91 ± 0.14	0.86-0.95	0.96 ± 0.56	0.91-1.01	0.115	0.063
• **Visual ratio**	0.51 ± 0.22	0.43-0.60	0.70 ± 0.18	0.61-0.79	0.005*	0.187
• **Vestibular ratio**	0.25 ± 0.18	0.17-0.34	0.47 ± 0.22	0.37-0.56	0.002*	0.229
Strategy score						
• **Condition 1**	96.6 ± 12.4	92.46-100.69	98.4 ± 4.1	94.01-102.87	0.537	0.010
• **Condition 2**	97.1 ± 5.3	95.33-98.91	99.0 ± 2.1	97.11-100.96	0.149	0.053

• **Condition 3**	95.9 ± 10.2	92.42-99.40	97.5 ± 4.5	93.77-101.28	0.527	0.010
• **Condition 4**	77.4 ± 13.3	72.58-82.27	83.5 ± 8.2	78.24-88.67	0.094	0.070
• **Condition 5**	58.3 ± 14.3	51.09-65.57	71.8 ± 19.3	63.98-79.56	0.015*	0.413
• **Condition 6**	47.4 ± 30.6	36.56-58.26	66.9 ± 16.7	55.24-78.59	0.018*	0.136

*p<0.05

Table 3.6 Results from the Sensory Organization Test (boys and girls)

	DCD group Mean ± SD			Control group Mean ± SD			p value (Effect size)		
Equilibrium score	**All (n=22)**	**Boys (n=16)**	**Girls (n=6)**	**All (n=19)**	**Boys (n=13)**	**Girls (n=6)**	**All**	**Boys**	**Girls**
• **Condition 1**	82.4±12.9	79.2±13.8	91.0±1.9	87.2±5.4	86.4±6.1	88.8±3.3	0.143	0.093	0.192 (0.164)
• **Condition 2**	73.6±11.5	69.9±11.3	83.5±3.7	83.5±5.5	82.8±6.3	85.0±3.0	0.001*	0.001*	0.454 (0.057)
• **Condition 3**	71.3±16.1	67.9±17.3	80.2±7.6	79.4±7.6	78.5±8.7	81.4±4.0	0.051	0.056	0.747 (0.011)
• **Condition 4**	43.0±20.2	35.9±18.9	61.9±7.1	61.2±16.6	57.0±17.5	70.3±10.4	0.003*	0.005*	0.132 (0.212)
• **Condition 5**	21.2±17.0	14.2±8.4	39.9±20.7	40.6±19.2	40.4±21.2	40.9±15.7	0.001*	<0.001*	0.926 (0.001)
• **Condition 6**	14.6±15.8	7.9±11.9	32.4±9.9	28.4±17.6	27.9±20.0	29.5±12.7	0.012*	0.002*	0.670 (0.019)
Composite ES	43.3±12.8	37.6±9.5	58.5±5.8	57.1±9.6	55.8±10.4	59.8±7.7	<0.001*	<0.001*	0.742 (0.011)
Sensory ratio analysis									
• **Somatosensory ratio**	0.91±0.14	0.90±0.16	0.9±0.0	0.96±0.56	0.96±0.06	1.0±0.0	0.115	0.222	0.122 (0.222)
• **Visual ratio**	0.51±0.22	0.45±0.22	0.7±0.1	0.70±0.18	0.66±0.19	0.8±0.1	0.005*	0.012*	0.070 (0.291)
• **Vestibular ratio**	0.25±0.18	0.19±0.10	0.4±0.2	0.47±0.22	0.47±0.24	0.5±0.2	0.002*	<0.001*	0.815 (0.006)
Strategy score									
• **Condition 1**	96.6±12.4	95.5±14.6	99.4±0.8	98.4±4.1	97.7±4.8	99.9±0.1	0.537	0.600	0.139 (0.205)
• **Condition 2**	97.1±5.3	96.3±6.1	99.4±0.6	99.0±2.1	98.6±2.5	99.9±0.3	0.149	0.197	0.098 (0.250)
• **Condition 3**	95.9±10.2	94.5±11.7	99.6±0.7	97.5±4.5	96.8±5.3	99.1±1.1	0.527	0.524	0.369 (0.081)
• **Condition 4**	77.4±13.3	73.9±13.9	86.8±3.7	83.5±8.2	81.0±8.8	88.9±2.6	0.094	0.124	0.292 (0.110)
• **Condition 5**	58.3±14.3	52.9±10.8	72.7±12.8	71.8±19.3	66.4±21.5	83.3±2.0	0.015*	0.036*	0.073 (0.286)
• **Condition 6**	47.4±30.6	36.5±28.7	76.6±7.3	66.9±16.7	63.3±18.2	74.7±10.1	0.018*	0.007*	0.718 (0.014)

*p<0.05

Boys were affected more than girls.

3.9 Relevance to the main study (study 6)

- This study supplements the findings of study 1 by using a relatively homogeneous group of children. Children with DCD (with limited co-morbidities) have balance and sensory organization deficits, particularly visual and/or vestibular deficits.

- Children with DCD also demonstrate excessive use of hip strategy when standing in sensory conflicting or vestibular-only environments.

- Balance training program that places emphasis on sensory organization and postural control strategies should be explored. Again, this could be TKD (will be proved in the main study).

RESEARCHES ON TAEKWONDO

CHAPTER 4 (STUDY 3): TAEKWONDO TRAINING SPEEDS UP THE DEVELOPMENT OF BALANCE AND SENSORY ORGANIZATION IN YOUNG ADOLESCENTS

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4.1 Rationale of study 3

In studies 1 to 2, we found that children with DCD have impaired sensory organization and postural control. It is well known that sports training can improve sensori-motor elements and efficiency of postural control (Anderson & Behm, 2005; Mesure et al., 1997). Taekwondo (TKD) is a popular sport among young people (Pieter, 2009). Previous studies have shown that TKD training may have positive effects on balance control in the elderly (Brudnak et al., 2002; Cromwell et al., 2007) and in adult populations (Leong et al., 2011), but no study has reported its effects in children and young adolescents. Therefore, in study 3, we pilot tested the potential benefits of TKD (i.e. whether it could facilitate sensory organization and balance development) in young adolescents with normal motor development. If the result was positive, we could implement TKD training in children with DCD (study 6).

4.2 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 functions in young adolescents.

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 pressure 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 three 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.

Keywords: Martial arts, postural control, maturation, sensory organization, stability

4.3 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 (Nashner, 1997). These three sensory systems develop at different rates in children and adolescents (Woollacott & Shumway-Cook, 1990; Woollacott & Shumway-Cook, 1994). Regarding the development of somatosensory function, some studies reported that the somotosensory function matures by nine to twelve years of age (Cherng et al., 2001; Riach & Hayes, 1987) while other studies found that maturation of the somatosensory function occurs much earlier at three to four years of age (Cumberworth et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006).

For the visual function, the time of maturation also varies according to the literature. Cherng and colleagues found that children at seven to ten years old develop the same efficiency of using vision for standing balance as adult (Cherng et al., 2001; Cherng et al., 2003). However, Hirabayashi & Iwasaki (1995) and Cumberworth's research team (2007) 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 & Woollacott (1985 & 2007) suggested that by the age of seven, children are able to balance efficiently with vestibular cues only. However, some researchers reported that vestibular function would fully develop at the age of 15 to 16 (Cumberworth et al., 2007; Ionescu et al., 2006; Steindl et al., 2006). 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 (Peterson et al., 2006; Rine et al., 1998; Shumway-Cook & Woollacott, 2007). Training in dynamic sports such as Judo and gymnastics has been reported to improve postural control of the young athletes (Herpin et al., 2010; Lephart et al., 1996; Perrin et al., 2002).

Taekwondo, besides being an official Olympic sport, is also one of the world's most popular sports among children and adolescents (Pieter, 2009). It is famous with its kicking techniques, in which unilateral stance stability is crucial and is a determining factor of success in competitions (Pieter, 2009). However, only few studies had investigated the effect of TKD training on balance control and most of them focused on the aged population (Brudnak et al., 2002; Cromwell et al., 2007). Regarding the young TKD athletes, Sadowski (2005) reported that balance was amongst the most important 'coordination motor abilities' of elite level athletes 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 (Pieter, 2009), there is a need to examine the impact of TKD training on balance development in young adolescents. This study aimed (1) to identify the developmental status of balance and sensory functions in young adolescents as compared to that in adults, and (2) to explore the balance performance and sensory organization development among adolescent TKD practitioners, adolescent non-TKD practitioners and matured adults.

4.4 Methods

4.4.1 Study design

This was a cross-sectional study.

4.4.2 Participants

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; 13 males and 8 females) who had practised TKD for one to nine years with a minimum of four hours of training per week. Another 21 adolescents were non-TKD practitioners (11 to 14 years old; 14 males and 7 females) 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; 15 males and 9 females) 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 (objectives 1 and 2). The exclusion criteria were the presence of vestibular or visual disorder, musculoskeletal or neurological disorder, history of injury in the past twelve 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 (Appendix IV). 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.

4.4.3 Unilateral Stance Test

Participants stood with bare foot on their non-dominant leg (dominant leg was defined as the one used to kick a ball) for ten 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 side 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 (Figure 4.1). The sway velocity of the center of pressure (COP) was recorded by the machine and three trials were performed with 10 seconds of rest in between (NeuroCom, 2008). The mean COP sway velocity across the three trials was used for analysis.

4.4.4 Sensory Organization Test

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 six different combinations of visual and support surface conditions during the test (Table 4.1). 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 three times in each condition (NeuroCom, 2008).

The machine detected the trajectory of the center of pressure (COP) of the participant which was then used to calculate the equilibrium score (ES) (Nashner, 1997). 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 COP sway angle attained by the participant and θ_{min} is the lowest AP COP 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 (Nashner, 1997). The mean ES of each testing condition across the three 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 4.2).

4.4.5 Statistical analysis

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 three times with 25 normal young participants who were not involved in the main study. The absolute values of COP sway velocity and SOT equilibrium scores for conditions 1 to 6 in the three trials were used to calculate the ICC values.

One-way analysis of variance (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 that were different. For between-group comparisons of the four outcomes of COP 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.

Fig. 4.1 Standardized posture during the Unilateral Stance Test

Table 4.1 The six testing conditions of the Sensory Organization Test

Testing condition	Description
1	Eyes open, fixed support
2	Eyes closed, fixed support
3	Sway-referenced[a] vision, fixed support
4	Eyes open, sway-referenced[a] support
5	Eyes closed, sway-referenced[a] support
6	Sway-referenced[a] vision and support

[a]Sway-referenced – tilting of support surface and/or the visual surround about an axis co-linear with the ankle joints to directly follow the anterior-posterior sways of the participant's centre of gravity (Nashner, 1997; NeuroCom, 2008)

Table 4.2 Sensory analysis ratio and their functional relevance (Nashner, 1997; NeuroCom, 2008)

Sensory ratio[a]	**Computation**	**Functional relevance**
Somatosensory ratio	ES of condition 2 / ES of condition 1	Participant's ability to use input from the somatosensory system to maintain balance.
Visual ratio	ES of condition 4 / ES of condition 1	Participant's ability to use input from the visual system to maintain balance.
Vestibular ratio	ES of condition 5 / ES of condition 1	Participant's ability to use input from the vestibular system to maintain balance.

ES: Three-trial average equilibrium score

[a]The sensory ratios were generated automatically by the SMART Balance Master system; computational formulas are shown

4.5 Results

The ICC value for the UST COP sway velocity was 0.77 (95% CI 0.56-0.89) 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 (Portney & Watkins, 2009).

4.5.1 Demographic characteristics

One-way ANOVA revealed significant differences between the adult participants and the two adolescent groups in age, height and weight, but no difference was found between the adolescent TKD practitioners and non-practitioners (Table 4.3). 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 (Peterson et al., 2006).

4.5.2 Sensory organization and balance performance

Significant between-group differences in the visual ratio ($p<0.001$), vestibular ratio ($p<0.001$) and COP sway velocity ($p<0.001$) were found, but not in the somatosensory ratio ($p=0.711$) (Table 4.4). 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 COP sway velocity in adolescent TKD practitioners was 57.8% higher than the adults while the COP sway velocity in non-TKD adolescents was 150% higher than the adults (Table 4.4).

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 4.4). 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 4.4).

Table 4.3 Comparison of age, height, body weight and gender between adolescent TKD practitioners, adolescent non-TKD practitioners and adult non-TKD practitioners

	TKD adolescents (n=21)	Control adolescents (n=21)	Control adults (n=24)	p value
Mean age±SD (age range), year	13.1±1.0† (11-14)	12.1±1.2† (11-14)	20.2±1.1 (18-23)	<0.001*
Mean height±SD, cm	156.0±9.5†	149.7±8.1†	165.1±7.8	<0.001*
Mean body weight±SD, kg	48.3±10.9†	45.6±7.8†	57.2±8.6	<0.001*
Sex, n	13 males & 8 females	14 males & 7 females	15 males/ 9 females	0.940

*Denotes significant difference at p<0.001 using one-way ANOVA

†Denotes significant difference at p<0.01 between TKD adolescents and control adults, and between control adolescents and control adults

Table 4.4 Comparison of balance control under different sensory conditions and the COP sway velocity in single leg standing among adolescent TKD practitioners, adolescent non-TKD practitioners and adult non-TKD practitioners

Sensory ratio (Mean±SD)	TKD adolescents	Control adolescents	Control adults	p value	Effect size
Somatosensory ratio	0.98±0.02	0.98±0.03	0.98±0.03	0.711	0.01
Visual ratio	0.85±0.10	0.81±0.06	0.93±0.04	<0.001*	0.36
Vestibular ratio	0.62±0.15	0.45±0.20	0.69±0.12	<0.001*	0.30
COP sway velocity in UST, °/s	1.01±0.18	1.60±0.66	0.64±0.12	<0.001*	0.52

*Denotes significant difference at p<0.001 among the three groups by using univariate tests

4.6 Discussion

4.6.1 Development of vestibular function and TKD training

The present study revealed that adolescents (11-14 years old) not involved in TKD training had most body sway in unilateral stance and attained significantly lower vestibular ratio than the adult participants (18-23 years old). 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 (Cherng et al., 2001; Cumberworth et al., 2007; Hirabayashi & Iwasaki, 1995).

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 (Hirabayashi & Iwasaki, 1995; Nashner, 1997). This system also has a role in the vestibulo-ocular reflex (VOR) which stabilizes visual images on the retina during head and body movements (Tanguy et al., 2008). 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 and speed up the development of vestibular function (Pieter, 2009). 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 function in adolescents so that the TKD practitioners out-performed their non-TKD counterparts in the SOT condition 5 (i.e. participants relied primarily on vestibular input to balance). With a well developed vestibular function, 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.

4.6.2 Development of visual function and TKD training

The contribution of vision to balance control is well documented (Nashner, 1997). 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 (Ionescu et al., 2006). The visual function does not fully mature until 15 or 16 years of age (Cumberworth et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006). 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.

4.6.3 Development of somatosensory function and TKD training

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 three or four years and becomes comparable with adult very early on (Cumberworth et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006). 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 (part of the somatosensory system) could be improved by sports training in young athletes (Lephart et al., 1996). The possible explanation of this discrepancy is that the somatosensory ratio, which compared SOT condition 2 to condition 1 (Table 4.2), 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 (Fong & Ng, 2006).

4.6.4 Clinical implication and limitations of the study

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 (Hirabayashi & Iwasaki, 1995; Peterson et al., 2006; Steindl et al., 2006) 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 (Woollacott & Shumway-Cook, 1990) 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.

4.7 Conclusions

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.

4.8 Annex (Study 3)

- There are a number of exercises that help improve balance performance. For example, gymnasts and dancers use somatosensory inputs more than otholitic cues or visual cues for perception of body orientation and balance (Aydin et al. 2002; Bringoux et al., 2000; Golomer et al. 1999a & 1999b; Lephart et al. 1996). Judoists rely heavily on proprioceptive senses to adjust their posture and maintain balance during competitions (Perrin et al. 2002; Perrot et al. 1998a & 1998b). Ironmen are less dependent on vision than normal active subjects in maintainig standing balance (Nagy et al. 2004). Shooters and fencers use proprioceptive and vestibular cues more than vision to stabilize posture and save the visual sense to focus on sports related events (Aalto et al. 1990; Herpin et al. 2010). Synchronized ice skaters depend on the vestibular system to fine tune body posture (Alpini et al. 2008). Cerebral mechanisms for integrating the visual, somatosensory and vestibular inputs might become more effective with prolonged karate training and so result in less body sway in standing (Del Percio et al., 2007). It seems that only synchronized ice skating (and may be karate training) is suitable for children with DCD because of the visual and vestibular training effects. Other sports may not be specific enough to remediate the sensory deficits in this particular group of children. However, synchronized ice skating is not common in the local environment and requires expensive equipment. Therefore, we tried to explore the beneficial effects of a more cost-effective sport, Taekwondo, in study 3.

- Moreover, TKD is an Olympic sport and is a popular martial art among children and adolescents (Park et al., 1989). It is a kind of physical (renowned for its swift kicking techniques) and spiritual training (can improve self-esteem and induce positive mood state) (multi-dimensional exercise) (Toskovic, 2001). TKD practitioners have many opportunities to stand on one leg during training and sparring (Pieter & Heijmans, 2000). Previous studies have shown that TKD training may have positive effects on balance control in the elderly (Brudnak et al., 2002; Cromwell et al., 2007) and in adult populations (Leong et al., 2011). Therefore, we hypothesized that TKD training would also hasten the development of balance and sensory organization ability in normal children/ young adolescents with immature balance systems (studies 3 to 5) as well as in children with DCD (study 6).

- Precision and accuracy of the evaluation devices used in this study are presented in section 2.8 and Table 1.3.

- UST was found to have good known-group validity in children with hearing impairments and typically developing children (De Kegel et al., 2010).

- Sample size calculations were based on a statistical power of 0.80 and an alpha level of 0.05 (two-tailed). Hirabayashi & Iwasaki (1995) previously reported SOT composite equilibrium scores of 68.1±7.3 and 75.7±7.2 for the adolescent group (n=20) and adult group (n=26) respectively, which translates into a large effect size (0.52) (three groups). Based on this study, the minimum sample size needed to detect a significant between-group difference in outcomes (objective 1) is 13 for each group (Portney & Watkins, 2009). For objective 2, Leong et al. (2011) reported the SOT condition 2 mean equilibrium scores of 95.0±1.0 and 93.3±1.8 for the TKD group (n=11) and control group (n=11) respectively, which translates into a large effect size of 0.61 (three groups). Based on Leong et al. (2011)'s study, the minimum sample size needed to detect a significant between-group difference in outcomes (objective 2) is 10 for each group (Portney & Watkins, 2009).

- Participants were recruited from local TKD associations, community & university by convenient sampling. They were included by pediatric physiotherapist. The TKD practitioners had one to nine years of TKD experience (color to black belt qualified) with at least 4 hours of training per week. Volunteers who had regular physical or sport training other than TKD were excluded.

- This pilot TKD study recruited older children (11 to 14 years of age) while previous DCD studies (studies 1 and 2) recruited younger children (6 to 12 years of age). We postulated that if TKD had positive sensory-organization-enhancing effects in older children (with more matured sensory functions), younger children (with developing sensory functions) might also benefit from TKD (motor) training due to greater 'neuro-plasticity'.

- Additional results:

Table 4.5 Comparison of age, height, body weight and gender between adolescent TKD practitioners, adolescent non-TKD practitioners and adult non-TKD practitioners (boys and girls)

	TKD adolescents			Control adolescents			Control adults			p values		
	All (n=21)	Boys (n=13)	Girls (n=8)	All (n=21)	Boys (n=14)	Girls (n=7)	All (n=24)	Boys (n=15)	Girls (n=9)	All	Boys	Girls
Mean age ± SD (range), year	13.1 ± 1.0*	13.2 ± 1.0*	13.1 ± 1.1*	12.1 ± 1.2*	11.9 ± 1.2*	12.6 ± 1.3*	20.2 ± 1.1	20.3 ± 1.2	20.0 ± 1.1	<0.001*	<0.001*	<0.001*
Mean height ± SD, cm	156.0 ± 9.5*	159.5 ± 8.5*	150.3 ± 8.5	149.7 ± 8.1*	148.7 ± 6.9*	151.7 ± 10.4	165.1 ± 7.8	169.3 ± 5.7	158.0 ± 5.2	<0.001*	<0.001*	0.134
Mean body weight ± SD, kg	48.3 ± 10.9*	51.4 ± 10.4*	43.3 ± 10.3	45.6 ± 7.8*	44.4 ± 6.4*	48.0 ± 10.2	57.2 ± 8.6	61.0 ± 8.5	50.7 ± 3.3	<0.001*	<0.001*	0.210
Mean BMI ± SD, kg/m^2	19.7 ± 3.4	20.2 ± 3.7	18.9 ± 2.9	20.2 ± 2.0	20.0 ± 2.0	20.6 ± 2.2	20.9 ± 2.0	21.2 ± 2.2	20.4 ± 1.6	0.289	0.430	0.310

*p<0.05

Table 4.6 Comparison of balance control under different sensory conditions and the COP sway velocity in single leg standing among adolescent TKD practitioners, adolescent non-TKD practitioners and adult non-TKD practitioners (boys and girls)

	TKD adolescents			**Control adolescents**			**Control adults**			**p value**		
	All (n=21)	**Boys (n=13)**	**Girls(n=8)**	**All (n=21)**	**Boys (n=14)**	**Girls (n=7)**	**All (n=24)**	**Boys (n=15)**	**Girls (n=9)**	**All**	**Boys**	**Girls**
Somato-sensory ratio	0.98±0.02	0.98±0.02	0.99±0.02	0.98±0.03	0.98±0.03	0.98±0.03	0.98±0.03	0.98±0.03	0.98±0.03	0.711	0.980	0.422
Visual ratio	0.85±0.10[e, f]	0.83±0.11[a]	0.88±0.06	0.81±0.06[e]	0.80±0.06[a]	0.82±0.07[c]	0.93±0.04	0.93±0.05	0.93±0.03	<0.001*	<0.001*	0.002*
Vestibular ratio	0.62±0.15[f]	0.57±0.16	0.70±0.07[d]	0.45±0.20[e]	0.45±0.18[a]	0.45±0.26[c]	0.69±0.12	0.67±0.12	0.72±0.11	<0.001*	0.002*	0.006*
COP sway velocity in UST	1.01±0.18[e, f]	1.05±0.18[b]	0.96±0.17[d]	1.60±0.66[e]	1.74±0.71[a]	1.33±0.47[c]	0.64±0.12	0.64±0.14	0.64±0.05	<0.001*	<0.001*	<0.001*

* Significant difference at p<0.05 among the 3 groups by using univariate tests.
[a] Significantly different from male control adults (p<0.05).
[b] Significantly different from male control adolescents (p<0.05).
[c] Significantly different from female control adults (p<0.05).
[d] Significantly different from female control adolescents (p<0.05).
[e] Significantly different from control adults (males & females) (p<0.05).
[f] Significantly different form control adolescents (males & females) (p<0.05).

No significant gender effect was observed.

Table 4.7 Correlations with COP sway velocity in UST

	Correlation coefficients		
	Somatosensory ratio in SOT	**Visual ratio in SOT**	**Vestibular ratio in SOT**
COP sway velocity in UST	-0.166	-0.541*	-0.458*

*Significant correlation with COP sway velocity in UST (p<0.001)

4.9 Relevance to the main study (study 6)

- Study 3 provides some evidence of the beneficial effects of TKD training for young people. TKD may facilitate the development of unilateral stance postural control and vestibular function in typically developing adolescents.
- In studies 1 to 2, we found that children with DCD have balance and sensory organization problems, especially the vestibular and visual functions.
- Is TKD a suitable exercise for children with DCD? Can TKD be a therapeutic exercise to remediate the postural control problems in children with DCD? Our main study will provide the answers.

CHAPTER 5 (STUDY 4): SENSORY ORGANIZATION AND STANDING BALANCE IN ADOLESCENT TAEKWONDO PRACTITIONERS OF DIFFERENT TRAINING LEVELS

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- Fong, S.S.M., & Ng, G.Y.F. (2010). The effect of Taekwondo training on balance and sensory performance in young adolescents. *Hong Kong Physiotherapy Journal*, 28, 24.

5.1 Rationale of study 4

In study 3, we found that young adolescents practicing TKD had better single-leg standing balance and that they relied more than non-TKD adolescents on the contribution of vestibular input to balance (ability comparable to that of adults). TKD training appears to speed up the development of postural control. However, participants in study 3 had trained in TKD for one to nine years. From the clinical perspective, it is unrealistic to prescribe long-term (e.g. nine years) balance exercises for children/ adolescents with and without normal development. Therefore, in study 4, we aimed to differentiate long- and short-term training effects of TKD in young adolescents with normal motor development.

5.2 Abstract

Objectives: This study aimed (1) to compare the balance performance between adolescent taekwondo (TKD) practitioners at different levels of expertise with non-practitioners, and (2) to determine the sensory functions that contributed to the balance function in adolescents with and without TKD training.

Methods: Participants with more than five years of TKD training (n=11), less than four years of training (n=10), and no training (n=10) participated in this study. The sway velocity, somatosensory, vestibular and visual ratios were recorded during standing on a balance testing system.

Results: Both short- and long-term TKD practitioners swayed slower than control participants when standing on one leg (p=0.016 and 0.012, respectively). However, only short-term practitioners had better visual ratio (p=0.018) and vestibular ratio (p=0.029) than control participants. There was no significant difference in the somatosensory ratio among the three groups.

Conclusions: We conclude that adolescents undertaking long- or short-term TKD training may have better balance performance than untrained participants.

Keywords: Taekwondo, postural control, proprioception, vision, vestibular system

5.3 Introduction

Taekwondo (TKD) is an Olympic sport and a popular martial art among children and adolescents (Park et al., 1989). Despite its combative nature, it is relatively safe because protective gears are mandatory and practitioners must follow strict rules during competitions. According to Pieter (2005), concussion injuries ranged between 5% and 8.8% of all injuries in young male TKD practitioners whereas for females, it ranged between 8.1% and 9.6%. This injury rate was slightly higher than that reported in judo and karate practitioners. However, more serious injuries like joint dislocation in young TKD practitioners were far lower than those of other martial arts (Pieter, 2005).

TKD is renowned for its swift kicking techniques and practitioners have many opportunities to stand on one leg during training and sparring (Pieter & Heijmans, 2000). Therefore, unilateral stance stability is crucial for TKD practitioners. The ability in balance and postural control is a determining factor for the athletes' performance in competitions (Pieter, 2009) but there have been very few studies investigating the effect of TKD training on balance control. Brudnak and colleagues (2002) was the first group who reported a beneficial effect of TKD training on single leg standing balance in the elderly population. They found an improvement in standing balance time on each leg after 17 weeks of TKD training. However, the major limitation of that study was the lack of a control group due to the dropping out of all the control participants after the study had started and the data were not statistically analyzed. So their conclusion should be interpreted with caution. Later, Cromwell et al. (2007) studied the effect of

TKD training on balance and walking ability in older adults and found that the participants' multi-directional reaching ability, gait stability and walking velocity had more significant improvements after eleven weeks of training than the control group that did not receive any training. They concluded that TKD was effective for improving balance and walking ability in community-dwelling elderly (Cromwell et al., 2007). However, the authors did not report any interaction effect between the two independent variables and did not take the possible confounding factors (e.g. health status) into account.

Hitherto, the scientific evidence on the effect of TKD training on functional balance is patchy and inconclusive. Most previous studies have only focused on the adult population. In light of the increasing popularity of this sport and majority of its practitioners start training at a very young age (Park et al., 1989), there is a need to examine the effect of TKD training on balance in younger population.

The ability for one to maintain balance is dependent on the function of the central nervous system (CNS) in selecting and integrating accurate sensory inputs from the visual, vestibular and somatosensory systems (Nashner, 1997). The use of various sensory information is needed because different types of balance disturbances stimulate different sensors. When one or more of the systems provide misleading information to the CNS, inputs from the other systems might be able to compensate (Nashner, 1997). It has been reported that training in sport activities could enhance the choice of an appropriate sensory cue for balance in young people (Mesure et al., 1997). Sportsmen would select the most appropriate information from the sensory systems in order to maintain posture according to the requirements of their sports. Therefore, it has been well reported that sports training could induce the development of specific postural control strategies (Alpini et al., 2008; Bringoux et al., 2000; Golomer et al., 1999a & 1999b; Herpin et al., 2010; Lephart et al., 1996; Nagy et al., 2004; Perrot et al., 1998a & 1998b). For example, gymnasts and dancers use somatosensory inputs more than otholitic cues or visual cues for perception of body orientation and balance (Bringoux et al., 2000; Lephart et al., 1996). Judoists rely heavily on proprioceptive senses to adjust their posture and maintain balance during competitions (Perrot et al., 1998a). Ironmen are less dependent on vision than normal active participants (Nagy et al., 2004). Shooters and fencers use proprioceptive and vestibular cues more than vision to stabilize posture and save the visual sense to focus on sports related events (Herpin et al., 2010). Synchronized ice skaters depend on the vestibular system to fine tune body posture (Alpini et al., 2008).

Despite the popularity of TKD, no study has investigated the sensori-motor specificities in young TKD practitioners. Therefore, this study aimed (1) to compare the balance performance of adolescent TKD practitioners at different levels of expertise with non-practitioners, and (2) to determine the sensory functions that contributed to the balance performance in adolescents with and without TKD training. We hypothesized that TKD practitioners had better balance ability and could develop specific sensory organization specific to the combative kicking nature of TKD. Findings of this study might provide the evidence of and insight for designing specific balance exercises for young adolescents in order to enhance their sensory organization and balance ability.

5.4 Methods

5.4.1 Study design

This was a cross-sectional study.

5.4.2 Participants

Thirty-one participants (19 males and 12 females; 11 to 14 years old) volunteered for this study. Eleven were long-term TKD practitioners with five to nine years of TKD experience and black belt qualified. Ten participants were short-term TKD practitioners with one to four years of TKD experience and not black belt qualified (Table 5.1). All TKD participants were trained for a minimum of four hours per week. The other ten were normal control participants without previous experience in TKD or other martial arts. The exclusion criteria were the presence of vestibular or visual disorders, musculoskeletal or neurological diseases, history of injury in the past twelve months requiring medical attention, and regular training in sports other than TKD. The study was approved by the human participants ethics review subcommittee of the Hong Kong Polytechnic University (Appendix IV). The procedures were fully explained to the participants and their parents, who gave their written consents before testing. All procedures of this study were performed in accordance with the Declaration of Helsinki.

Table 5.1 Comparison of age, height, body weight and sex between long-term, short-term TKD practitioners and control participants

	Long-term TKD group (n=11)	Short-term TKD group (n=10)	Control group (n=10)	p value
Mean age±SD (range), year	13.4±0.8 (12-14)	12.9±1.2 (11-14)	12.3±1.3 (11-14)	0.102
Mean height±SD, cm	156.4±7.3	155.6±11.8	149.6±10.2	0.254
Mean body weight±SD, kg	49.2±8.5	47.3±13.4	46.5±9.0	0.830
Sex, n	7 males & 4 females	6 males & 4 females	6 males & 4 females	

5.4.3 Unilateral Stance Test (UST)

The participants took a single leg standing balance test with a Computerized Dynamic Posturography machine (NeuroCom International Inc., Smart Equitest ® system) by barefoot standing with their non-dominant leg on the machine for ten seconds. During the test, a standardized posture was adopted with arms by the side of trunk, eyes looking forward and the hip of the non-supporting leg flexed at 45° so as to resemble the starting position of front kick in TKD practice (Figure 5.1). The sway velocity of the center of pressure (COP) was recorded by the machine (NeuroCom, 2008). Three trials were performed with a ten-second rest in between. The mean COP sway velocity across the three trials was obtained and then used for analysis.

Fig. 5.1 Standardized posture in the Unilateral Stance Test

5.4.4 Sensory Organization Test

After the UST, postural sway was assessed in bipedal stance under reduced or conflicting sensory conditions with the Sensory Organization Test (SOT). The SOT is commonly used to evaluate the participant's ability to make effective use of visual, vestibular and somatosensory inputs separately and filter out inappropriate sensory information when they are maintaining balance.

Participants stood with bare foot on the platform of the Computerized Dynamic Posturography (CDP) machine (NeuroCom International Inc., Smart Equitest® system). They wore a security harness to prevent fall. All participants were asked to stand still with arms resting on both sides of the trunk and eyes looking forward. During the test, participants were exposed to six different combinations of visual and support surface conditions (Table 5.2).

Participants were asked to ignore any motion in the supporting surface or visual surround and remain in an upright position as steadily as possible for 20 seconds. If the participants took a step or required assistance of the harness, the trial was rated as a fall (NeuroCom, 2008). Each participant was tested for three times in each condition.

Table 5.2 The six testing conditions of the Sensory Organization Test

Testing condition	Description
1	Eyes open, fixed support
2	Eyes closed, fixed support
3	Sway-referenced[a] vision, fixed support
4	Eyes open, sway-referenced[a] support
5	Eyes closed, sway-referenced[a] support
6	Sway-referenced[a] vision and support

[a]Sway-referenced – tilting of support surface and/or the visual surround about an axis co-linear with the ankle joints to directly follow the anterior-posterior sways of the participant's centre of gravity (NeuroCom, 2008)

The machine detected the trajectory of the center of pressure (COP) of the participant which was then used to calculate the equilibrium score (ES) (Nashner, 1997). Equilibrium score was defined as the non-dimensional percentage which compared the participant's peak amplitude of antero-posterior (AP) sway to the theoretical limits of antero-posterior stability (12.5°). The theoretical limit of stability was influenced by the individual's height and size of the supporting base. It represents an angle (8.5° anteriorly and 4.0° posteriorly) 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 by the NeuroCom software with the formula:

$$12.5° - [(\theta_{max} - \theta_{min})/12.5°] \text{ x } 100$$

where θ_{max} is the greatest AP COP sway angle attained by the participant and θ_{min} is the lowest AP COP sway angle. An ES of 100 represented no sway (excellent balance control), whereas 0 indicated a sway exceeding the limit of stability, resulting in a fall (Herpin et al., 2010; Nashner, 1997). After obtaining the ES, the mean equilibrium scores of each testing condition across the three trials were calculated and these averaged scores were used to calculate the somatosensory, visual and vestibular ratios (Table 5.3). These three sensory ratios were then used to identify the significance of each sensory system in balance control. High sensory ratio of close to 1 reflected the participant had superior ability to rely on that particular sensory input for balance (Nashner, 1997).

Table 5.3 Sensory analysis ratios and their functional relevance

Sensory ratio[a]	Computation	Functional relevance
Somatosensory ratio	ES of condition 2 / ES of condition 1	Participant's ability to use input from the somatosensory system to maintain balance.
Visual ratio	ES of condition 4 / ES of condition 1	Participant's ability to use input from the visual system to maintain balance.
Vestibular ratio	ES of condition 5 / ES of condition 1	Participant's ability to use input from the vestibular system to maintain balance.

ES: Three-trial average equilibrium score
[a]The sensory ratios were generated automatically by the SMART Balance Master system (Nashner, 1997; NeuroCom, 2008)

5.4.5 Statistical analysis

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

SPSS version 17.0 was employed for all statistical analyses. The level of significance was set at 0.05. Normality of data was first checked with Shapiro-Wilk tests. One-way analysis of variance (ANOVA) was used to compare the age, height and body weight among the three groups. For between-group comparisons of the four outcomes, namely, COP 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. Cohen's d, which is the standardized measure of effect size between two groups, was also presented for each primary outcome. By convention, Cohen's d values of 0.20, 0.50, and 0.80 are considered to be small, medium, and large, respectively (Portney & Watkins, 2009).

5.5 Results

The ICC value for the COP sway velocity was 0.77 which indicated a good reliability for the UST. 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.

5.5.1 Demographic characteristics

Between-group comparisons revealed no significant difference in age, height, body weight and sex among the three groups (Table 5.1). In addition, the numbers of male and female participants were similar across the three groups.

5.5.2 Sensory organization and balance performance

Univariate tests revealed significant differences in visual ratio, vestibular ratio and COP sway velocity, but not the somatosensory ratio among the three groups (Table 5.4). Post hoc analyses revealed that both short-term and long-term TKD practitioners had swayed significantly slower than the control participants during single leg stance with eyes open. The COP sway velocity in long-term TKD practitioners was 36% less than the controls while the COP sway velocity in short-term TKD practitioners was 35.4% less than the controls (Table 5.4). However, only short-term TKD practitioners had better visual ratio than the control participants and they even outperformed the long-term TKD practitioners. The short-term TKD practitioners also had better vestibular ratio than the control participants but there was no significant difference in the somatosensory ratio among the three groups and the effect sizes for the different group comparisons ranged from 0.39 (medium) to 1 (large) (Table 5.5).

Table 5.4 Comparison of balance control under different sensory conditions and the COP sway velocity in single leg standing among long-term, short-term TKD, and control participants

Sensory ratio	Long-term TKD participants	Short-term TKD participants	Control participants	Effect size (f)	p value
Somatosensory ratio±SD	0.98±0.03	0.99±0.02	0.97±0.02	0.40	0.476
Visual ratio±SD	0.81±0.11	0.90±0.05	0.80±0.05	2.22	0.011*
Vestibular ratio±SD	0.57±0.17	0.67±0.09	0.46±0.23	4.22	0.033*
COP sway velocity in UST±SD, °/s	1.01±0.14	1.02±0.22	1.58±0.68	13.21	0.006*

*Denotes significant difference at $p<0.05$ among the three groups by using univariate tests

Table 5.5 Effect sizes and p values for the pairwise comparisons

	Long-term Vs short-term TKD participants		**Long-term TKD Vs control participants**		**Short-term TKD Vs control participants**	
	Effect size (d)	**p value**	**Effect size (d)**	**p value**	**Effect size (d)**	**p value**
Somatosensory ratio	0.39	1.000	0.39	1.000	1.00	0.683
Visual ratio	1.05	0.036*	0.12	1.000	2.00	0.018*
Vestibular ratio	0.74	0.587	0.54	0.419	1.20	0.029*
COP sway velocity in UST	0.05	1.000	1.16	0.012*	1.11	0.016*

*Denotes significant difference at $p<0.05$

5.6 Discussion

5.6.1 TKD training and single leg standing balance control

The present study revealed that both short-term and long-term TKD practitioners had significantly slower body sway than the control participants during non-dominant leg standing. The superior upright unilateral stance stability in the young TKD participants may result from the repeated practice of high kicks during training. According to the competition rules, kicks to the head would score more points than the trunk and fast offensive kicks have accounted for more than half of the techniques used to score points during TKD competitions (Kazemi et al., 2006). Practicing high kicks requires high level of balance thus improve the postural regulation in unilateral stance (Paillard et al., 2006).

Del Percio et al. (2009) studied the neuro-physiological mechanisms of improved standing balance in elite karate (a martial sport similar to TKD) athletes and suggested that practice of frequent kicking to a mobile visuo-spatial target enabled the athletes to cope with highly demanding visual-somatosensory-vestibular integration. Cerebral mechanisms for integrating the visual, somatosensory and vestibular inputs might become more effective with prolonged training and result in less body sway in standing. Furthermore, Perrin et al. (1998) proposed that athletes of combat sports could improve adaptive postural control with the skills acquired in training. TKD practitioners might develop better postural adjustment strategies and body alignment during kicking and blocking which would all improve body balance (Violan et al., 1997). These could explain the phenomenon that TKD participants swayed less in UST than the control participants.

5.6.2 TKD training and visual function

The contribution of vision to balance has been well documented (Nashner, 1997). The current study revealed that short-term TKD practitioners had significantly better visual ratio in the SOT than long-term TKD practitioners and control participants. This implies that short-term TKD practitioners relied more on visual input to balance than long-term practitioners and control participants.

Vision is important for orientating the body parts in space during form practice (Golomer et al., 1999a & 1999b). Through TKD training, participants could develop superior attention focus on changing visual cues. It has been suggested that athletes in combat sports such as karate and fencing would maximize the changing visual information in order to maintain upright standing (Del Percio et al., 2007). It is possible that this change also happens in TKD practitioners.

However, our results revealed that long-term TKD practitioners had less reliance on visual input for balance than short-term practitioners. This is in agreement with the reports by many researchers who studied balance ability in athletes of different sports (Bringoux et al., 2000; Golomer et al., 1999a & 1999b; Mesure et al., 1997; Paillard et al., 2006; Perrot et al., 1998b). For example, Perrot and his team found that balance control improved and the influence of visual input decreased with increasing level of expertise in karate and French boxing athletes (Perrot et al., 1998b). Paillard et al. (2006) reported that non-professional soccer players were more dependent on vision for balance than players of the national team. The authors hypothesized that the elite players had better internal postural representations thus saving the vision for the information that emanated from the game. Bringoux et al. (2000) also postulated that prolonged intensive gymnastics training would develop a more complete and precise internal model of verticality. Furthermore, it has also been reported that professional dancers had higher accuracy of proprioceptive inputs and they would shift the sensori-motor dominance from vision to proprioception (Golomer et al., 1999a & 1999b; Mesure et al., 1997).

Vecchio et al. (2008) explained the phenomenon of decreased visual reliance with increasing sports experience from the neuro-physiological perspective that visual information would affect the cortico-muscular coherence in upright standing in untrained participants and amateur karate practitioners only, but not in elite practitioners. In elite athletes, long-term training could sharpen the proprioceptive and tactile sensory routes and these would contribute to postural stability thus reducing the reliance on visual sense (Vecchio et al., 2008).

The ability to balance on one leg is an essential skill of experienced TKD athletes so that during competition, they can spare their visual attention to their opponents' actions and find opportunities to attack. Thus, postural control might become subconscious in advanced practitioners. Less reliance on visual input for balance could also prevent over dependence on a sensor that relay external cues only (Herpin et al., 2010). This would enable the TKD practitioners to balance effectively in a moving visual surround such as during turning or spinning kicks.

5.6.3 TKD training and somatosensory function

Previous studies suggested that proprioception could be improved by sports training (Golomer et al., 1999a & 1999b; Lephart et al., 1996; Perrot et al., 1998a; Violan et al., 1997). For example, elite soccer players and dancers had improved proprioceptive capacities and shifted the sensori-motor dominance from vision to proprioception for postural adjustment (Golomer et al., 1999a & 1999b). Judo training would improve proprioception in dynamic situations (Perrot et al., 1998a) similar to gymnastics training on knee and ankle joint proprioception (Lephart et al., 1996). School boys trained in karate had demonstrated larger improvements in standing balance with eyes closed than eyes open and this suggested that proprioception had improved with karate training (Violan et al., 1997).

Contrary to the above findings, the present study demonstrated that the somatosensory ratios in both TKD groups were similar to the control group. This could be due to the inadequate number of participants thus compromising the statistical power. In fact, the effect size between short-term TKD group and control group was large (Table 5.5) which is suggestive that short-term TKD practitioners might have better somatosensory function than non-practitioners. Further study should include more participants to confirm this finding.

5.6.4 TKD training and vestibular function

The present study revealed that short-term TKD practitioners relied more on vestibular input for balance than control participants. In light that TKD training involves acrobatic jump kicks and spinning kicks, these would stimulate the vestibular system and function and might increase its sensitivity (Tanguy et al., 2008). The vestibular system is the most reliable sensor, especially in challenging conditions, because it does not rely on external references for postural control. Rather, it measures gravitational, linear and angular accelerations of the head in relation to inertial space or gravity (Nashner, 1997). A sensitive vestibular system would thus enable the TKD practitioners to maintain stability in challenging conditions such as performing spinning kicks on mattress.

Apart from being an organ for balance, the vestibular system also transmits information that triggers the vestibulo-ocular reflex which is important for stabilizing the visual images on the retina during head and body movements by rotating the eyes in an opposite direction to head movement. Therefore, with a sensitive vestibular function, the short-term TKD practitioners could also use vision to enhance balance during movements (Tanguy et al., 2008).

5.6.5 Limitations and suggestions for future studies

There were some limitations in this study that need to be considered when interpreting the findings. First, the present study showed a relationship between TKD experience and postural ability but whether this relationship is influenced by the amount of training or natural predispositions is not known. This would best be tested by a longitudinal study. Second, the number of participants in this study was small. Further study should include more participants in order to differentiate the balance and sensory abilities between TKD practitioners and non-practitioners. Third, more studies are needed to confirm which sensory/ motor system(s) had contributed to the better single leg standing balance in the long-term TKD practitioners. Finally, maturity of the participants and the age at which they started TKD training should also be considered in future studies as they may have an effect on the balance performance.

5.7 Conclusions

We conclude that young TKD practitioners have better balance control than non-practitioners. Less experienced TKD practitioners might rely more heavily on their visual and vestibular inputs for balance whereas experienced practitioners may rely more on the vestibular input. Further study should explore the longitudinal training effect of TKD so as to develop the evidence base for this exercise option to improve balance for adolescents.

5.8 Annex (Study 4)

- This study attempted to differentiate the long-term and short-term training effects of TKD in healthy young individuals. It provides foundation knowledge for designing the TKD exercise used in the main study (in children with DCD). Both studies 4 and 6 used the same outcome measures to document the potential benefits of TKD training.

- Precision and accuracy of the evaluation devices used in this study are presented in sections 2.8 and 4.8, and Table 1.3.

- Sample size calculation was not done. Data of study 3 was re-analyzed: (1) differentiate long-term (n=11) and short-term (n=10) TKD practitioners; (2) 10 sex-/ weight-/ height-matched control participants were selected.

- Participants were recruited from local TKD associations, community & university by convenient sampling. They were included by pediatric physiotherapist. The short-term TKD practitioners had one to four years of TKD training experience (color belt qualified) with at least 4 hours of training per week. The long-term practitioners had five to nine years of TKD experience and were black belt qualified. Their training frequency and intensity were same as the short-term practitioners. Volunteers who had regular physical or sport training other than TKD were excluded.

• Additional results:

Table 5.6 Comparison of age, height, body weight and sex between long-term, short-term TKD practitioners and control participants (boys and girls)

	Long-term TKD practitioners			Short-term TKD practitioners			Controls			p value		
	All (n=11)	**Boys (n=7)**	**Girls (n=4)**	**All (n=10)**	**Boys (n=6)**	**Girls (n=4)**	**All (n=10)**	**Boys (n=6)**	**Girls (n=4)**	**All**	**Boys**	**Girls**
Mean age ± SD, year	13.4 ± 0.8	13.1 ± 0.9	13.8 ± 0.5	12.9 ± 1.2	13.2 ± 1.2	12.5 ± 1.3	12.3 ± 1.3	11.8 ± 1.0	13.0 ± 1.4	0.102	0.056	0.342
Mean height ± SD, cm	156.4 ± 7.3	157.1 ± 7.5	155.0 ± 7.8	155.6 ± 11.8	162.3 ± 9.4 (sig. diff. from male controls, p=0.028)	145.5 ± 6.8	149.6 ± 10.2	147.5 ± 9.2	152.8 ± 12.1	0.254	0.028*	0.356
Mean body weight ± SD, kg	49.2 ± 8.5	48.5 ± 10.2	50.6 ± 5.7	47.3 ± 13.4	54.8 ± 10.6	36.0 ± 8.6	46.5 ± 9.0	45.1 ± 7.9	48.7 ± 11.4	0.830	0.236	0.090
Mean BMI ± SD, kg/m^2	20.1 ± 2.6	19.5 ± 3.0	21.0 ± 1.4	19.3 ± 4.2	20.9 ± 4.6	16.8 ± 2.4	20.7 ± 2.3	20.7 ± 2.5	20.6 ± 2.5	0.628	0.738	0.039*

*p<0.05

Table 5.7 Comparison of balance control under different sensory conditions and the COP sway velocity in single leg standing among long-term, short-term TKD, and control participants (boys and girls)

	Long-term TKD practitioners			Short-term TKD practitioners			Controls			p value		
	All (n=11)	Boys (n=7)	Girls (n=4)	All (n=10)	Boys (n=6)	Girls (n=4)	All (n=10)	Boys (n=6)	Girls (n=4)	All	Boys	Girls
Somato-sensory ratio	0.98 ± 0.03	0.98 ± 0.03	0.99 ± 0.03	0.99 ± 0.02	0.98 ± 0.02	1.00 ± 0.01	0.97 ± 0.02	0.98 ± 0.03	0.96 ± 0.02	0.476	0.966	0.072
Visual ratio	0.81 ± 0.11[a]	0.78 ± 0.13	0.86 ±0.07	0.90 ± 0.05[b]	0.90 ± 0.05[c]	0.91 ± 0.06	0.80 ± 0.05	0.77 ± 0.03	0.84 ± 0.04	0.011 *	0.031 *	0.291
Vestibular ratio	0.57 ± 0.17	0.50 ± 0.18	0.70 ± 0.04	0.67 ± 0.09[b]	0.65 ± 0.09	0.71 ± 0.09	0.46 ± 0.23	0.52 ± 0.15	0.36 ± 0.31	0.033 *	0.193	0.047 *
COP sway velocity in UST, °/s	1.01 ± 0.14[b]	1.03 ± 0.14[c]	0.98 ± 0.15	1.02 ± 0.22[b]	1.07 ± 0.23[c]	0.95 ± 0.21	1.58 ± 0.68	1.78 ± 0.76	1.28 ± 0.48	0.006 *	0.016 *	0.312

* Significant difference at $p<0.05$ among the 3 groups by using univariate tests.
[a] Significantly different from short-term TKD practitioners (males & females) ($p<0.05$).
[b] Significantly different from control adolescents (males & females) ($p<0.05$).
[c] Significantly different from male control adolescents ($p<0.05$).

5.9 Relevance to the main study (study 6)

- Based on the results of study 3, this study found that only a relatively short period (more than one year) of TKD training is needed in order to have the beneficial effects (i.e. better single leg standing balance, visual and vestibular functions).
- In the previous study (study 3), we found that TKD practitioners (1 to 9 years of TKD experience) relied on visual input to balance that is similar to the controls. However, in this study, we realized that only long-term TKD practitioners relied on visual input to balance similarly as controls. Short-term TKD practitioners relied more on visual input to balance than controls.
- We can now refine the research question: Can short-term TKD training remediate the postural control problems in children with DCD? Our main study will provide the answer.
- Moreover, this study guides the design of the TKD training program (e.g. optimal duration of training) in the main study. The short-term TKD practitioners in this study practiced TKD for at least a year (four hours per week) that is equivalent to 192 hours of TKD training.
- The TKD training regime in the main study would also consist of a minimum of 150 training hours that is comparable to the training intensity received by the short-term TKD practitioners in this study.

CHAPTER 6 (STUDY 5): LOWER LIMB JOINT SENSE, MUSCLE STRENGTH AND POSTURAL STABILITY IN ADOLESCENT TAEKWONDO PRACTITIONERS

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- Fong, S.S.M., & Ng, G.Y.F. (2010, November 6). The effect of Taekwondo training on leg muscle strength, joint sense and balance in adolescents. Paper presented at *Conference on Public Health and Preventative Medicine 2010*, Hong Kong.
- Fong, S.S.M., & Ng, G.Y.F. (2010, September 11). The effect of Taekwondo training on sensori-motor performance and balance in adolescents in Hong

Kong. Paper presented at *Health Research Symposium 2010: Improving Health and Recognizing Excellence,* Hong Kong. Hong Kong: Food and Health Bureau, The Government of the Hong Kong Special Administrative Region.

6.1 Rationale of study 5

As a continuation of study 4, we explored more potential benefits of long-term and short-term TKD training in adolescents with normal motor development. It is well documented that postural stability requires contributions from multiple systems (Nashner, 1997). Apart from sensory contributions from the somatosensory, visual and vestibular systems (addressed in study 4), motor responses and lower limb muscle strength are also important factors that affect postural stability in athletes (Bressel et al., 2007; Horak, 2006). Therefore, in study 5, we explore the knee joint proprioceptive sense, knee muscle strength and correlate them with the single leg standing balance performance in adolescent TKD practitioners.

6.2 Abstract

Objectives: This study aimed (1) to compare the effects of short-term and long-term taekwondo (TKD) training on the lower limb joint proprioception, muscle strength and balance performance of adolescents, and (2) to explore the relationships among these outcome measures.

Methods: Thirty-one adolescents including long-term (n=11), short-term (n=10), and non-practitioners (n=10) of TKD participated in the study. The knee joint position sense, isokinetic strength of the quadriceps and hamstrings, and body sway in prolonged single leg standing were measured.

Results: Long-term TKD practitioners made significantly smaller errors in knee joint repositioning test than the control group. No significant difference was found in the body-weight-adjusted isokinetic peak torque of the quadriceps or hamstrings among the three groups. Both short- and long-term TKD practitioners swayed significantly slower than control participants while standing on one leg. Moreover, the accuracy of knee joint angle repositioning was significantly correlated with sway velocity.

Conclusions: More than one year of TKD training might improve single leg standing balance. The better postural stability demonstrated by long-term TKD practitioners might be associated with better knee joint position sense rather than knee muscle strength.

Keywords: Taekwondo, balance, muscle strength, proprioception

6.3 Introduction

Sports training can improve sensori-motor performance and postural control (Anderson & Behm, 2005; Mesure et al., 1997). Previous studies have shown that experienced dancers, gymnasts and soccer players have static and dynamic balance superior to those of non-sportsmen (Davlin, 2004; Golomer et al., 1999a & 1999b; Paillard et al., 2006). Taekwondo (TKD) is a sport renowned for its swift kicks and fast actions. Dynamic standing balance, particularly on one leg, is therefore expected to be better in TKD practitioners. Indeed, the ability to maintain single leg standing balance is crucial in TKD competitions (Pieter, 2009) and is also essential in many daily activities such as donning pants and ascending or descending stairs (NeuroCom, 2008).

Some young people with motor control problems (e.g. children with developmental coordination disorder) demonstrate deficits in balancing on one leg and falls and injuries in their daily activities result (Grove & Lazarus, 2007). TKD may be an exercise which can improve single leg standing balance in this population, but no study has investigated the effect of TKD training on single leg standing balance in young people. Previous studies report only that TKD training might have positive effects on the balance control of the elderly. A group led by Brudnak, for example (Brudnak et al., 2002) was the first to demonstrate a positive effect of short-term TKD training (17 weeks) on the single leg standing balance of the elderly. However, all of the participants dropped out of their control group and the results could not be statistically analyzed. Their conclusions must therefore be interpreted with caution. Later, Cromwell's group also reported (Cromwell et al., 2007) that multi-directional reaching ability, gait stability and walking velocity in the elderly were improved after 11 weeks of TKD training. But they did not take possible confounding factors (e.g. health status) into account.

Our group has recently demonstrated that young people with low-level TKD training (mean age 20.9 years) had better balance than their untrained counterparts. This might be because TKD practitioners relied more on somatosensory and vestibular inputs to maintain balance in the face of conflicting sensory stimuli and in landing from height without visual input (Leong et al., 2011). Those results deepen our understanding of balance and sensory organization in young TKD practitioners, but their single leg balance ability per se remains unknown. Moreover, which component of the somatosensory system (e.g. tactile sensation, joint proprioception) could be strengthened by TKD training remains elusive.

Lower limb joint proprioception is known to play a key role in maintaining normal body posture (Gardner et al., 2000), and it can be strengthened by training in judo, golf or tai chi (Fong & Ng, 2006; Perrot et al., 1998a & 1998b; Tsang & Hui-Chan, 2004b). Our previous study hinted that TKD practitioners swayed significantly less than healthy control adults when compelled to rely more on somatosensory input for maintaining balance (Leong et al., 2011). This suggests that lower limb joint proprioception might also improve with TKD training.

Postural stability requires contributions from multiple systems. Apart from the sensory contributions, motor responses and leg strength are also important factors (Bressel et al., 2007; Horak, 2006). Increased knee muscle strength is known to be associated with better postural control in elderly tai chi practitioners (Tsang & Hui-Chan, 2005). There have been some research results which support the proposition that TKD training can improve lower limb muscle strength (Pieter et al., 1989; Fong & Tsang, 2012), but no study has yet linked this up with the balance performance of young TKD practitioners. It is important to elucidate the sport-specific balance strategies of young TKD practitioners if TKD is to be suggested as an exercise to improve the balance of young people with balance difficulties.

This study was therefore designed to compare (1) knee joint proprioceptive sense, (2) lower limb muscle strength, and (3) single leg standing balance performance of adolescent TKD practitioners at different levels of expertise with that of adolescent non-TKD practitioners. In addition, it explored the relations between knee joint proprioception, knee muscle strength and balance performance in TKD practitioners. The findings were intended to shed light on the potential use of TKD in a rehabilitation program for children or adolescents with balance difficulties.

6.4 Methods

6.4.1 Study design

This was a cross-sectional study.

6.4.2 Participants

Thirty-one participants (19 males and 12 females) aged 11 to 14 years old volunteered for this study. Eleven of them were long-term TKD practitioners who had practiced TKD for five to nine years and reached the black belt level. Ten were short-term TKD practitioners who had practiced TKD for one to four years and not yet earned a black belt. The rest were normal controls who were of average fitness for their age but not involved in TKD or any other martial arts training.

The exclusion criteria were the presence of any vestibular or visual disorder, a significant musculoskeletal problem, any neurological disease, a history of significant injury in the past twelve months, or regular involvement in other organized sports. This study was approved by the human subjects ethics review subcommittee of the Hong Kong Polytechnic University (Appendix IV). The procedures were fully explained to the participants and they all gave their written consent before testing. All procedures were performed in accordance with the Declaration of Helsinki.

6.4.3 Knee joint angle active repositioning

Each participant was blindfolded and positioned lying on the non-dominant side on a plinth. Their dominant leg was suspended horizontally in slings, and both hips were kept at 45° of flexion. The dominant leg was defined as the one the participant claimed to use for kicking a ball. Only the dominant leg was tested because there is no difference in knee joint position sense between the dominant and non-dominant side in young athletes such as handball players (mean age 23.5 years) (Panics et al., 2008). To minimize the influence of cutaneous stimulation of the calf, an air splint was applied to the participant's foot and ankle. An electrogoniometer (Penny and Giles Biometric Ltd, XM180) was attached on the lateral side of the knee along the femur and fibula to measure the knee joint angle (Fong & Ng, 2006) (Figure 6.1).

Since the midrange of knee flexion has been shown to be most reliable for joint repositioning measurements (Tsang & Hui-Chan, 2004b), the starting position was set at 35° of knee flexion (Corrigan et al., 1992). The examiner slowly moved the knee to a random new position within the range of 20° to 75°. Held it there for three seconds, and then returned it to the starting position. Five seconds later, the participant was asked to actively reproduce the previous position. The angle that the participant reproduced was recorded and the absolute error was calculated. Three trials were conducted at different angles with 30 seconds of rest between trials. The three absolute error values were averaged, and this value was used for comparison across the three groups (Lam et al., 2002; Fong & Ng, 2006).

6.4.4 Isokinetic knee muscle strength

The isokinetic concentric muscle strength of the knee extensors and flexors of each participant's dominant leg was tested using a Cybex Norm isokinetic dynamometer (Computer Sports Medicine, Inc., Stoughton, MA). Only the dominant leg was tested because there is no significant difference in the isokinetic peak torques of the quadriceps and hamstrings between the dominant and non-dominant limbs in the normal young population (Holmes & Alderink, 1984). Each participant sat on the chair of the machine, with the hips in 85° of flexion. The knee joint axis of the dominant leg was aligned with the dynamometer axis. The participant's trunk and thigh were stabilized with straps such that the starting position was full knee flexion, and the endpoint was full knee extension (Figure 6.2). The speed of testing was set at 180 °/s. Familiarization trials were performed in the form of three sub-maximal and three maximal concentric quadriceps and hamstring contractions (Chan et al., 1996). After correcting for the gravitational effect on knee torque, five maximal concentric contractions of the quadriceps and hamstrings were recorded as a test ensemble (CSMI, 2005). The average values of the five body-weight-adjusted peak torques were used for analysis.

Fig. 6.1 Knee joint angle passive positioning and active repositioning test

Fig. 6.2 Isokinetic testing of knee flexors and extensors

6.4.5 Standing balance (Unilateral Stance Test)

A Smart Equitest® computerized dynamic posturography machine (NeuroCom International Inc., OR, USA) was used to measure single leg standing balance. Each participant stood on the platform for ten seconds on their non-dominant leg, barefoot with their eyes focused on a distant visual target. The standardized posture was with the arms on either side of trunk, eyes looking forward and the dominant leg flexed at 45° at the hip so that the foot was off the ground. This posture simulates the TKD kicking posture (Figure 5.1). The non-dominant leg was tested instead of the dominant leg (as in the other two tests) because during TKD practice, the practitioners usually support themselves on their non-dominant leg and kick with their dominant one (Pieter, 2009). The sway velocity of the center of pressure (COP) in all directions, which reflects stability of the center of gravity, was measured by sensors mounted on the support surface (NeuroCom, 2008). Three trials were performed with 10 seconds of rest in between. The mean COP sway velocity across three trials was used for analysis.

6.4.6 Statistical analysis

Intraclass correlation coefficients ($ICC_{3,3}$) were calculated to assess the test-retest reliability of the Unilateral Stance Test (UST), knee joint angle repositioning test and the isokinetic muscle strength test using data from another group of adolescents similar in age to the studied groups. Each outcome measure was tested three times with five participants (isokinetic test), 10 participants (knee joint angle repositioning test) or 25 participants (UST) within the same day. The absolute values of COP sway velocity, knee joint angle repositioning error, and isokinetic peak torque of the quadriceps and hamstring over the three trials were used to calculate the ICCs.

One-way analysis of variance (ANOVA) was used to compare age, height and body weight among the three groups. Sex was compared using a Chi-square test. One-way ANOVA was also performed to determine if there were significant differences among the three groups in the outcome measurements (i.e. knee joint angle repositioning error, isokinetic peak torque of the quadriceps and hamstring muscles, and COP sway velocity). Significant results were further analyzed with post hoc Bonferroni multiple comparisons to control for type I error. A significance level of 0.05 was adopted for all the statistical comparisons. Pearson's correlation coefficient (two-tailed) was also calculated to examine the relationship among the four outcome measures among the TKD practitioners.

6.5 Results

The ICC value for the COP sway velocity was 0.77 (95% CI: 0.56-0.89). For the knee joint angle repositioning error it was 0.62 (95% CI: -0.11-0.90). For the isokinetic peak torque of the quadriceps and hamstring muscles it was 0.94

(95% CI: 0.43-0.99) and 0.88 (95% CI: -0.20-0.99) respectively. These ICC results indicate moderate to good reliability for all the tests (Portney & Watkins, 2009).

6.5.1 Demographic characteristics

There was no significant difference in age, height, body weight or sex distribution among the three groups (Table 6.1).

6.5.2 Single leg standing balance and knee joint proprioception

The results of the ANOVA were significant only for UST COP sway velocity ($p<0.01$) and knee joint angle repositioning error ($p<0.01$). Post hoc Bonferroni multiple comparisons revealed that both short-term and long-term TKD practitioners swayed significantly slower than control participants while standing on the non-dominant leg with their eyes open ($p<0.05$ in both cases). The COP sway velocity of long-term TKD practitioners was 36% less than among the control group, while the short-term TKD practitioners had 35.4% slower sway than the control group (Tables 6.2 & 6.3).

For the knee joint angle repositioning error, post hoc Bonferroni multiple comparisons revealed that on average, long-term TKD practitioners had smaller errors (47.7%; $p<0.01$) than the control participants. There was no significant difference, however, between errors of the long- and short-term TKD practitioners.

6.5.3 Knee muscle strength

ANOVA did not reveal any significant difference in the average isokinetic peak torque of either the quadriceps or the hamstrings among the three groups, and the effect sizes for the TKD and control group comparisons ranged from 0.42 to 0.88 (Tables 6.2 & 6.3).

6.5.4 Relationships among single leg standing balance, knee joint proprioception and knee muscle strength in TKD practitioners

COP sway velocity was moderately correlated with knee joint angle repositioning error ($r=0.499$, $p<0.01$) in the TKD practitioners ($n=21$). However, there was no significant correlation between COP sway velocity and the isokinetic strength of the quadriceps or hamstring muscles.

6.6 Discussion

6.6.1 Single leg standing balance

Both short-term and long-term TKD practitioners swayed more slowly, on average, than the control participants when standing on their non-dominant leg. COP sway velocity has often been used to indicate postural stability in children (Nolan et al., 2005) because it reflects the performance of the open-loop postural control mechanism (Chiari et al., 2000) and is important in controlling ankle extensor activities during quiet stance (Masani et al., 2003). Our results show that TKD practitioners have better postural stability in unilateral stance than their untrained counterparts. Indeed, this is probably a determining factor in their success in competition (Pieter, 2009). According to the competition rules, kicks to the opponent's head score more points than to the trunk (Pieter, 2009). Fast offensive kicks have accounted for more than half of the techniques used to score points during TKD competitions (Kazemi et al., 2006). Practicing high kicks repetitively enables TKD practitioners to spend more time standing on one leg, and this should improve their postural control in unilateral stance (Paillard et al., 2006).

A group led by Del Percio studied the neuro-physiological mechanisms underlying better standing balance among elite karate fighters, a martial sport similar to TKD (Del Percio et al., 2007). They concluded that frequently practicing leg attacks on a mobile visuo-spatial target would train the athletes to cope with highly demanding visual-somatosensory-vestibular integration.

Integrating somatosensory, visual and vestibular inputs and switching between them could become more effective with prolonged training. Furthermore, Perrin and his colleagues have proposed that combat sports training can improve adaptive postural control (Perrin et al., 1998). From a biomechanical point of view, TKD practitioners have to develop correct lower limb and spinal alignment and special balancing skills through their combat training (Violan et al., 1997). All these studies help explain the finding that TKD practitioners sway more slowly in unilateral stance than the control group.

Table 6.1 Participant descriptors

	Long-term TKD group (n=11)	Short-term TKD group (n=10)	Control group (n=10)	p value
Mean age±SD (age range), years	13.4±0.8 (12-14)	12.9±1.2 (11-14)	12.3±1.3 (11-14)	0.102
Mean height±SD, cm	156.4±7.3	155.6±11.8	149.6±10.2	0.254
Mean body weight±SD, kg	49.2±8.5	47.3±13.4	46.5±9.0	0.830
Sex, n	7 males & 4 females	6 males & 4 females	6 males & 4 females	1.0

Table 6.2 Means and standard deviations of the measured parameters

	Long-term TKD group (n=11)	Short-term TKD group (n=10)	Control group (n=10)	p value	Effect size
Mean UST COP sway velocity±SD, °/s	1.01±0.14*	1.02±0.22*	1.58±0.68	0.006	0.31
Mean knee joint angle repositioning error±SD, degrees	3.94±1.54*	5.27±2.10	7.53±2.40	0.001	0.37
Mean isokinetic peak torque of quadriceps±SD, Nm/kg	95.73±54.30	96.20±38.31	67.90±24.91	0.231	0.10
Mean isokinetic peak torque of hamstrings±SD, Nm/kg	63.55±39.02	67.40±36.34	50.50±19.71	0.495	0.05

*Denotes a difference from the control group significant at 5%

Table 6.3 Effect sizes and p values for the pairwise comparisons

	Long-term vs short-term TKD groups		Long-term TKD vs controls		Short-term TKD vs controls	
	Effect size d	**p value**	**Effect size d**	**p value**	**Effect size d**	**p value**
Knee joint angle repositioning error	0.72	0.436	1.78	0.001*	1.00	0.056
Isokinetic peak torque of quadriceps at 180 °/s	0.01	1.000	0.66	0.409	0.88	0.416
Isokinetic peak torque of hamstring at 180 °/s	0.10	1.000	0.42	1.000	0.58	0.788
COP sway velocity	0.05	1.000	1.16	0.012*	1.11	0.016*

*Denotes a difference from the control group significant at 5%

6.6.2 Knee joint proprioception

Previous studies have reported that long-term practice of a high-skill sport activity can improve proprioception and balance (Ashton-Miller et al., 2001; Lephart et al., 1996; Lin et al., 2006; Mesure et al., 1997), and our findings also revealed that long-term TKD practitioners had better knee joint proprioceptive sense than the control participants. This was related to their better standing balance on one leg. Those who had received shorter TKD training (one to four years) were not found to have better knee joint proprioception but their single-legged standing balance was still better than that of the untrained participants.

There are some possible explanations for the improved joint sense among the long-term TKD practitioners. First, TKD emphasizes postural awareness and exact joint positioning of the lower limbs, which could have improved the acuity of joint repositioning directly. Second, through repeated positioning of body parts in space during TKD training, practitioners might have developed selective attention to the biomechanical cues that are important to their performance and to balance. They could have improved the cortical representation of certain joints, leading to enhanced joint proprioception (Ashton-Miller et al., 2001). These neuro-physiological changes might not have yet occurred among the short-term TKD practitioners.

6.6.3 Knee muscle strength

Both the long- and short-term TKD practitioners tended to have about 40% greater body-weight-adjusted isokinetic quadriceps strength and about 30% greater hamstring strength than the untrained controls, though these differences were not statistically significant with such small groups. Our relatively small sample sizes might compromise the statistical power. In fact, the effect sizes between TKD practitioners (both short-term and long-term TKD training groups) and the control group ranged from medium to large (Table 6.3) (Portney & Watkins, 2009). TKD practitioners would certainly be expected to have better isokinetic knee muscle strength than those not involved in any organized sporting activity, but larger samples would be needed to properly confirm this.

6.6.4 Limitations

This testing revealed that knee joint proprioception was better in participants who had practiced TKD for five years or more but not for those with less TKD training experience. This indicates that there might be some time-dependent training effect involved in achieving better joint proprioception. However, this was a cross-sectional study. Changes with time remain uncertain, and only a part of the sensori-motor aspect of balance was considered in this study. Further studies might fruitfully adopt a longitudinal design and explore other neuro-physiological changes which might affect balance with TKD training.

Moreover, larger sample sizes would be needed in future studies to confirm a difference in knee muscle strength between TKD practitioners and untrained controls.

6.7 Conclusions

These experiments revealed improved single leg standing balance among both short- and long-term TKD practitioners, and better knee joint proprioception among long-term TKD practitioners. These findings suggested that long-term TKD exercise might be a suitable therapeutic intervention for children with balance or sensory dysfunctions. Further study is needed to identify the correlates of improved balance in short-term TKD practitioners.

6.8 Annex (Study 5)

Table 6.4 Test-retest reliability of UST, knee joint angle active repositioning test and isokinetic knee muscle strength test

Testing conditions	$ICC_{3,3}$ (95% CI)	p value
Unilateral stance test COP sway velocity	0.77 (0.56-0.89)	<0.001
Knee joint angle repositioning error	0.62 (-0.11-0.90)	0.039
Isokinetic peak torque of quadriceps at 180°/s	0.94 (0.43-0.99)	0.009
Isokinetic peak torque of hamstring at 180°/s	0.88 (-0.20-0.99)	0.034

- Concurrent validity of knee joint angle active repositioning test - Strong correlation (r=0.86) between knee joint angle repositioning test and kinaesthesia test (Grob et al., 2002).

- Validity of isokinetic dynamometry – It is the most valid tool for muscle function assessment (gold standard). For example, it was used to determine the criterion validity of hand-held dynamometers (Jones & Stratton, 2000).

- Sample size calculation was not done. Data of study 3 was re-analyzed: (1) differentiate long-term (n=11) and short-term (n=10) TKD practitioners; (2) 10 sex-/ weight-/ height-matched control participants were selected.

- Peak-torque-to-body weight ratio is commonly used to represent lower limb muscle strength in elderly, sportsmen (including TKD) and healthy individuals (CSMI, 2005; Fong & Tsang, 2012; Pieter et al., 1989; Toskovic et al., 2004; Tsang & Hui-Chan, 2005) because it allows comparison of results between individuals or with the norm (CSMI, 2005) and is correlated with single leg stance stability in elderly people (Tsang & Hui-Chan, 2005).

- Time to peak torque is also measured and the results are presented in Table 6.7. We found that TKD practitioners were not faster in building up peak torque when compared to the control participants.

- The knee joint passive positioning and active repositioning test was done in side lying (non-weight-bearing position) in order to minimize the motor contribution, which has been found to aid proprioceptive acuity (Asthton-

Miller, 2001). Moreover, non-weight-bearing single joint positioning assessment is more specific for the examined (lower limb) joint and is more valid (Stillman & McMeeken, 2001). Therefore, this test was adopted in the present study.

- Results of this non-weight-bearing joint position test may not be transferrable to a standing, weight-bearing, one legged standing joint position test (Stillman & McMeeken, 2001). However, the non-weight-bearing joint position test result correlates with standing balance in the elderly. Previous study found that larger absolute knee joint angle errors were associated with smaller movement of the normalized COP in the LOS test (Tsang & Hui Chan, 2003). We hypothesized that such correlation might also exist in the younger population.

- Additional results:

Table 6.5 Comparison of age, height, body weight and sex between long-term, short-term TKD practitioners and control participants (boys and girls)

	Long-term TKD practitioners			Short-term TKD practitioners			Controls			p value		
	All (n=11)	**Boys (n=7)**	**Girls (n=4)**	**All (n=10)**	**Boys (n=6)**	**Girls (n=4)**	**All (n=10)**	**Boys (n=6)**	**Girls (n=4)**	**All**	**Boys**	**Girls**
Mean age ± SD, year	13.4 ± 0.8	13.1 ± 0.9	13.8 ± 0.5	12.9 ± 1.2	13.2 ± 1.2	12.5 ± 1.3	12.3 ± 1.3	11.8 ± 1.0	13.0 ± 1.4	0.102	0.056	0.342
Mean height ± SD, cm	156.4 ± 7.3	157.1 ± 7.5	155.0 ± 7.8	155.6 ± 11.8	162.3 ± 9.4 (sig. diff. from male controls, p=0.028)	145.5 ± 6.8	149.6 ± 10.2	147.5 ± 9.2	152.8 ± 12.1	0.254	0.028*	0.356
Mean body weight ± SD, kg	49.2 ± 8.5	48.5 ± 10.2	50.6 ± 5.7	47.3 ± 13.4	54.8 ± 10.6	36.0 ± 8.6	46.5 ± 9.0	45.1 ± 7.9	48.7 ± 11.4	0.830	0.236	0.090
Mean BMI ± SD, kg/m^2	20.1 ± 2.6	19.5 ± 3.0	21.0 ± 1.4	19.3 ± 4.2	20.9 ± 4.6	16.8 ± 2.4	20.7 ± 2.3	20.7 ± 2.5	20.6 ± 2.5	0.628	0.738	0.039*

*p<0.05

Table 6.6 Means and standard deviations of the measured parameters (boys and girls)

	Long-term TKD practitioners			Short-term TKD practitioners			Controls			p value		
	All (n=11)	Boys (n=7)	Girls (n=4)	All (n=10)	Boys (n=6)	Girls (n=4)	All (n=10)	Boys (n=6)	Girls (n=4)	All	Boys	Girls
Mean knee joint angle repositioning error ± SD, °	3.94 ± 1.54 [a]	4.38 ± 0.85 [b]	3.17 ± 2.28	5.27 ± 2.10	5.06 ± 2.62	5.58 ± 1.26	7.53 ± 2.40	7.89 ± 2.72	6.99 ± 2.07	0.001*	0.026*	0.056
Mean isokinetic peak torque of quadriceps at 180°/s ± SD, Nm	95.73 ± 54.30	116.71 ± 55.88	59.00 ± 27.53	96.20 ± 38.31	103.33 ± 48.36	85.50 ± 15.84	67.90 ± 24.91	80.33 ± 18.24	49.25 ± 23.11	0.231	0.364	0.118
Mean isokinetic peak torque of hamstrings at 180°/s ± SD, Nm	63.55 ± 39.02	75.43 ± 43.42	42.75 ± 19.96	67.40 ± 36.34	75.33 ± 45.74	55.50 ± 12.61	50.50 ± 19.71	59.17 ± 17.08	37.50 ± 17.41	0.495	0.695	0.346
Mean UST COP sway velocity ± SD, °/s	1.01 ± 0.14 [a]	1.03 ± 0.14 [b]	0.98 ± 0.15	1.02 ± 0.22 [a]	1.07 ± 0.23 [b]	0.95 ± 0.21	1.58 ± 0.68	1.78 ± 0.76	1.28 ± 0.48	0.006*	0.016*	0.312

* Significant difference at $p<0.05$ among the 3 groups by using univariate tests.
[a] Significantly different from control adolescents (males & females) ($p<0.05$).
[b] Significantly different from male control adolescents ($p<0.05$).

Table 6.7 Correlations between outcomes (boys and girls)

	UST COP sway velocity (non-dominant leg with eyes open), °/s	
	Boys (n=13)	**Girls (n=8)**
Knee joint angle repositioning error, °	r=-0.374	r=-0.378
Isokinetic peak torque of quadriceps at 180°/s, Nm	r=-0.280	r=-0.099
Isokinetic peak torque of hamstrings at 180°/s, Nm	r=-0.282	r=-0.360

*p<0.05 (2-tailed)

Table 6.8 Comparison of time to peak torque among three groups

	Long-term TKD group (n=11)	Short-term TKD group (n=10)	Control group (n=10)	p value	Effect size (f)
Mean time to peak torque at 180°/s ± SD, s					
• **Quadriceps**	0.32±0.13	0.31±0.11	0.31±0.10	0.989	0.001
• **Hamstrings**	0.36±0.18	0.30±0.11	0.35±0.05	0.546	0.042

Not faster in TKD practitioners.

6.9 Relevance to the main study (study 6)

- In this study, we tried to explore other factors that contribute to the better postural control in adolescent TKD practitioners. We found that better knee joint position sense was related to the better single leg stance stability in TKD practitioners, but such improvement was confined to the long-term (i.e. with five to nine years of training experience) TKD practitioners only. Furthermore, isokinetic concentric knee muscle strength was no better in TKD practitioners than the control participants.

- These findings indicate that the differential training effects of TKD may be time dependent: 'the longer time the better'.

- However, we would not implement TKD for a prolonged period of time (e.g. five years) in the main study because of the practical issues and clinical applicability.

- Since children with DCD have sensory organization deficits mainly as described in studies 1 and 2, it would be more appropriate to implement short-term TKD training program in order to address their balance and sensory problems in the main study (based on the findings of studies 3 and 4).

MAIN STUDY

CHAPTER 7 (STUDY 6 MAIN STUDY): TAEKWONDO TRAINING IMPROVES BALANCE AND SENSORY ORGANIZATION IN CHILDREN WITH DEVELOPMENTAL COORDINATION DISORDER: A RANDOMIZED CONTROLLED TRIAL

Publication:

- Fong, S.S.M., Tsang, W.W.N., & Ng, G.Y.F. (2012b). Taekwondo training improves balance and sensory organization in children with developmental coordination disorder: A randomized controlled trial. *Research in Developmental Disabilities,* 33, *85-95*.

Published abstracts:

- Fong, S.M., & Tsang, W.N. (2012, July 23-25). Taekwondo training improves balance and sensory organization in children with developmental coordination disorder: A randomized controlled trial. Paper presented at *Third International Conference on Sport and Society*, Cambridge, UK.
- Fong, S.S.M., & Tsang, W.W.N. (2011, November 26). Taekwondo training improves sensory organization and balance control in children with developmental coordination disorder: A randomized controlled trial. Paper

presented at *Hong Kong Association of Rehabilitation Medicine Annual Scientific Meeting 2011*, Hong Kong. **(Won the Best Free Paper Presentation Award)**

- Fong, S.M., & Tsang, W.N. (2011, November 18-21). The effect of Taekwondo training on balance and sensori-motor performance in children with developmental coordination disorder. Paper presented at *The Hong Kong Society of Child Neurology and Developmental Paediatrics Annual Scientific Meeting 2011*, Hong Kong.

7.1 Rationale of study 6 (main study)

In studies 1 and 2, we confirmed that children with DCD have impaired postural control and sensory organization ability (exceptionally low SOT visual and vestibular ratio scores). Children with DCD participated in fewer activities, and their balance deficits accounted for 10.9% of the variance in activity participation (study 1). To prevent a vicious cycle of activity avoidance, poor balance performance and decreased participation in all activities, a multi-dimensional activity that can facilitate the development of postural control is deemed appropriate.

In studies 3 to 5, we found that TKD training might speed up the development of single-leg standing balance and vestibular function for postural control in normal young adolescents. Short-term TKD practitioners might rely more heavily on visual and vestibular inputs to maintain standing balance, whereas long-term TKD practitioners might have better knee joint position sense associated with their better unilateral stance balance performance.

From the above-described five studies, it seems that short-term TKD training might be suitable for children with DCD to improve their single leg standing balance and sensory organization ability (e.g. reliance on visual and vestibular inputs to maintain balance). However, all five studies were cross-sectional in design; a prospective randomized controlled trial (RCT) is needed to establish a causal relation between TKD training and balance performance in children with DCD. We hypothesized that a relatively short period of TKD training could improve the sensory organization (especially visual and vestibular functions) and postural control (especially single leg standing balance) in children with DCD.

7.2 Abstract

Background: Children with developmental coordination disorder (DCD) have poorer postural control and are more susceptible to falls and injuries than their healthy counterparts. Sports training may improve sensory organization and balance ability in this population.

Objectives: This study aimed to evaluate the effects of three months of taekwondo (TKD) training on the sensory organization and standing balance of children with DCD.

Design: It is a randomized controlled trial.

Participants: Forty-four children with DCD (mean age 7.6±1.3 years) and 18 typically developing children (mean age 7.2±1.0 years) participated in the study.

Interventions: Twenty-one children with DCD were randomly selected to undergo daily TKD training for three months (one hour per day). Twenty-three children with DCD and 18 typically developing children received no training as controls.

Main outcome measures: Sensory organization and standing balance were evaluated using a Sensory Organization Test (SOT) and Unilateral Stance Test (UST), respectively.

Results: Repeated measures MANCOVA showed a significant group by time interaction effect. Post hoc analysis demonstrated that improvements in the vestibular ratio (p=0.003) and UST sway velocity (p=0.007) were significantly greater in the DCD-TKD group than in the DCD-control group. There was no significant difference in the average vestibular ratio or UST sway velocity between the DCD-TKD and normal-control group after three months of TKD training (p>0.05). No change was found in the somatosensory ratio after TKD training (p>0.05). Significant improvements in visual ratios, vestibular ratios, SOT composite scores and UST sway velocities were also observed in the DCD-TKD group after training (p<0.01).

Conclusions: Three months of daily TKD training can improve sensory organization and standing balance control for children with DCD. Clinicians can suggest TKD as a therapeutic leisure activity for this population.

Keywords: sport, postural control, sensory inputs, clumsy children

7.3 Introduction

Approximately six percent of school-aged children are known to have developmental coordination disorder (DCD). These children experience difficulty in daily activities due to their marked motor impairments including poor postural control (APA, 2000). Previous studies have reported that 73% to 87% of children with DCD actually have balance problems (Macnab et al., 2001). The ability to maintain postural stability in children with DCD is an important area that needs to be addressed because any impairment in postural control may limit the child's activity participation (Fong et al., 2011a & 2011b; Smyth & Anderson, 2001), increase their risk of falling, hinder motor skills development (Grove & Lazarus, 2007) and have a negative impact on their psychosocial functioning (Cantell et al., 1994; Skinner & Piek, 2001).

The control of posture involves efficient use of information from the somatosensory, visual and vestibular systems (Nashner, 1997). Children with DCD have below-normal balance ability together with wide-spread impairment in their sensory organization (Fong et al., 2011a; Inder & Sullivan, 2005). Their ability to rely on vestibular input to maintain standing balance is worse than that of children with normal motor development (Grove & Lazarus, 2007). Without proper intervention, the balance and motor deficits that arise from DCD may persist into adolescence and even adulthood (Fitzpatrick & Warkinson, 2003; Losse et al., 1991). Early intervention to enhance motor and balance performance is thus very important.

Sports training is often a viable and enjoyable way of improving the balance of children with DCD (Hung & Pang, 2010; Mercer et al., 1997). Indeed, a survey shows that physiotherapists often refer children with motor dysfunctions to participate in sports activities (Westcott et al., 1998). Taekwondo (TKD) is a popular sport among children and adolescents (Park et al., 1989). It is renowned for its swift kicks and fast action. Practitioners have ample opportunity to practise single leg standing while maintaining body balance (Pieter, 2009). Previous studies in our own laboratory have demonstrated that participation in TKD can enhance postural control and sensory organization in typically developing adolescents. TKD practitioners rely primarily on visual and vestibular inputs to maintain standing balance (Fong et al., 2012a; Fong & Ng, 2010; Leong et al., 2011). The potential benefits of TKD training may exactly address the balance difficulties and sensory organization deficits experienced by children with DCD. However, the training effect of TKD has not been investigated formally with a DCD population.

This randomized controlled study aimed (1) to investigate the effect of short-term (three months) intensive TKD training on the sensory organization and balance performance of children with DCD, and (2) to identify the developmental status of balance and sensory organization in children with DCD, both with and without TKD training, as compared to children with normal motor development.

7.4 Methods

7.4.1 Study design

This was a single-blinded, stratified, randomized and controlled trial. The outcome assessors were blinded to the group allocation. Since the participants were not blinded to group assignment, they were instructed not to inform the assessors about their group assignments to avoid possible bias during measurement.

7.4.2 Participants

According to a meta-analysis by Pless & Carlsson (2000), the minimal effect size for gross motor training (group training) in improving the motor proficiency, including balance ability, of persons with DCD is 0.54. Therefore, a sample of 29 participants was necessary to achieve a statistical power of 0.8 in pretest and post-test measurements of two DCD groups with the alpha level set at 0.05. Anticipating a possible dropout of 30% (Hiller et al., 2010), 38 children were needed (i.e. 19 per group).

Participants with DCD were recruited from local child assessment centres (CACs) and hospitals (Appendix 7). Inclusion criteria were: (1) a formal diagnosis of DCD according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) (APA, 2000); (2) aged between six and nine years; (3) study in a regular education framework; and (4) no intellectual impairment. Exclusion criteria were: (1) a formal diagnosis of emotional, neurological, or other movement disorders; or (2) a significant congenital, musculoskeletal or cardiopulmonary condition that might influence balance performance; or (3) were receiving physical or occupational therapy training; or (4) demonstrated excessive disruptive behavior; or (5) could not follow instructions thoroughly (Figure 7.1). Children with normal motor development were recruited from the community by convenience sampling to form a normal control group using the same inclusion and exclusion criteria except that they did not have any history of DCD. Each child in the normal-control group was screened by an experienced pediatric physical therapist using the Movement Assessment Battery for Children-2 (Movement ABC-2). Children with a Movement ABC-2 total percentile score at or below the 15^{th} percentile (i.e. those at risk of significant movement difficulty) were excluded (Henderson et al., 2007).

A no-training DCD-control group was also included to account for the effect of maturation and to track whether the balance deficits of those with DCD might recover spontaneously over time. The normal children were included as another control group to determine whether or not short-term TKD training can improve the balance ability of children with DCD to normal standards.

Ethical approval was obtained from the human subjects ethics review subcommittee of the Hong Kong Polytechnic University (Appendix IV). The study was explained to each participant and their parents, and written informed consent was obtained. Data collection was performed by pediatric physical therapists in the sports medicine and rehabilitation laboratory of the Hong Kong

Polytechnic Unversity. All procedures were conducted in accordance with the Declaration of Helsinki.

7.4.3 Randomization

The eligible participants with DCD were stratified by sex and then randomly assigned to either the DCD-TKD training group or the DCD-control group. This ensured an approximately equal number of boys and girls in each group. The randomization procedure was done by drawing lots and was completed by a person independent of the study. Twenty-one and twenty-three children with DCD were assigned to the DCD-TKD group and DCD-control group, respectively (Figure 7.1). Eighteen typically developing children were included in the normal-control group without randomization.

7.4.4 Intervention

The children in the DCD-TKD training group attended a weekly one-hour session of TKD training held at the Hong Kong Polytechnic University for twelve consecutive weeks. The TKD training protocol is outlined in Table 7.1 and illustrated in Figure 8.1. This protocol was modified from a typical TKD syllabus for beginners (Park et al., 1989) by an experienced physical therapist and a skilled taekwondo practitioner to suit the motor ability of the participants. The TKD training sessions were conducted by a World Taekwondo Federation 4th dan black belt qualified as a chief instructor and a 2nd dan black belt qualified as an assistant instructor.

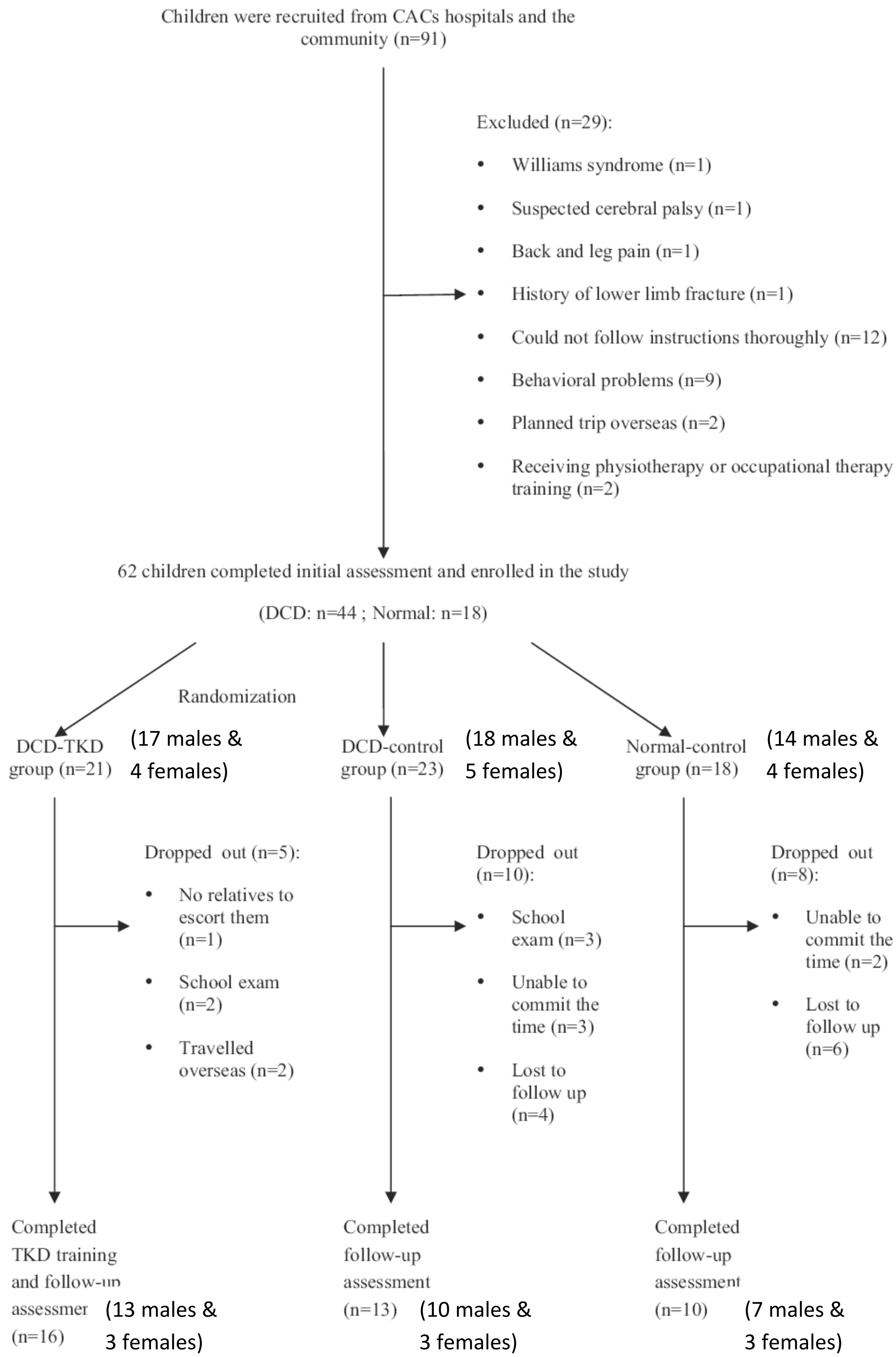

Fig. 7.1 Study flowchart (Fong et al., 2012b)

In addition, each participant was given TKD home exercises to reinforce what had been learned at each training session and to increase the exercise frequency. The home exercises were same as those practiced during face-to-face TKD training sessions. The children were instructed to perform these TKD exercises daily (excluding the TKD class days) throughout the three month study period. Their parents were provided with clear written instructions and a log book (Appendix 6), and were asked to coach or assist their children in performing the TKD home exercises. The home exercise program was designed to take approximately an hour to complete. The log books were designed to be completed daily by the parents. To ensure all participants complied with the home exercises, the TKD instructors checked the participants' daily log books at each training session and the parents were required to submit their signed log books to the researchers at the post-intervention assessment. The DCD-control and normal-control groups received no training within the study period.

Table 7.1 Three-month taekwondo training protocol for the TKD-DCD group (Park et al., 1989)

Exercise or technique	**Frequency**	**Intensity**	**Duration**	**Type of activity and postural control requirements**
Warm up		Mild sweating	5 minutes	Jogging Dynamic balance
Stretching		Mild tension of muscles	5–10 minutes	Static stretch of all large muscle groups
Punching and blocking in horseback riding stance: • Body punch • Rising block[a] • Outside block • Inside block • Down block[b]	TKD class: once per week Self practice (documented by logbook): daily (excluding the TKD class days)	20 repetitions for each technique. Performed with alternate upper limbs.	10–15minutes	Lower limb static and upper limb dynamic muscle contractions Maintain static and dynamic balance in bipedal stance
Break			5 minutes	

Kicking in fighting stance: • Front kick • Round house kick • Side kick[a] • Back kick[b] (With or without a kick pad)	40 repetitions for each technique. Performed with alternate lower limbs.	20–30 minutes	Dynamic coordinated muscle contractions in the upper limbs, lower limbs and trunk Maintain dynamic balance in unilateral stance and during turning/ pivoting on one foot Progressed by increasing the speed of movements
Cool-down, strengthening & stretching		10 minutes	Jogging and static stretch of large muscle groups Dynamic balance

[a] Techniques practiced from the 2nd week onward

[b] Techniques practiced from the 4th week onward

7.4.5 Outcome measurements

All participants were assessed one month before the start of the TKD intervention and again within two weeks after it ended by assessors blinded to the group allocation. Each participant, regardless of group assignment, underwent the following pre- and post-intervention assessments.

7.4.6 Sensory organization of balance control

Sensory organization was evaluated using the Sensory Organization Test (SOT) with a computerized dynamic posturography (CDP) machine (Smart Equitest, NeuroCom International Inc., Clackamas OR, USA). The SOT is commonly used to evaluate the use of somatosensory, visual and vestibular inputs and the ability to filter out inappropriate sensory information in maintaining balance in bipedal stance (Nashner, 1997; NeuroCom, 2008). The results have been found to be reliable and valid with young subjects (Fong & Ng, 2012; Fong et al., 2011a).

The participants stood with bare foot on the platform of the CDP machine for testing and wore a security harness to prevent falls. They were instructed to stand quietly with both arms resting by the sides of the trunk and eyes looking forward at a distant visual target (Figure 7.2). They were exposed to six different combinations of visual and support surface perturbations in sequence according to the protocol provided by NeuroCom Inc. In conditions 1 to 3 the participants stood on a fixed platform with their eyes open (condition 1), eyes closed (condition 2) and eyes open in a sway-referenced visual surround (condition 3). In conditions 4 to 6 the participants stood on a sway-referenced platform with their eyes open (condition 4), eyes closed (condition 5) and eyes open in a sway-referenced visual surround (condition 6). The term ‘sway-referenced’ is used to describe the tilting of the support surface and/ or the visual surround about an axis co-linear with the ankle joints to closely follow the anterior-posterior sway of the participant’s centre of gravity (Nashner, 1997; NeuroCom, 2008). After familiarization trials, each participant was tested three times in each condition at each evaluation. They were instructed to ignore any support surface or visual surround motion and remain upright as steady as possible for 20 seconds in each trial. No feedback was given to the participants during the testing (NeuroCom, 2008).

The CDP machine captured the trajectory of the participant’s center of pressure (COP), which was then used to generate an equilibrium score (ES). The score was calculated by subtracting each participant’s peak antero-posterior (AP) sway angle from the theoretical limit of AP stability (assumed to be 12.5°) and dividing the difference by the limit. So an ES of 100 represented no sway in bipedal standing whereas a score of zero indicated sway exceeding the stability limit, which would normally result in a fall (Nashner, 1997; NeuroCom, 2008).

The three ES scores in each testing condition were averaged, and these average scores were used to calculate a somatosensory ratio (the mean ES of condition 2 divided by the mean ES of condition 1), a visual ratio (the mean ES of condition 4 divided by the mean ES of condition 1) and a vestibular ratio (the mean ES of condition 5 divided by the mean ES of condition 1) (NeuroCom, 2008). These three sensory ratios were then used to identify the contribution of each sensory system—somatosensory, visual and vestibular—to balance control. A sensory ratio close to 1 reflected superior ability in relying on that particular sensory input for balance (Nashner, 1997). A composite ES was also generated by the NeuroCom software taking into account the ESs in all the six testing conditions (NeuroCom, 2008). The composite ES and the three sensory ratios were used for analysis.

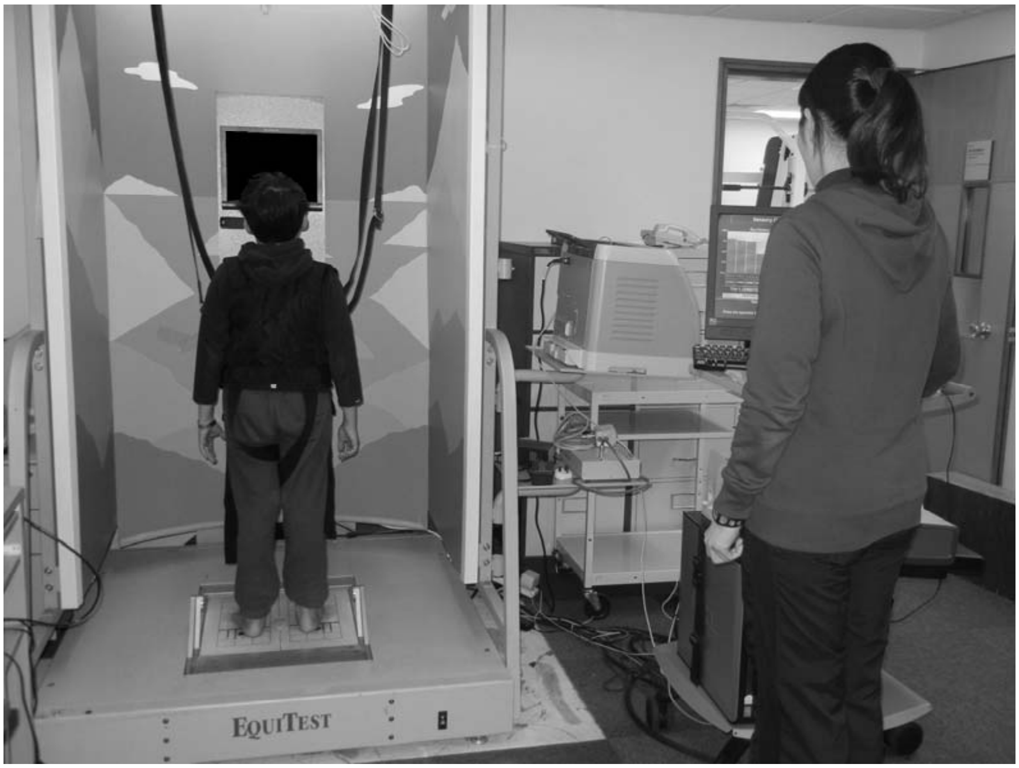

Fig. 7.2 Standardized posture in the Sensory Organization Test

7.4.7 Single leg standing balance

Single leg standing balance was measured in a Unilateral Stance Test (UST) with the same CDP machine. Participants stood barefoot on their non-dominant leg for ten seconds. (The dominant leg was defined as the one each participant reported using to kick a ball.) (Fong et al., 2011a). The non-dominant leg was tested because it is usually the supporting leg during TKD. The standardized testing posture was arms by the side of trunk, eyes looking forward at a distant visual target and the hip of the non-supporting leg flexed at 45° so as to resemble the starting position of a front kick in TKD (Figure 7.3). The sway velocity of the center of pressure (COP) was recorded by the machine (NeuroCom, 2008). Three trials were performed with a ten-second rest in between. The mean COP sway velocity across the three trials was obtained and used for analysis. Previous study has shown that the test-retest reliability of the UST is good with an intraclass correlation coefficient of 0.77 (Fong et al., 2011a).

Fig. 7.3 Standardized posture in the Unilateral Stance Test

7.4.8 Statistical analysis

One-way analysis of variance (ANOVA) and chi-square tests were conducted to compare the three groups in terms of age, weight, height and sex distribution. To test the overall effect of TKD training and to reduce the probability of type I error due to multiple comparisons, two-way repeated measures multivariate analysis of covariance (MANCOVA) was conducted incorporating all the outcome measures (somatosensory ratio, visual ratio, and vestibular ratio, SOT composite score, UST COP sway velocity). The within-subject factor was time and the between-subject factor was group. The intention-to-treat principle (last observation carried forward) was employed. Baseline (pretest) somatosensory ratio, visual ratio, vestibular ratio, SOT composite score, and UST COP sway velocity were entered as covariates if there was any significant baseline between-group difference in these measures.

If the MANCOVA demonstrated a significant effect overall, follow-up analyses were performed using one-way analysis of covariance (ANCOVA) and post-hoc pairwise comparisons. In addition, pairwise t-tests were used to investigate whether there was any within-group difference within the two assessment intervals. All of the statistical analyses were performed using SPSS version 17.0 software (SPSS Inc., Chicago, IL, USA). The significance level was set at 0.05 (two-tailed) and corrected using an appropriate Bonferroni adjustment for the univariate tests in order to maintain the overall type one error at 5% (i.e. alpha=0.01 for comparisons of the five outcomes among groups).

7.5 Results

Figure 7.1 shows that 62 children with DCD (n=44) and without DCD (n=18) who met the inclusion criteria participated in the study. Twenty three of them (37%) dropped out—five from the DCD-TKD group (i.e. 76.2% completed the TKD intervention), ten from the DCD-control group (i.e. 56.5% completion rate), and eight from the normal-control group (i.e. 55.6% completion rate). The self-reported reasons for drop-out are listed in Figure 7.1. The average attendance at the face-to-face training sessions for those who completed the TKD intervention was 90.9%. No adverse events were reported during the TKD training. The self-reported TKD home exercise compliance rate was 95.2%.

7.5.1 Comparison of baseline characteristics

The demographics of the three groups are outlined in Table 7.2. There was no significant difference in boy to girl ratio or average BMI, height, age or weight among the three groups ($p>0.05$). Significant differences were found in the pretest measurements of vestibular ratio ($p=0.012$) and UST COP sway velocity ($p=0.003$) among the three groups (Table 7.3). The baseline vestibular ratio and the UST COP sway velocity were therefore treated as covariates in the subsequent multivariate and univariate analyses.

Table 7.2 Participant characteristics at baseline

	DCD-TKD group (n=21)	DCD-control group (n=23)	Normal-control group (n=18)	p value
Mean age±SD, year	7.7±1.3	7.4±1.2	7.2±1.0	0.411
Sex, n	17 males & 4 females	18 males & 5 females	14 males/ 4 females	0.965
Mean height±SD, cm	127.4±9.9	123.2±11.2	122.7±10.1	0.294
Mean body weight±SD, kg	28.1±9.2	26.7±10.1	27.3±8.4	0.892
Mean BMI±SD, kg/m^2	16.8±3.2	17.0±3.2	17.5±2.7	0.774
Co-morbidity				
Attention deficit hyperactivity disorder	3	4	0	
Attention deficit disorder	3	4	0	
Dyslexia	4	2	0	
Asperger syndrome	2	3	0	
Autism spectrum disorders	1	0	0	

7.5.2 Changes in the somatosensory ratio

No significant time by group interaction was found involving the somatosensory ratio ($p=0.332$). There was no significant pretest or post-test difference ($p>0.01$) among the groups, which indicates that the three groups were comparable in terms of somatosensory ratio before and after three months, regardless of TKD training. The children with normal development demonstrated some improvement in their somatosensory ratios over time ($p=0.048$) (Table 7.3 & Figure 7.4).

7.5.3 Changes in the visual ratio

For the visual ratio, a significant time by group interaction ($p<0.001$) was found. Paired t-tests revealed that only children with DCD who received TKD training had significant improvement (increased by 25.9%, $p=0.001$) after three months. No improvement was found in the two control groups ($p>0.05$). Between-group comparisons demonstrated that the differences among the three groups were not statistically significant after the intervention ($p>0.01$) (Table 7.3 & Figure 7.5).

7.5.4 Changes in the vestibular ratio

Repeated measures MANCOVA revealed a significant time by group interaction effect ($p<0.001$) in terms of the vestibular ratio. Children with DCD showed a significant improvement (71.9%, $p<0.001$) in vestibular ratio after three months of TKD training. No significant improvement was found in either control group over time ($p>0.05$). The average vestibular ratio of the DCD-TKD group was significantly lower (37.3%, $p=0.012$) than that of the normal-control group before receiving TKD training. However, after three months of TKD training the average vestibular ratio of the DCD-TKD group was 61.8% higher than that of the DCD-control group and comparable to that of the normal-control group ($p>0.01$) (Table 7.3 & Figure 7.6).

7.5.5 Changes in the SOT composite score

There was a significant time by group interaction ($p=0.026$) in the SOT composite score. DCD-TKD group demonstrated the greatest improvement over time (18.5%, $p=0.001$), followed by the DCD-control group (5.8%, $p=0.023$) (Table 7.3). Within-group differences were not significant ($p>0.05$) in the normal-control group. However, there was no difference ($p>0.01$) in the composite scores among the three groups pretest or post-test (Figure 7.7).

7.5.6 Changes in the UST COP sway velocity

Repeated measures MANCOVA also showed a significant time by group interaction (p=0.001) in the UST COP sway velocity. Post hoc univariate analyses revealed that the DCD-TKD training group had significantly greater improvement in average UST COP sway velocity than the two control groups. Children with DCD swayed 30.5% slower when standing on one leg after three months of TKD training (p=0.004) and their UST COP sway velocity became comparable to that of their typically developing peers (p>0.05). The DCD-control group (without TKD training) did not improve over time (p>0.05) and their post-test UST COP sway velocity was 121.6% higher than that of the normal-control group (p=0.001) and 71.5% higher than that of the DCD-TKD group (p=0.007) (Table 7.3 & Figure 7.8).

Table 7.3 Comparison of outcome measurements among the three groups (pre- and post-TKD training) and within individual groups (Fong et al., 2012b)

Measurements	DCD-TKD group ($n = 21$)		DCD-control group ($n = 23$)		Normal-control group ($n = 18$)		p Value		
	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test	Pretest (Group effect)	Post-test (Group effect)	Group × time effect
SOT									
Somatosensory ratio	0.93 ± 0.07	0.91 ± 0.13	0.91 ± 0.09	0.92 ± 0.07	0.96 ± 0.04	0.97 ± 0.04[d]	0.074	0.503	0.332
Visual ratio	0.58 ± 0.19	0.73 ± 0.19[d]	0.57 ± 0.24	0.57 ± 0.23	0.74 ± 0.15	0.75 ± 0.16	0.019	0.012	<0.001[e]
Vestibular ratio	0.32 ± 0.16	0.55 ± 0.23[a,d]	0.35 ± 0.21	0.34 ± 0.20[c]	0.51 ± 0.20	0.52 ± 0.17	0.010[f]	<0.001[f]	<0.001[e]
Composite score	49.00 ± 10.36	58.05 ± 16.55[d]	49.26 ± 12.30	52.13 ± 12.51[d]	57.83 ± 8.30	60.94 ± 9.87	0.018	0.048	0.026[e]
UST									
COP sway velocity (°/s)	3.18 ± 2.17	2.21 ± 1.88[a,d]	3.56 ± 1.85[b]	3.79 ± 1.77[b,c]	1.68 ± 0.70[a,c]	1.71 ± 1.06[a]	0.003[e]	0.001[e]	0.001[e]

Note. Values are mean ± SD or p values.

Among groups:

[a] Denotes a difference significant at $p \leq 0.01$ when compared with the DCD-control group.

[b] Denotes a difference significant at $p \leq 0.01$ when compared with the Normal-control group.

[c] Denotes a difference significant at $p \leq 0.01$ when compared with the DCD-TKD group.

Within group (time effect):

[d] Denotes a difference significant at $p \leq 0.05$ when compared with pretest values.

Group by time interaction and among three groups:

[e] Denotes a difference significant at the $p \leq 0.05$ confidence level.

[f] Denotes a difference significant at $p \leq 0.01$.

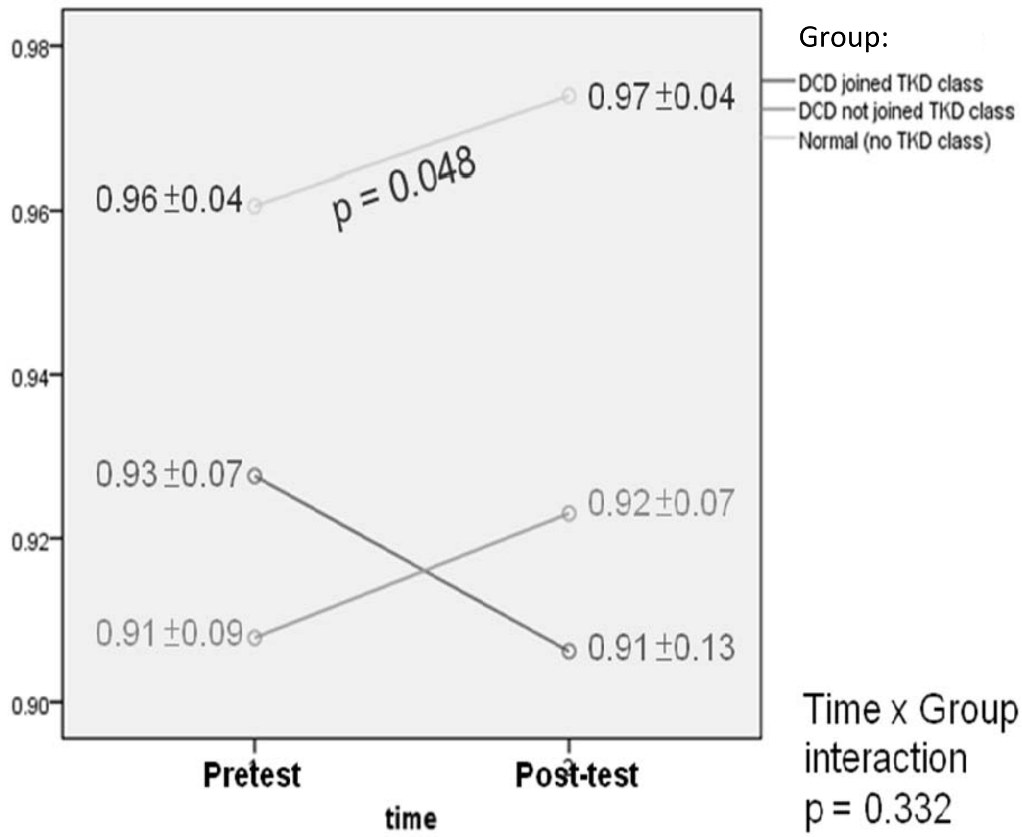

Fig. 7.4 Changes in the somatosensory ratio

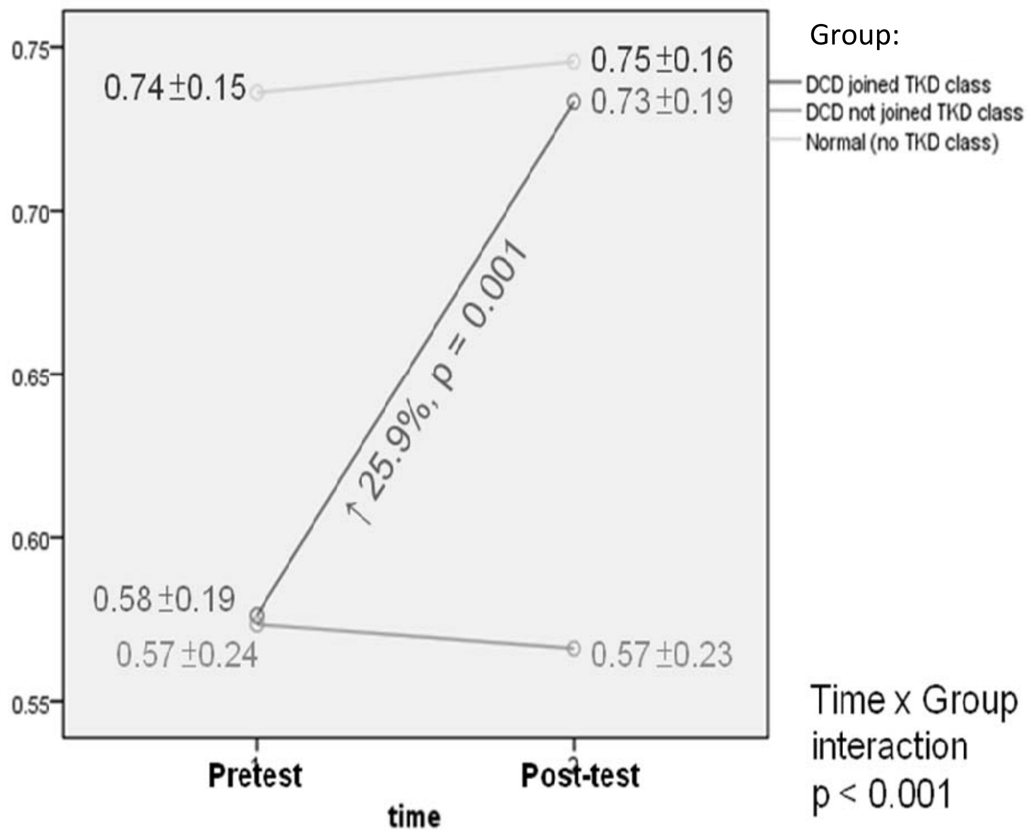

Fig. 7.5 Changes in the visual ratio

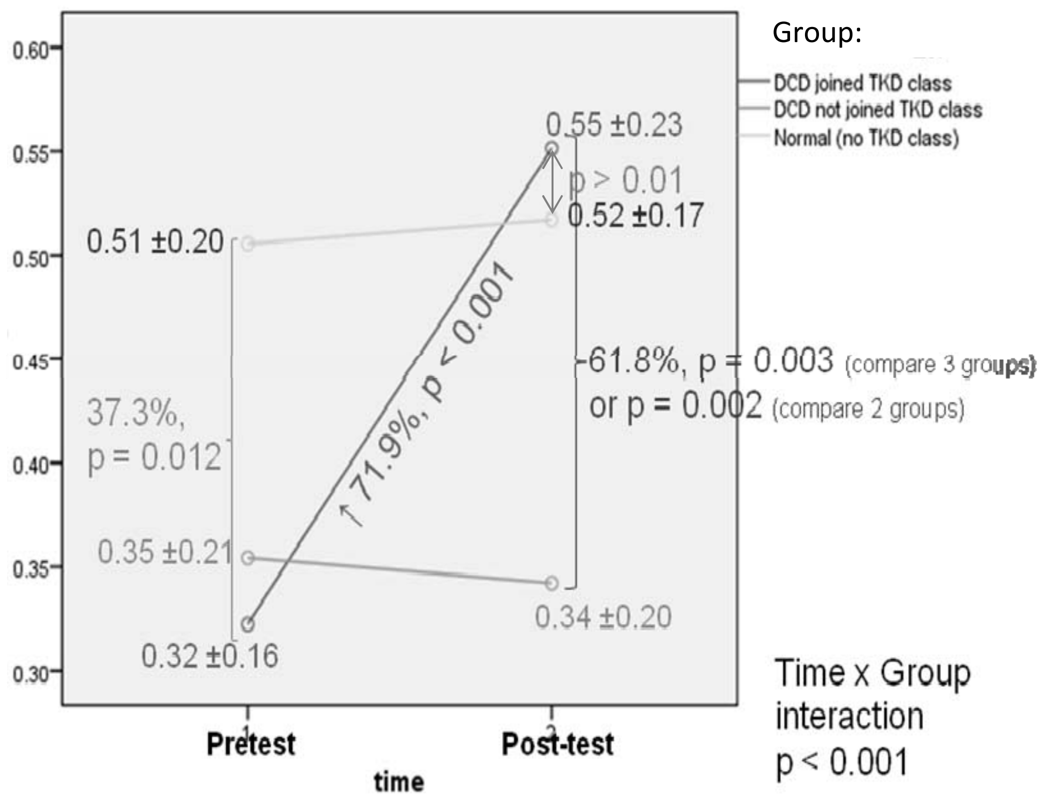

Fig. 7.6 Changes in the vestibular ratio

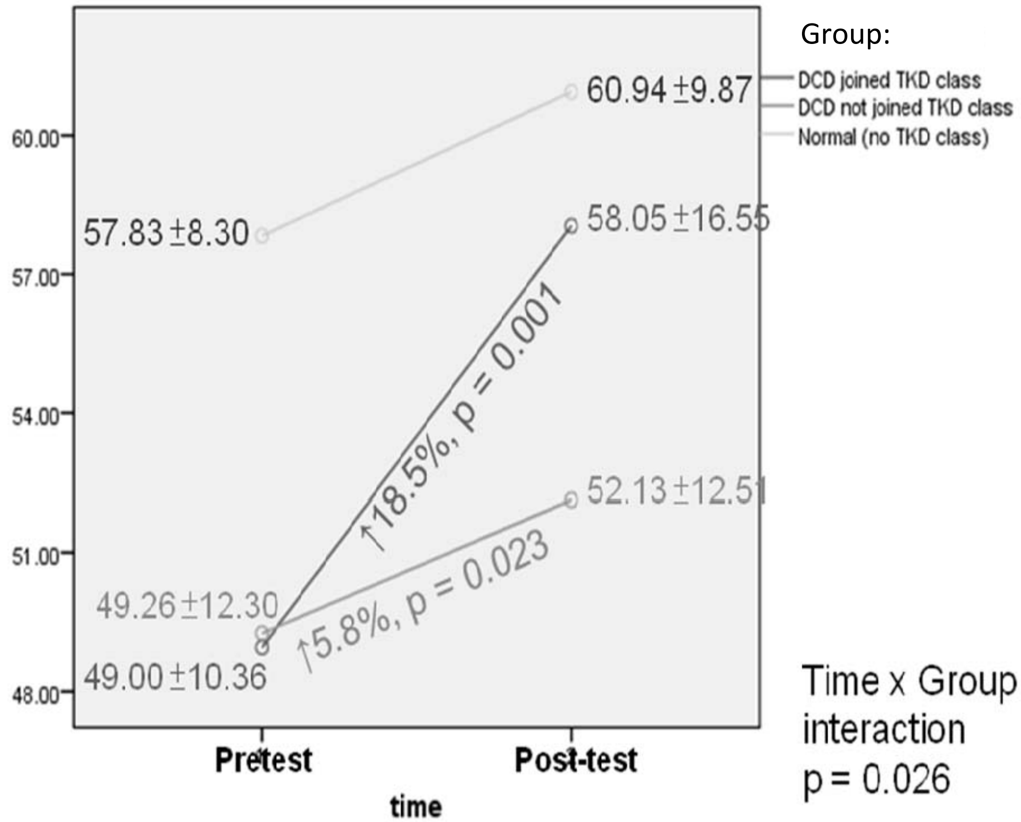

Fig. 7.7 Changes in the SOT composite score

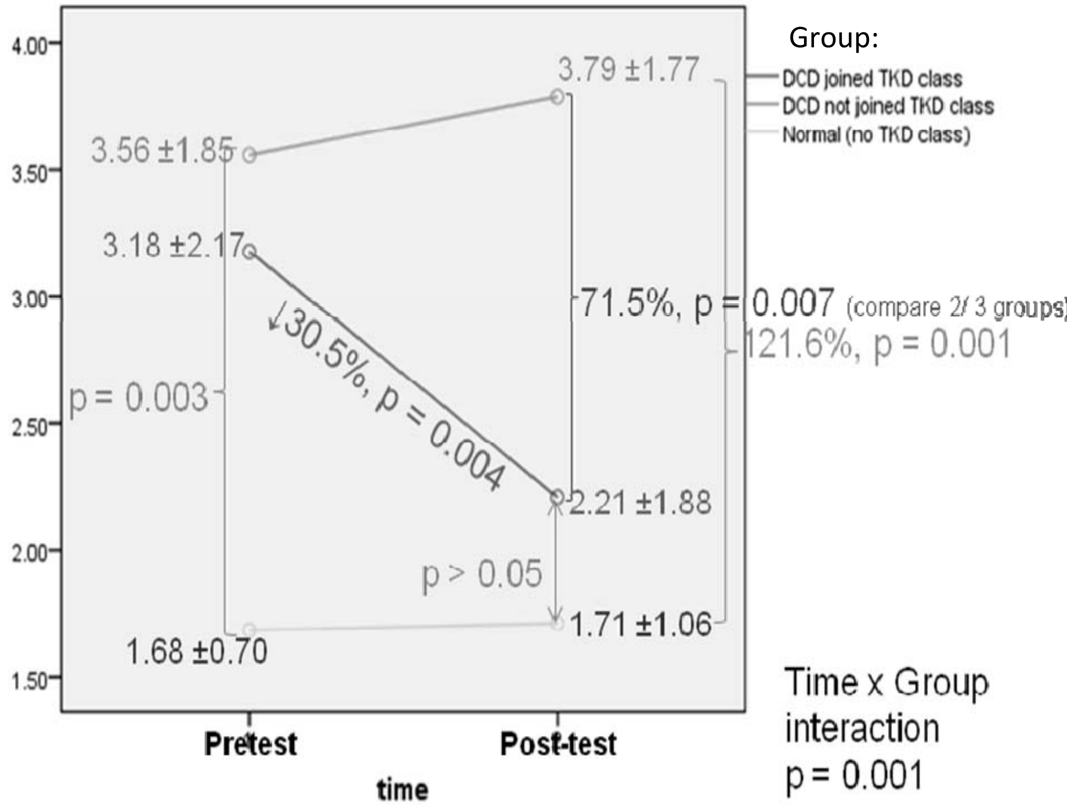

Fig. 7.8 Changes in the UST COP sway velocity (°/s)

7.6 Discussion

7.6.1 Development of postural control in children with DCD

Our findings reveal that before the TKD intervention, children with DCD (six to nine years old) demonstrated faster COP sway in single leg standing and lower vestibular ratio in the SOT than typically developing children. The somatosensory ratios, visual ratios and SOT composite scores were similar, however (Table 7.3). These findings partially agree with those of previous researchers (Fong et al., 2011a; Grove & Lazarus, 2007; Inder & Sullivan, 2005). For example, Grove & Lazarus (2007) evaluated 16 children with DCD and 14 children with normal motor development using the Equitest SOT and found that the ability to use vestibular feedback for balance was impaired in children with DCD (six to twelve years old), somatosensory and visual inputs were thus weighted more heavily in postural control. Recently, a group led by Fong has reported more generalized deficits in the sensory systems for postural control in a DCD population (Fong et al., 2011a). They found that the SOT composite score and all the sensory ratios were lower in the DCD group (n=81; six to twelve years old) when compared to a control group (n=67). These inconsistent findings may be due to the heterogeneity of DCD populations and the different gender mixes among the studies.

A group led by Cherng used the modified Clinical Test of Sensory Interaction and Balance (CTSIB) and found that children with DCD (four to six years old) could use information from the three sensory systems to maintain balance as efficiently as typically developing children. They concluded that the poor standing balance observed in children with DCD was likely due to a deficit in sensory organization rather than compromised effectiveness in individual sensory systems (Cherng et al., 2007). Their distinct findings could be explained by the use of younger children and different testing instruments.

Children with DCD certainly demonstrate deficits in standing balance and sensory organization, though the extent of involvement of the three sensory systems remains unclear. Further study is needed to take all the possible confounding factors (e.g. sex, age) into account and used standardized instruments in order to properly confirm the extent of sensory deficits in this population.

7.6.2 Sensory organization and postural control following TKD training

This has been the first study to investigate the effect of short-term, intensive TKD training on sensory organization and balance control in children with DCD. The TKD exercise program was achievable for most of the participants, and improvements in postural stability and the sensory organization of balance control were observed in those participants who complied with the TKD regime.

DCD-affected children's somatosensory ratio was comparable to that of normal children at both pretest and post-test (Table 7.3). This could be attributed to the fact that the somatosensory function matures at the age of three or four (Cumberworth et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006). These children (six to nine years old) could already have had mature somatosensory functioning. TKD training may not have been able to improve it further (Fong et al., 2012a). This is contrary to some reports that proprioception can be further improved in mature adults by sports training (Lephart et al., 1996; Tsang & Hui-Chan, 2003). One possible explanation might be that the somatosensory ratio studied here compared SOT in condition 2 to condition 1, quantifying the extent of stability loss when the participant closed their eyes in standing (Nashner, 1997). This may not be a valid reflection of the DCD-TKD participants' ability to use somatosensory information for balance, as the TKD intervention did not involve balancing with the eyes closed. The intervention was also relatively short. Three months of TKD training may not be enough to significantly improve the participants' ability to rely on somatosensory input for balance. Further study might fruitfully measure proprioception directly and explore the optimal duration of TKD training in order to improve proprioception in children with DCD.

Although the visual ratio was not significantly different among the three groups at post-test, TKD training significantly facilitates the development of visual function and organization in children with DCD. The visual ratio of the DCD-TKD group was 21.6% lower than that of the normal-control group before TKD training. After training, their average visual ratio was only 2.7% lower (Table 7.3). One may question whether this improvement was due to the training or simply to physiological maturation, as visual function does not fully mature until 15 or 16 years old (Cumberworth et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006). The DCD-control group, however, did not improve over time, which indicates that the TKD training had a differential effect.

Similar to soccer training, TKD involves the control of posture while kicking. The dual task demands on children who have to use vision to help maintain posture is considerable (Smyth & Anderson, 2001). Training may thus strengthen the ability to use visual input to maintain balance. Indeed, previous studies have found that TKD experts have greater visual field dependence than other physically active participants (Christelle & Jacques, 2005). The absence of a significant difference among the three groups at post-test might be due to inadequate training duration. Further study should explore the optimal training duration in order to improve visual function and organization in children with DCD.

We found that children with DCD who received the TKD training achieved less body sway than those without training when they had to rely more on vestibular input to maintain standing balance. Of particular interest is that their vestibular ratio improved significantly (71.9%) and achieved the standard of typically developing children after TKD training, while the DCD-control participants (without TKD training) did not improve at all (Table 7.3). These findings suggest that TKD was very effective in improving the use of vestibular information for balance control in children with DCD. This is in line with our previous findings that TKD training might enhance the vestibular function for maintaining postural equilibrium as reflected by quicker stabilization after landing from an unexpected drop in young adults (Leong et al., 2011).

So what contributed to the significant improvement in vestibular function in the DCD-TKD participants? A clear answer could have clinical implications. Analyzing the TKD techniques may provide some insights. The TKD protocol (Table 7.1) covered many movements that are actually similar to the vestibular exercises (e.g. spinning, jumping) commonly used in sensory integration (SI) therapy. SI therapy is known to be effective in remediating sensory deficits and enhancing motor skill development in children with DCD (Ayres, 1979; Cermak & Larkin, 2002; Sugden, 2007). TKD techniques such as the roundhouse kick, side kick and back kick may similarly stimulate sensory and vestibular functions, as they involve quick spinning (head and trunk rotation in unstable body positions) and vertical movements (Hansson, 2007). During TKD training these kicks were practiced repeatedly (Table 7.1), which presumably stimulated the vestibular function and developed single leg standing balance simultaneously in these children with DCD.

Unilateral stance stability is crucial for executing TKD high kicks (Pieter, 2009) and is essential for many daily activities such as donning pants, climbing stairs and even walking (NeuroCom, 2008; Stout, 2006). Three months of TKD training significantly improved the single leg standing balance of these children with DCD, bringing their balance performance up to the normal level. Without

TKD training, unilateral stance stability did not improve over time and remained inferior to that of typically developing children (Table 7.3). Relying on maturation alone may not be able to improve single leg standing balance sufficiently in children with DCD. Sport training is thus vital (Smyth & Anderson, 2001).

Previous studies have proposed some explanations to clarify the improved single leg standing balance in martial art athletes (Del Percio et al., 2009; Perrin et al., 1998; Violan et al., 1997). Del Percio has suggested that frequent kicking practice with a mobile visuo-spatial target helps karate (a martial sport similar to TKD) athletes to cope with highly demanding visual-somatosensory-vestibular integration (Del Percio et al., 2009). Cerebral mechanisms for integrating somatosensory, visual and vestibular inputs might become more effective with prolonged training and result in less body sway in single leg standing. Furthermore, Perrin has proposed that athletes in combat sports improve adaptive postural control with the skills acquired in training (Perrin et al., 1998). TKD practitioners might develop better postural adjustment strategies and body alignment during kicking and blocking, which would all improve body balance on one leg (Violan et al., 1997).

We incorporated static bipedal standing balance exercises (e.g. punching and blocking in horseback riding stance) in the TKD intervention because it is the foundation of unilateral stance stability. Thus we also examined balance ability in bipedal stance. The results reveal that both the DCD-TKD and DCD-control groups improved in bipedal standing balance over time, and the SOT composite scores were similar among the three groups at post-test (Table 7.3). This indicates that effect of maturation in children with DCD may be more profound than the effect of TKD training. Moreover, testing static balance in bipedal stance may not be challenging enough to expose the balance difficulties of children with DCD (Grove & Lazarus, 2007).

7.6.3 Limitations and future research direction

First, the total attrition rate in this study was quite high. The greatest attrition was in the two control groups, and the major reason was ‘lost to follow up’ or ‘unable to commit the time’. The children in the control groups did not receive any intervention, which may have disappointed the children and parents. They might not have been motivated to be assessed again at post-test. Future studies might better adopt a crossover design with an adequate washout period (Portney & Watkins, 2009). Second, although the TKD protocol was effective for improving certain balance processes, it is possible that longer intervention might be optimal for improving the sensory organization ability of children with DCD. Moreover, a follow-up assessment may be warranted to explore whether the balance ability gained can be retained and to define the washout period stated above. Finally, the relationships between balance measurements and fall risk or activity participation are not yet clear. Further study is required to address the clinical importance of these positive changes.

7.7 Conclusions

TKD training can remedy unilateral standing balance and vestibular function impairments in children with DCD. Their standing balance performance can reach normal standards after only three months of daily TKD exercise. Clinicians can therefore suggest TKD as a therapeutic leisure activity for children with DCD.

7.8 Annex (Study 6)

- Precision and accuracy of the evaluation devices used in this study are presented in sections 2.8 and 4.8, and Table 1.3.

- One of the major limitations of this study is the high drop out rate in the two control groups. This would dilute the effect of random assignment, decrease the sample size and power. Therefore, significant effects may be missed and may bias the outcomes. We have made follow-up telephone calls to the non-responders and asked for the reasons (Figure 7.1). Most of them refused to come back for re-assessment. We could not ascertain if the drop-out children were different from those who stayed in the study. Moreover, intention-to-treat analysis (last observation carried forward) was employed. This might underestimate the effect of maturation in the two control groups. We should try our best to minimize attrition in future studies. For example, give adequate explanation and inform the subjects sufficiently before the study/ consent, or provide ongoing support (e.g. English tutorial classes) for the control participants. A crossover design with an adequate washout period could also be considered (Portney & Watkins, 2009).

- Future studies could also implement TKD in a larger group of children, perhaps in the school system; include longer intervention period and follow-up assessments to see whether the beneficial effects of TKD could be maintained over time; and include a normal-TKD group for comparison etc.

- Additional results:

Table 7.4 Participant characteristics at baseline (3-group and 2-group comparisons)

	DCD-TKD group (n=21)	DCD-control group (n=23)	Normal-control group (n=18)	p value (3-group comparison)	p value (2-DCD group comparison)
Mean age±SD, year	7.7±1.3	7.4±1.2	7.2±1.0	0.411	0.433
Sex, n	17 males & 4 females	18 males & 5 females	14 males/ 4 females	0.965	0.825
Mean height±SD, cm	127.4±9.9	123.2±11.2	122.7±10.1	0.294	0.197
Mean body weight±SD, kg	28.1±9.2	26.7±10.1	27.3±8.4	0.892	0.648
Mean BMI±SD, kg/m^2	16.8±3.2	17.0±3.2	17.5±2.7	0.774	0.849
Co-morbidity:					
Attention deficit hyperactivity disorder	3	4	0		
Attention deficit disorder	3	4	0		
Dyslexia	4	2	0		
Asperger syndrome	2	3	0		
Autism spectrum disorders	1	0	0		

Table 7.5 Participant characteristics at baseline (boys and girls)

	DCD-TKD group			DCD-control group			Normal-control group			p value		
	All (n=21)	Boys (n=17)	Girls (n=4)	All (n=23)	Boys (n=18)	Girls (n=5)	All (n=18)	Boys (n=14)	Girls (n=4)	All	Boys	Girls
Mean age ± SD, year	7.7±1.3	7.5±1.2	8.5±1.3	7.4±1.2	7.4±1.2	7.5±1.5	7.2±1.0	7.1±1.1	7.5±0.6	0.411	0.629	0.399
Mean height ± SD, cm	127.4±9.9	127.5±10.0	127.0±10.7	123.2±11.2	123.6±11.3	121.8±11.9	122.7±10.1	121.6±10.9	126.5±5.9	0.294	0.306	0.697
Mean body weight ± SD, kg	28.1±9.2	28.2±8.8	27.4±12.3	26.7±10.1	27.5±10.9	24.0±6.9	27.3±8.4	26.7±9.0	29.0±7.1	0.892	0.915	0.705
Mean BMI ± SD, kg/m^2	16.8±3.2	17.0±3.0	16.4±4.5	17.0±3.2	17.3±3.4	15.9±2.5	17.5±2.7	17.4±2.7	17.9±3.0	0.774	0.897	0.682
Co-morbidity:												
Attention deficit hyperactivity disorder	3	2	1	4	3	1	0	0	0			
Attention deficit disorder	3	2	1	4	3	1	0	0	0			
Dyslexia	4	4	0	2	2	0	0	0	0			
Asperger syndrome	2	2	0	3	3	0	0	0	0			
Autism spectrum disorders	1	1	0	0	0	0	0	0	0			

Table 7.6 Comparison of outcome measurements between the two DCD groups (pre- and post-TKD training) and within individual groups

	DCD-TKD group (Male n=17; Female n=4)		DCD-control group (Male n=18 ; Female n=5)		p value (2 DCD groups)		
	Pretest (95% CI)	Post-test (95% CI)	Pretest (95% CI)	Post-test (95% CI)	Pretest (Group effect) (f)	Post-test (Group effect) (f)	Group x time effect (η^2_p)
SOT							
Somato-sensory ratio	0.93± 0.07 (0.89-0.96)	0.91± 0.13 (0.86-0.95)	0.91± 0.09 (0.87-0.94)	0.92± 0.07 (0.88-0.97)	0.422 (0.015)	0.578 (0.007)	0.264 (0.030)
Visual ratio	0.58± 0.19 (0.48-0.67)	0.73± 0.19[b] (0.64-0.83)	0.57± 0.24 (0.48-0.66)	0.57± 0.23 (0.48-0.66)	0.967 (<0.001)	0.012 (0.141)	0.001[c] (0.221)
Vestibular ratio	0.32± 0.16 (0.24-0.41)	0.55± 0.23[b] (0.46-0.65)	0.35± 0.21 (0.28-0.43)	0.34± 0.20 (0.25-0.43)	0.576 (0.008)	0.002[a] (0.198)	<0.001[c] (0.423)
Composite score	49.00±10.36 (43.93-53.98)	58.05± 16.55[b] (51.63-64.47)	49.26±12.30 (44.46-54.07)	52.13± 12.51[b] (46.00-58.27)	0.929 (<0.001)	0.186 (0.041)	0.022[c] (0.120)
UST							
COP sway velocity, °/s	3.18± 2.17 (2.29-4.06)	2.21± 1.88[b] (1.41-3.01)	3.56± 1.85 (2.71-4.40)	3.79± 1.77 (3.02-4.56)	0.533 (0.009)	0.007[a] (0.163)	0.003[c] (0.186)

Note. Values are mean ± SD or p values.
Between groups:
[a]Denotes a difference significant at $p<0.01$.
Within group (time effect):
[b]Denotes a difference significant at $p<0.05$ when compared with pretest values.
Group by time interaction and between 2 groups:
[c]Denotes a difference significant at $p<0.05$.

Table 7.7 Comparison of outcome measurements among the three groups (pre- and post-TKD training) and within individual groups (boys and girls)

	DCD-TKD group (Male n=17; Female n= 4)						DCD-control group (Male n=18 ; Female n=5)						Normal-control group (Male n= 14; Female n=4)						p value								
	Pretest			Post-test			Pretest			Post-test			Pretest			Post-test			Pretest			Post-test			Group x time effect		
	All	M	F	All	M	F	All	M	F	All	M	F	All	M	F	All	M	F	All	M	F	All	M	F	All	M	F
SOT																											
Somato-sensory ratio	0.93 ± 0.07	0.93 ± 0.08	0.93 ± 0.05	0.91 ± 0.13	0.89 ± 0.14	0.97 ± 0.02	0.91 ± 0.09	0.90 ± 0.10	0.93 ± 0.04	0.92 ± 0.07	0.93 ± 0.08	0.91 ± 0.02	0.96 ± 0.04	0.96 ± 0.04	0.97 ± 0.05	0.97 ± 0.04[d]	0.97 ± 0.04	0.99 ± 0.02	0.074	0.147	0.328	0.503	0.236	0.026	0.332	0.125	0.148
Visual ratio	0.58 ± 0.19	0.58 ± 0.19	0.54 ± 0.20	0.73 ± 0.19[d]	0.73 ± 0.21[d]	0.77 ± 0.09	0.57 ± 0.24	0.55 ± 0.26	0.68 ± 0.08	0.57 ± 0.23	0.55 ± 0.25	0.64 ± 0.15	0.74 ± 0.15	0.74 ± 0.16	0.71 ± 0.12	0.75 ± 0.16	0.74 ± 0.17	0.77 ± 0.14	0.019	0.031	0.212	0.012	0.027	0.287	<0.001[e]	0.006[e]	0.052
Vestibular ratio	0.32 ± 0.16[b]	0.31 ± 0.16	0.39 ± 0.15	0.55 ± 0.23[a,d]	0.54 ± 0.24[a,d]	0.61 ± 0.21	0.35 ± 0.21	0.34 ± 0.20	0.41 ± 0.24	0.34 ± 0.20[c]	0.33 ± 0.19	0.39 ± 0.23	0.51 ± 0.20	0.54 ± 0.21	0.39 ± 0.08	0.52 ± 0.17	0.54 ± 0.17	0.46 ± 0.16	0.010[f]	0.003[f]	0.984	<0.001[f]	<0.001[f]	0.169	<0.001[e]	<0.001[e]	0.058
Composite score	49.00±10.36	48.41±11.05	51.25 ± 7.41	58.05±16.55[d]	56.35±17.27[d]	65.25 ± 12.28	49.26±12.30	46.89±12.63[b]	57.80±6.14	52.13±12.51[d]	49.44±12.70	61.80±5.17	57.83±8.30	59.07±8.6	53.50±6.14	60.94±9.87	61.43±9.24	59.25±13.33	0.018	0.008[f]	0.348	0.048	0.089	0.392	0.026[e]	0.089	0.260
UST																											
COP sway velocity, °/s	3.18 ± 2.17	3.40 ± 2.33	2.23 ± 0.99	2.21 ± 1.88[a,d]	2.39 ± 1.94[d]	1.43 ± 1.56	3.56 ± 1.85[b]	3.68 ± 2.00	3.10 ± 1.20	3.79 ± 1.77[b,c]	3.96 ± 1.88[b]	3.16 ± 1.27	1.68 ± 0.70[a,c]	1.71 ± 0.78	1.60 ± 0.32	1.71 ± 1.06[a]	1.76 ± 1.19	1.53 ± 0.40	0.003[e]	0.012[e]	0.105	0.001[e]	0.005[e]	0.067	0.001[e]	0.005[e]	0.067

Note. Values are mean ± SD or p values.

Among groups:

[a]Denotes a difference significant at $p<0.01$when compared with the DCD-control group;
[b]Denotes a difference significant at $p<0.01$when compared with the Normal-control group;
[c]Denotes a difference significant at $p<0.01$when compared with the DCD-TKD group.

Within group (time effect):

[d]Denotes a difference significant at $p<0.05$ when compared with pretest values.

Group by time interaction and among three groups:

[e]Denotes a difference significant at the $p<0.05$ confidence level.
[f]Denotes a difference significant at $p<0.01$.

CHAPTER 8: GRAND DISCUSSION AND CONCLUSIONS

The main purpose of the thesis studies described herein was to gain new knowledge about the effects of taekwondo (TKD) training on postural control in children with developmental coordination disorder (DCD). Chapters 2 to 3 describe separate experiments in which sensori-motor and balance problems in children with DCD were evaluated. Chapters 4 to 6 describe three experimental studies in which the effects of TKD training on balance and sensori-motor performance in typically developing adolescents were explored. Results of these cross-sectional studies provide background knowledge and serve as the building blocks of the main study (a prospective randomized controlled trial) described in chapter 7. It is hoped that the results of the main study will contribute to solving the problems of the poor balance control and falls associated with DCD in children.

This chapter 8 summarizes our findings regarding balance and sensori-motor problems in children with DCD and the effects of TKD training in young persons aged 6 to 14 years. A specific TKD exercise paradigm for children with DCD is presented.

8.1 Balance and sensori-motor deficits in children with DCD

The following conclusions are drawn by comparing and contrasting the results of studies 1, 2 and 6 (based on the pre-TKD training data).

8.1.1 Somatosensory input for postural control

Children with DCD rely on somatosensory information for postural control as effectively as do typically developing children (studies 2 and 6). The lower SOT somatosensory ratio in the DCD group in study 1 may be due to existing co-morbidities (e.g. ADHD) rather than to DCD itself. This conclusion is in agreement with Grove & Lazarus (2007) and Przysucha & Taylor (2004), who reported that somatosensory feedback is re-weighted more heavily for postural control in children with DCD. Somatosensory function normally matures at a very young age (three to four years of age) (Steindl et al., 2006). Therefore, the sensory function in our children with DCD (aged six to twelve years) may have already caught up with that of the normal participants (with matured somatosensory function).

8.1.2 Visual input for postural control

Of the three sensory systems, the visual system may be most involved in the balance deficits of children with DCD (study 1). This finding is confirmed by the results of study 2, in which we used DCD-affected children with limited co-morbidities and a narrower age range. Neuroimaging studies have provided an explanation for this sensory deficit. For example, Kashiwagi et al. (2009) reported that brain activity in the left posterior parietal cortex was lower in boys with DCD than in boys without DCD. The parietal cortex integrates multimodal sensory information necessary for motor control, and sensory information dysfunction can cause visual-motor deficits (Kashiwagi et al., 2009). In addition, Knuckey and colleagues (1983) noted non-specific ventricular dilatation and cortical sulcal prominence in 'clumsy children' (an old term of DCD), indicating poor development of visual-motor integration.

However, the results of studies 1 to 2 (visual deficits in children with DCD) were not replicated in our main study (study 6). In the main study, we did not find any difference in the SOT visual ratio between the DCD-affected participants and the normal participants before intervention. This may be due to differences in boy/ girl ratios and the presence of different co-morbidities between studies.

8.1.3 Vestibular input for postural control

It is evident that children with DCD have difficulty using vestibular information to maintain balance; the SOT vestibular ratio was significantly lower in DCD-affected children than in children with normal motor development, as demonstrated in studies 1, 2 and 6. Our finding concurs with Grove & Lazarus (2007), who reported that 7 of 16 children with DCD (information on co-morbidities was not available) demonstrated impaired postural stability under SOT conditions 5 and 6, in which vestibular input was the sole accurate source of orienting feedback for postural control. However, because the SOT is not a direct measure of engagement of the complex vestibular system in active postural control, further research is needed to confirm and localize vestibular dysfunction in children with DCD, particularly by vestibular function tests and neurotologic examination etc. (Grove & Lazarus, 2007).

8.1.4 Motor strategy for postural control

In study 2, we found that under less challenging standing conditions, the movement strategies adopted by children with DCD to maintain balance did not differ from those adopted by the normal participants. However, the same DCD-affected children had difficulty adjusting their postural control strategy under conditions that forced them to rely on vestibular input for standing balance (conditions 5 and 6 of the SOT). Unlike the normal group, the DCD group responded by over-reliance on the hip strategy rather than appropriate utilization of the ankle strategy.

8.1.5 Static bipedal, unipedal and functional standing balance

Different types of balance control were assessed in our studies. In general, children with DCD have inferior static standing balance in both bipedal (studies 1 and 2) and unipedal stance (study 6) than that of children with normal development. Although the SOT composite scores were comparable ($p>0.05$) between children with and without DCD in study 6, this could be, again, due to differences in the boy/ girl ratio and the presence of co-morbidities. Moreover, functional balance performance, including walking with heels raised or with tandem gait, jumping and hopping, was shown to be below normal in children with DCD (study 1).

8.2 Potential benefits of TKD training

The following conclusions are drawn by comparing and contrasting the findings from studies 3 to 5.

8.2.1 Somatosensory input and knee joint proprioception for postural control

We found that TKD training may not improve somatosensory function for standing balance control in young adolescents, regardless of the training duration (studies 3 and 4). However, several previous studies have indicated that lower limb joint proprioception (part of the somatosensory system) can be improved by sports training in young athletes (Golomer et al., 1999; Lephart et al., 1996; Perrot et al., 1998a). Thus, we tested knee proprioception by the passive positioning and active repositioning test (involves both sensory and motor components) in study 5. Results revealed that only the long-term TKD practitioners (five to nine years of TKD experience) had better knee joint proprioceptive sense than the control participants, which correlated with the better single-leg standing balance. From the results of studies 3 to 5, we conclude that long-term TKD training may improve knee joint position sense and hence single-leg standing balance control. The differences (noted to be non-significant) in the SOT somatosensory ratios between TKD participants and control participants in studies 3 and 4 may be due to the different/ non-specific testing method alone.

8.2.2 Visual input for postural control

Despite the lack of a significant difference in the SOT visual ratio between TKD practitioners (one to nine years of TKD experience) and non-practitioners in study 3, we continued to explore the effect of TKD training on visual function for balance control because a previous study has suggested that elite karate and fencing athletes (given long-term training in the sports) can maximize changing visual information to maintain upright stance (Del Percio et al., 2007). We postulated that the absence of a significant difference in study 3 might have been due to the wide variation in TKD training duration. Therefore, in study 4, the TKD practitioners were grouped according to the duration of training: short-term (one to four years of TKD experience; colored-belt qualified) and long-term (five to nine years of TKD experience; black belt qualified). The visual ratio was significantly better in the short-term TKD practitioners than in the long-term practitioners and control participants. This implies that short-term TKD practitioners had better balance than long-term practitioners and control participants when they relied on visual input. An explanation for this interesting finding was given in chapter 5 (study 4).

8.2.3 Vestibular input for postural control

In terms of vestibular function, our results are promising. We found that adolescents trained in TKD (one to nine years of TKD training) had better vestibular function and achieved greater stability in unilateral stance than their non-TKD counterparts. Furthermore, vestibular function in the TKD-trained adolescents was as good as that in adults (study 3). It seems that TKD training may speed up the development of vestibular function for postural control in young adolescents. To further investigate this potential beneficial effect of TKD, we divided the TKD practitioners into long- and short-term training groups and compared them to a control group (study 4). Only the short-term TKD practitioners swayed less than controls when they relied on vestibular input for balance. Because the vestibular ratio in the long-term TKD practitioners was similar to that in the adult control participants ($p=0.259$), we postulate that the TKD training effect on vestibular function may reach a plateau in long-term practitioners.

8.2.4 Lower limb muscle strength

In study 5, both the long- and short-term TKD practitioners had approximately 40% greater body-weight-adjusted isokinetic quadriceps strength and approximately 30% greater hamstring strength than those of the untrained control participants, but these differences were not statistically significant, probably due to the small sample size. Further studies involving larger study groups are needed to properly confirm these differences.

8.2.5 Static unipedal standing balance control

Unlike the DCD studies (studies 1 & 2), static bipedal standing balance was not tested in healthy TKD participants. This is because standing steadily on both legs is not challenging enough in the normal population and, therefore, standing balance performance may not differ between TKD and non-TKD practitioners. In the unipedal (or unilateral) stance test, both long- and short-term TKD practitioners consistently swayed more slowly than their untrained counterparts, although their COP sway velocity (a reflection of postural stability) had not yet reached adult level (studies 3 to 5).

8.3 TKD training benefits children with DCD

In our DCD study series (studies 1 and 2), we found that children with DCD had poorer visual and vestibular functions than those of typically developing children. In addition, their motor control strategies (under sensory conflicting environments), unipedal, bipedal and functional standing balance were below the levels of their normal peers. In our TKD study series (studies 3 to 5), we found that short-term TKD practitioners swayed less when they relied on the visual and/or vestibular system to balance, and they were more stable when standing on one leg than their non-trained peers. Knee muscle strength and joint proprioception might also be better in TKD practitioners. From the results of these two series of studies, it appears that we can use TKD exercise to enhance visual and vestibular functions, and also unipedal and bipedal (foundation of unilateral stance stability) stance stability, in children with DCD. We tested this hypothesis by evaluating the effects of TKD training on balance and sensory functions in children with DCD in study 6 (main study) (Table 8.1).

Table 8.1 Comparative outcomes of the TKD and DCD research series

Outcome measure	DCD study series Balance in children with DCD	TKD study series Potential effects of TKD training
Somatosensory function	• Appears normal (comparable to typically developing peers)	• Not apparent; long-term training may improve knee joint proprioception
Visual function	• Impaired	• May improve with short-term training
Vestibular function	• Impaired	• May improve with short-term training
Motor strategy	• Over-reliance on hip strategy in sensory conflicting environments	• Not tested, but there tends to be greater knee muscle strength in both short-term and long-term TKD practitioners
Bipedal stance stability	• Below that of typically developing peers	• Not tested, because not challenging to normal young adolescents
Unipedal (or unilateral) stance stability	• Below that of typically developing peers	• Promising effect
Functional balance performance	• Below that of typically developing peers	• Not tested; need to include this outcome in future studies

8.4 Therapeutic TKD exercise program for children with DCD

Based on the results of studies 1 to 5 and the 'F.I.T.T. (frequency, intensity, time, type of exercise) exercise principles' (ACSM, 2006), we designed a specific three-month TKD exercise paradigm for children with DCD that aimed to improve balance control and sensory organization of these children. The TKD exercise protocol is given in Table 7.1 and illustrated in Figure 8.1. The effectiveness of this TKD intervention was tested by a randomized controlled trial in children with DCD (study 6).

The findings of study 6 are summarized as follows:

- Somatosensory function in children with DCD was not influenced by TKD training.
- Three-month TKD training improved visual function in children with DCD. The effect of training was more profound than the effect of physiologic maturation.
- Vestibular function improved significantly after three months of TKD training in children with DCD and became comparable to that of children with normal motor development. TKD exercise is suitable for vestibular training.
- The unilateral stance stability in children with DCD improved and reached the level of typically developing children after three months of TKD training.

- Although bipedal standing balance improved after three months in children with DCD, the effect of maturation was more profound than the TKD training effect.

In conclusion, this three-month TKD intervention, aimed at improving balance and sensory organization for children with DCD, showed promising results.

Horseback riding stance

10-15 minutes daily, perform with punching and blocking techniques

Fighting stance

20-30 minutes daily, perform with kicking techniques

Punch and down block

20 repetitions each, practice daily

Rising block

20 repetitions, practice daily

Fig. 8.1 Taekwondo exercises for children with DCD

Punch and inside block

20 repetitions each, practice daily

Outside block

20 repetitions, practice daily

Front kick

40 repetitions, practice daily

Round house kick

40 repetitions, practice daily

Fig. 8.1 Taekwondo exercises for children with DCD (continued)

Side kick

40 repetitions, practice daily

Back kick

40 repetitions, practice daily

Back kick with support (if necessary)

40 repetitions, practice daily

Strengthening exercises

(e.g. push ups)

Perform during cool down, around 5 minutes

Fig. 8.1 Taekwondo exercises for children with DCD (continued)

General stretching exercises

(e.g. medial hamstring stretch)

Perform after warm-up and during cool-down, around 5 minutes

We acknowledge Mr. Tang (center), chief instructor of the TKD class for children with DCD and instructors of the Eastern Dragon Taekwondo Association

Fig. 8.1 Taekwondo exercises for children with DCD (continued)

8.5 Limitations and future studies

In the studies described herein, all postural control outcome measures were recorded with the participants in upright stance. Standing does not reflect the full complexity of balance control required during performance of many functional tasks. Dynamic and functional balance performance should be assessed in future studies. Other aspects of postural control (e.g. lower limb muscle strength, joint proprioception, and motor strategies) that might be improved by TKD training should also be assessed in children with DCD.

Although our TKD training protocol was effective for improving certain balance parameters, it is possible that TKD intervention of longer duration might further improve the sensory organization ability in children with DCD. Moreover, follow-up assessment is warranted to explore whether the balance ability gained is retained after a period of non-intervention.

According to the ICF model, relationships between balance performance, the risk of falls and activity participation after TKD training (i.e. after improvement in balance performance) were not investigated in the studies described herein. Further study is needed to address the clinical importance of positive changes in balance and sensory performance in children with DCD.

An important future step in the study of postural control in children with DCD is analysis and extraction of the essential TKD elements (e.g. by kinetic and kinematic measurements) that contribute to improved postural control and sensory organization in children with DCD so as to refine the current TKD training protocol.

8.6 Conclusion

A specific TKD exercise protocol was devised to improve postural control and sensory organization in children with DCD. Clinicians can suggest this TKD exercise protocol as a therapeutic leisure activity for children with DCD.

<End>

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Appendix I: Description of scores within each participation dimension of the CAPE (King et al., 2004)

	Dimensions of the CAPE				
	Diversity	**Intensity**	**Companionship**	**Location**	**Enjoyment**
Raw data	Yes/ No response to whether an activity was done within past 4 months	Frequency scores: 1 = Once/ 4 months 2 = Twice/ 4 months 3 = Once/ month 4 = 2-3 times/ month 5= Once/ week 6 = 2-3 times/ week 7 = Once/ day	1 = Alone 2 = Close family 3 = Other relatives 4 = Friends 5 = Others	1 = At home 2 = Relatives home 3 = Neighbour-hood 4 = School (not class) 5 = In your community 6 = Beyond your community	1 = Not at all 2 = Somewhat 3 = Pretty much 4 = Very much 5 = Love it
Score	Count of the number of activities a child participates	Sum of 'frequency' score divided by total number of items in scale of interest	Sum of 'with whom' scores of activities child does divided by child's diversity score for scale of interest	Sum of 'where' scores for activities a child does divided by the child's diversity score in scale of interest	Sum of 'enjoyment' scores of items a child does divided by the child's diversity score in scale of interest

Score range	Overall: 0-55 Formal: 0-15 Informal: 0-40 Recreational: 0-12 Physical: 0-13 Social: 0-10 Skill-based: 0-10 Self-improvement: 0-10	0-7	1-5	1-6	1-5

Appendix II: Detailed differential participation patterns in children with and without DCD measured by CAPE (Fong et al., 2011b)

Outcome	DCD group [Mean (SD)]			Control group [Mean (SD)]		
	All ($n = 81$)	Male ($n = 63$)	Female ($n = 18$)	All ($n = 67$)	Male ($n = 48$)	Female ($n = 19$)
Total activities						
Total diversity score	23.40 (6.74)[c]	23.57 (7.05)[a]	22.78 (5.64)[b]	27.94 (4.99)	27.23 (5.12)	29.74 (4.25)
Total intensity score	108.37 (28.67)***	109.27 (30.10)[b]	105.22 (23.49)[c]	133.76 (26.61)	129.10 (27.11)	145.53 (21.74)
Total companionship score	2.40 (0.37)	2.39 (0.38)	2.41 (0.35)	2.45 (0.30)	2.38 (0.27)	2.64 (0.32)
Total location score	2.90 (0.42)	2.92 (0.43)	2.83 (0.35)	2.91 (0.52)	2.91 (0.58)	2.91 (0.30)
Total enjoyment score	3.76 (0.36)	3.72 (0.37)	3.89 (0.33)	3.78 (0.35)	3.73 (0.36)	3.92 (0.28)
Informal activities						
Diversity score	18.88 (5.23)[c]	18.97 (5.38)[b]	18.56 (4.82)[a]	22.37 (4.06)	22.13 (4.34)	23.00 (3.28)
Intensity score	2.17 (0.56)[c]	2.18 (0.58)[a]	2.13 (0.50)[c]	2.64 (0.52)	2.58 (0.55)	2.78 (0.41)
Companionship score	2.05 (0.31)	2.04 (0.31)	2.08 (0.32)	2.11 (0.28)	2.06 (0.25)	2.22 (0.32)
Location score	2.58 (0.43)	2.61 (0.44)	2.51 (0.39)	2.54 (0.36)	2.54 (0.34)	2.54 (0.43)
Enjoyment score	3.81 (0.38)	3.77 (0.38)	3.97 (0.35)	3.83 (0.35)	3.76 (0.36)	3.98 (0.28)
Formal activities						
Diversity score	4.53 (2.23)	4.62 (2.41)	4.22 (1.44)[c]	5.57 (1.92)	5.13 (1.90)	6.68 (1.53)
Intensity score	1.42 (0.68)[b]	1.45 (0.73)	1.34 (0.48)[c]	1.88 (0.71)	1.72 (0.67)	2.29 (0.65)
Companionship score	3.77 (1.07)	3.76 (1.07)	3.79 (1.12)	3.83 (0.74)	3.73 (0.77)	4.08 (0.63)
Location score	4.18 (0.75)	4.24 (0.76)	3.97 (0.65)	4.12 (0.57)	4.13 (0.59)	4.10 (0.50)
Enjoyment score	3.59 (0.84)	3.60 (0.91)	3.58 (0.56)	3.64 (0.57)	3.60 (0.63)	3.74 (0.38)
Recreational activities						
Diversity score	7.22 (2.25)	7.29 (2.22)	7.00 (2.40)	8.01 (1.67)	8.10 (1.77)	7.79 (1.40)
Intensity score	3.08 (0.98)[a]	3.09 (1.00)[a]	3.03 (0.90)	3.55 (0.86)	3.59 (0.92)	3.48 (0.67)
Companionship score	1.84 (0.42)	1.84 (0.45)	1.85 (0.29)	1.86 (0.44)	1.78 (0.36)	2.08 (0.53)
Location score	1.89 (0.65)[b]	1.92 (0.69)[a]	1.76 (0.47)	1.72 (0.44)	1.71 (0.47)	1.74 (0.38)
Enjoyment score	4.04 (0.46)	3.99 (0.46)	4.22 (0.43)	4.01 (0.41)	4.00 (0.42)	4.04 (0.37)
Physical activities						
Diversity score	3.20 (1.96)[a]	3.32 (1.99)	2.78 (1.86)[a]	4.13 (1.61)	3.92 (1.61)	4.68 (1.53)
Intensity score	1.05 (0.68)[a]	1.09 (0.71)	0.92 (0.59)[a]	1.43 (0.68)	1.37 (0.71)	1.57 (0.59)
Companionship score	3.13 (1.33)	3.11 (1.29)	3.19 (1.51)	3.06 (0.85)	3.01 (0.90)	3.19 (0.72)
Location score	4.17 (1.29)	4.28 (1.21)	3.74 (1.52)	4.09 (0.76)	4.14 (0.76)	3.97 (0.75)
Enjoyment score	3.64 (1.12)	3.70 (1.02)	3.45 (1.45)	3.89 (0.61)	3.90 (0.66)	3.85 (0.48)
Social activities						
Diversity score	4.93 (2.14)[b]	4.92 (2.19)[a]	4.94 (2.04)[a]	6.16 (1.64)	6.06 (1.77)	6.42 (1.26)
Intensity score	1.74 (0.88)[b]	1.75 (0.92)	1.68 (0.79)[c]	2.22 (0.77)	2.06 (0.79)	2.62 (0.56)
Companionship score	2.46 (0.53)	2.46 (0.52)	2.49 (0.61)	2.57 (0.41)	2.55 (0.41)	2.64 (0.43)
Location score	3.10 (0.87)	3.14 (0.91)	2.96 (0.72)	3.09 (0.63)	3.10 (0.63)	3.07 (0.65)
Enjoyment score	3.80 (0.65)	3.76 (0.66)	3.99 (0.62)	3.94 (0.49)	3.86 (0.50)	4.15 (0.40)
Skill-based activities						
Diversity score	2.64 (1.60)[a]	2.59 (1.65)	2.83 (1.42)[b]	3.46 (1.60)	3.02 (1.51)	4.58 (1.26)
Intensity score	1.20 (0.76)[b]	1.17 (0.77)	1.33 (0.74)[a]	1.74 (0.88)	1.49 (0.81)	2.37 (0.71)
Companionship score	3.25 (1.34)	3.30 (1.38)	3.09 (1.21)	3.49 (1.10)	3.28 (1.16)	4.02 (0.71)
Location score	3.68 (1.24)	3.80 (1.27)	3.24 (1.03)	3.61 (1.43)	3.48 (1.60)	3.94 (0.81)
Enjoyment score	3.60 (1.40)	3.53 (1.55)	3.86 (0.57)	3.54 (0.90)	3.44 (0.98)	3.79 (0.62)
Self improvement activities						
Diversity score	5.42 (1.65)[a]	5.48 (1.69)	5.22 (1.52)	6.16 (1.72)	6.15 (1.68)	6.21 (1.87)
Intensity score	2.79 (0.76)[c]	2.82 (0.75)[b]	2.69 (0.80)[a]	3.29 (0.80)	3.27 (0.81)	3.34 (0.79)
Companionship score	2.13 (0.59)	2.13 (0.54)	2.13 (0.77)	2.06 (0.45)	2.11 (0.39)	1.96 (0.58)
Location score	2.81 (0.73)	2.78 (0.63)	2.91 (1.05)	2.83 (0.63)	2.90 (0.64)	2.64 (0.56)
Enjoyment score	3.36 (0.49)	3.35 (0.47)	3.38 (0.55)	3.34 (0.60)	3.21 (0.59)	3.67 (0.48)

[a] $p \leq 0.05$.
[b] $p \leq 0.01$.
[c] $p \leq 0.001$.

Appendix III: Pictures illustrating the Movement ABC-2 balance tests (Henderson et al., 2007)

Age range: 3 - 6 years

- Balance 1 (static) – One-leg balance.
  - Right and left legs.
  - Timed balance (second).

- Balance 2 (dynamic) – Walking heels raised.
  - Number of correct consecutive steps from the beginning of the line.
  - Whether entire line was walked successfully.

- Balance 3 (dynamic) – Jumping on mats.
  - Number of consecutive jumps (max. of 5).

Age range: 7 – 10 years

- Balance 1 (static) – One-board balance.
  - Right & left legs.
  - Timed balance (second).

- Balance 2 (dynamic) – Walking heel-to-toe forwards.
  - Number of correct consecutive steps from the beginning of the line.
  - Whether the entire line was walked successfully.

- Balance 3 (dynamic) – Hopping on mats.
    - Right & left legs.
    - Number of consecutive hops (max. of 5).

Age range: 11 – 16 years

- Balance 1 (static) – Two-board balance.
    - Time balance (second).

- Balance 2 (dynamic) – Walking toe-to-heel backwards.
    - Number of correct consecutive steps from the beginning of the line.
    - Whether the entire line was walked successfully.

- Balance 3 (dynamic) – Zig-zag hopping.
    - Left & right legs.
    - Number of correct consecutive hops (max. of 5).

Appendix IV: Ethical approval by the Human Subjects Ethics Review Sub-committee of the Hong Kong Polytechnic University

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

MEMO

To : NG Yin Fat, Department of Rehabilitation Sciences
From : YIP Kam Shing, Chairman, Faculty Research Committee, Faculty of Health & Social Sciences

Ethical Review of Research Project Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following research project for a period from 16/11/2009 to 31/12/2012:

Project Title : The effects of Taekwondo training on balance, sensorimotor performance and muscle strength in young adolescents

Department : Department of Rehabilitation Sciences

Principal Investigator : NG Yin Fat

Please note that you will be held responsible for the ethical approval granted for the project and the ethical conduct of the research personnel involved in the project. In the case the Co-PI has also obtained ethical approval for the project, the Co-PI will also assume the responsibility in respect of the ethical approval (in relation to the areas of expertise of respective Co-PI in accordance with the stipulations given by the approving authority).

You are responsible for informing the Faculty Research Committee Faculty of Health & Social Sciences in advance of any changes in the research proposal or procedures which may affect the validity of this ethical approval.

You will receive separate notification should you be required to obtain fresh approval.

YIP Kam Shing
FOR Chairman
Faculty Research Committee
Faculty of Health & Social Sciences

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

MEMO

To : PANG Marco Yiu Chung, Department of Rehabilitation Sciences
From : NG Yin Fat, Chairman, Departmental Research Committee, Department of Rehabilitation Sciences

Ethical Review of Research Project Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following research project for a period from 13/12/2008 to 30/10/2010:

Project Title : Balance performance in children with Developmental Coordination Disorder

Department : Department of Rehabilitation Sciences

Principal Investigator : PANG Marco Yiu Chung

Please note that you will be held responsible for the ethical approval granted for the project and the ethical conduct of the research personnel involved in the project. In the case the Co-PI has also obtained ethical approval for the project, the Co-PI will also assume the responsibility in respect of the ethical approval (in relation to the areas of expertise of respective Co-PI in accordance with the stipulations given by the approving authority).

You are responsible for informing the Departmental Research Committee Department of Rehabilitation Sciences in advance of any changes in the research proposal or procedures which may affect the validity of this ethical approval.

You will receive separate notification should you be required to obtain fresh approval.

NG Yin Fat
Chairman
Departmental Research Committee
Department of Rehabilitation Sciences

[Adapted from Li, L.Y. (2010). Balance performance in children with developmental coordination disorder. *MSc in Health Care thesis*, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University.]

Appendix V: Consent forms

The Hong Kong Polytechnic University
Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project title:

The effects of Taekwondo training on balance, sensorimotor performance and muscle strength in young adolescents

Investigators:

Shirley Fong, PT MSc, PhD candidate, Clinical Associate, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University.

Gabriel Ng, PT PhD, Chair Professor and Associate Head, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University.

Project information:

This project pertains to determine the balance, sensorimotor performance and muscle strength of Taekwondo practitioners and non-practitioners. The findings will improve our understanding on the physical benefits of Taekwondo training and facilitate further planning of exercise program for improving balance performance in children and teenagers.

Methods:

You will need to complete a few tests on a machine that measures your balance performance under different environmental simulated conditions, and then the examiner will assess your balance, joint position sense and lower limb strength with an isokinetic machine. All the tests will be conducted in the Balance and Neural Control Laboratory in the Department of Rehabilitation Sciences of PolyU. The whole testing procedure will finish in less than 3 hours.

Risks and Benefits:

There is no known risk in the tests except that you may feel some mild muscle soreness afterwards. However, if you have any major illness or injuries, please inform the investigators immediately to determine your suitability in participating in this study. You will not have any direct benefit from this study but your participation will be important to further our understanding on the training effects of Taekwondo.

<u>Consent:</u>

I, ____________________________, have been explained the details of this study. I voluntarily consent to participate in this study. I understand that I can withdraw from this study at any time without giving reasons, and my withdrawal will not lead to any punishment or prejudice against me. I am aware of any potential risk in joining this study. I also understand that my personal information will not be disclosed to people who are not related to this study and my name or photograph will not appear on any publications resulted from this study.

I can contact the chief investigator, Ms Shirley Fong at telephone 2766 6739 for any questions about this study. If I have complaints related to the investigator(s), I can contact Ms Michelle Leung, secretary of Departmental Research Committee, at 2766 5397. I know I will be given a signed copy of this consent form.

Signature (subject): Date:

Signature (witness): Date:

香港理工大學康復治療科學系

科研同意書

科研題目：

跆拳道訓練對青少年的平衡能力、肌肉反應、膝關節本體感覺及肌力的影響

科研人員：

方少萌女士 (PT MSc, PhD candidate, 香港理工大學康復治療科學系臨床導師)

吳賢發教授 (PT PhD, 香港理工大學康復治療科學系講座教授兼副系主任)

科研目的：

是項研究旨在了解跆拳道練習者與非練習者的平衡能力、肌肉反應及力量，這將有助我們了解修練跆拳道的好處及厘定適當的運動來改善兒童及青少年的身體質素。

研究方法：

閣下將被邀請在本學系的平衡及腦功能實驗室內接受數項的測試，包括站立平衡能力，閣下將被邀請站在平衡儀器上，並在不同的環境狀態下保持平衡；然後研究員會利用等速肌力測試儀器，量度閣下的下肢肌肉力量及膝關節感應能力等。研究人員將會向閣下詳細解釋測試的方法。整個測試約需三小時。

潛在危險性及得益：

此項研究不會帶來直接的風險或得益。研究過程中不會產生任何副作用或危險，但可能會引致短暫性的肌肉疲勞酸痛。如果閣下患有嚴重疾病或受傷，請立即諮詢研究員，以決定閣下是否適合參予此項研究。

同意書：

本人____________已瞭解此次研究的具體情況。本人願意參加此次研究, 本人有權在任何時候、無任何原因之情況下放棄參與此次研究, 而此舉將不會導致我受到任何懲罰或不公平對待。本人明白參加此研究課題的潛在危險性以及本人的資料將不會洩露予與此研究無關的人員，我的名字或相片亦不會出現在任何出版物上。

本人明白可以致電 2766 6739 來聯繫此次研究課題的負責人，方少萌臨床導師，以查詢任何有關此次研究之問題。若本人對此研究的科研人員有任何投訴，亦可以聯繫梁女士（部門科研委員會秘書），電話：2766 5397。本人亦明白，參與此研究課題需要本人簽署一份同意書。

簽名（參與者）：___________ 日期：

簽名（證人）： ___________ 日期：

The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

Project: ‘The effects of Taekwondo training on balance, sensori-motor performance and muscle strength in young adolescents’

<u>Taekwondo training course (30-10-2010 to 22-1-2011)</u>

I, _______________________ (PARENT), hereby consent to have my son/ daughter: _______________________ (CLASS PARTICIPANT) to voluntarily engage in the Taekwondo training course.

I have been explained the details of this course. I understand the course will last for 3 months. Its main aims are to improve the balance ability, muscle strength and basic Taekwondo skills of the participants. Course content includes, but is not limited to the following activities: (1) Warm up and stretching exercises, (2) basic stances, punching, blocking and kicking techniques, (3) kick pad exercises, (4) strengthening and fitness exercises, and (5) basic form practice. Training will be progressive and according to the level or special needs of the participants. I understand that I must monitor the health status and physical condition of my son/ daughter during training. If he/ she (the undersigned participant) has any discomfort or symptoms, I will stop his/ her training and inform the Taekwondo coach immediately.

I voluntarily consent to allow my son/ daughter to participate in this Taekwondo course. I understand that I and my son/ daughter can withdraw from this course at any time without giving reasons, and our withdrawal will not lead to any punishment or prejudice against us. I also understand that my son/ daughter’s personal information or photos will not be disclosed to people who are not related to this study or Taekwondo course and our names or photographs will not appear in any publications resulted from this study or course. I also understand that I and my son/ daughter will not have any financial benefit or remuneration by joining this course.

I am aware of the potential risk in joining this Taekwondo course. **The Department of Rehabilitation Sciences and the Taekwondo association will not be responsible or liable for any injuries of my son/ daughter (undersigned participant) during Taekwondo training.**

I declare that my son/ daughter is physically fit to participate in this course. If there is any change in the participant’s health status or physical condition, I will inform the Taekwondo coach immediately. I can contact the chief investigator, Ms Shirley Fong, at telephone 9709 / 27666739 for any questions about this course.

I acknowledge that I have read this document in its entirely and understand the above as it relates to my son or daughter.

Signature (participant): _________________

Signature (parent/ guardian): _________________

Signature (witness): ____________________ Date: ________________________

香港理工大學康復治療科學系

香港理工大學
康復治療科學系

「跆拳道訓練對青少年的平衡能力、肌肉反應、膝關節本體感覺及肌力的影響」研究

跆拳道訓練班 (30-10-2010 至 22-1-2011)

本人 ________________(家長姓名) 同意本人的子女 ________________(參加者姓名) 自願參加由香港理工大學康復治療科學系舉辦之跆拳道訓練班。

本人明白此運動班為期三個月，目的為改進參加者的平衡能力、肌肉力量及跆拳道技術。課程包括(但並不局限於)以下項目：伸展、基本步法、手法、腳法、擊打腳靶練習、體適能訓練、套拳操練等，所有課程內容皆對身體加諸漸進性負荷，以求改善其功能及改進跆拳道技術。課程進度會根據參加者的身體狀況作出適當的調整。本人明白在訓練過程中，本人須負責監察子女的身體狀況。倘若參加者覺得不適或發現任何不沉常癥兆，本人會命令參加者立即停止參與練習及將情況告知當席教練。

本人/參加者有權在任何時候、無任何原因之情況下放棄參與此訓練課程, 而此舉將不會導致本人/參加者受到任何懲罰或不公平對待。研究人員會在訓練其間拍攝照片或短片作研究用途，**參加者的資料或相片將不會公開或洩露予與此研究/訓練班無關的人員**，參加者的名字或相片亦不會出現在任何出版物上。再者，本人及參加者將不會得到任何報酬或收益。

本人確定參加者在參與此課程之前已咨詢醫生之意見，並獲得同意。本人証明參加者的身體健康狀況良好，倘若有任何變化，本人會通知當席教練。若本人對此訓練班有任何疑問，可以聯繫理大康復治療科學系物理治療臨床導師方少萌女士，電話：9709 / 27666739。**本人明白跆拳道訓練存在一定的危險性，本人及參加者同意對運動過程中所造成的一切身體損傷自行作出承擔。**

在簽署此同意書前，本人及參加者肯定已詳閱此書及明白課程宗旨，而本人肯定對跆拳道課程所作出之疑問已獲得滿意答覆。

參加者簽署：____________________ 家長簽署 (十八歲以下之學員) ____________________

見証人：________________________ 日期：________________________

Appendix VI: Taekwondo training logbook

香港理工大學康復治療科學系

<u>跆拳道訓練班 (30-10-2010 至 22-1-2011)</u>

<u>家居跆拳道練習</u>

學員手冊

學員姓名：______________________

年齡：______________

跆拳道訓練班

訓練目標：

- 透過跆拳道訓練，增強學員的平衡能力、肌肉力量及體能，以使他們更能融入學校及社會生活
- 著重家居訓練及養成運動習慣
- 加強家長之間的互相支持及分享

上課日期：

- 2010 年 10 月 30 日,
- 2010 年 11 月 6 日, 13 日, 20 日, 27 日,
- 2010 年 12 月 4 日, 11 日, 18 日, 25 日
- 2011 年 1 月 8 日, 15 日, 22 日 (逢星期六)

時間：

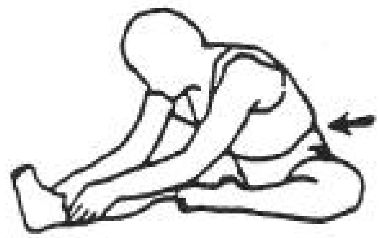
- 下午 3-4 時

地點：

- 理大 GH016 室

家居跆拳道練習內容

1. 伸展膕繩肌 – 維持 10 秒，大腿後方肌肉有拉緊感覺，左右腳輪流伸展，各重覆 10 次



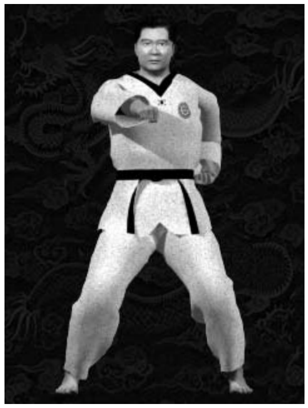
2. 前踢 (原位) – 左右腳輪流練習，各踢 20 次

3. 旋踢 (原位) – 左右腳輪流練習，各踢 20 次

4. 側踢 (原位) – 左右腳輪流練習，各踢 20 次

5. 後踢 (原位) – 左右腳輪流練習，各踢 20 次

6. 四平馬及中直拳 – 20 次



(Pictures adapted from
http://wustaekwondo.com/techniques/pattern/taegeuk1.htm)

- 建議每星期在家練習以上動作三遍或以上。

(以上動作只作參考之用，如對內容有任何疑問，請向教練查詢。香港理工大學康復治療科學系並不會因手冊內提供的建議、指示或運動方式而負上任何法律責任。)

家居跆拳道練習紀錄

日期	練習內容 (請圈出已練習的動作)	家長簽署
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	

日期	練習內容 (請圈出已練習的動作)	家長簽署
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	

日期	練習內容 (請圈出已練習的動作)	家長簽署
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	

日期	練習內容 (請圈出已練習的動作)	家長簽署
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
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	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	
	動作 1 / 2 / 3 / 4 / 5 / 6	

Appendix VII: Subject recruitment posters

動作協調障礙系列一

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

香港理工大學 康復治療科學系

兒童平衡力健康檢查及跆拳道訓練班

完全免費！
有交通津貼！

香港理工大學康復治療科學系現正進行一項「跆拳道訓練與平衡能力」的研究項目，對象是患有**動作協調障礙**的孩子，我們的**物理治療師**會監察他們在成長期間平衡力的變化及練習跆拳道對他們平衡能力的影響。

- **對象： 6 - 9 歲，患有動作協調障礙的兒童**

<u>程序及日期：</u>

第一次檢查	2010 年 9 月- 10 月 (2 小時，電話預約，理大)
參予跆拳道訓練 (出席率達 9 成，才有津貼)	2010 年 10 月 30 日 - 2011 年 1 月 22 日 (逢星期六，3-4pm，理大，家長陪同參予)
第二次檢查及收取報告	2011 年 1 月 - 2 月 (2 小時，電話預約，理大)

- 所有檢查均是安全的，沒有不良影響。每次交通津貼$30。
- 參加者可選擇不參予跆拳道訓練，只接受兩次健康檢查。

有興趣參予健康檢查或跆拳道訓練班之人仕或家長，請至電 9709 / 27666739 Shirley Fong 查詢及報名。
或下載報名表格：
http://myweb.polyu.edu.hk/~rssfong/TKD/

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

康復治療科學系
Department of Rehabilitation Sciences

你有幾強？

費用全免！

骨質密度及健康檢查

香港理工大學康復治療科學系現正進行一項「跆拳道訓練與青少年身心發展」的研究項目，我們會監察練習跆拳道的青少年二十個月，記錄他們在成長期間的骨質密度、生理及心理變化，藉此了解跆拳道訓練對青少年身心發展的影響。

對象：11至14歲，**即將**參予跆拳道訓練班的青少年 (白帶)

程序及日期：

程序	日期
第一次健康檢查	2009 年 9 月 – 2010年1月
參予跆拳道訓練	第一次至第二次檢查期間
第二次健康檢查	2011年4月 – 9 月
收取報告	2011年9月 – 12月

檢查時間：電話預約 (每次檢查約 4 小時)

地點：紅磡香港理工大學康復治療科學系

檢查內容：骨質密度、 肌肉力量、 柔韌度及心肺功能

【所有身體檢查均是安全的，沒有不良影響。參加者還需匯報個人飲食習慣、考試成績及填寫心理測驗問卷。所有資料只會用作研究用途，絕對保密。】

有興趣參予此項研究之人仕或家長，請填妥報名表格，電郵或寄回本學系。

地址：九龍紅磡香港理工大學康復治療科學系ST511 (Shirley Fong 收)

查詢電郵：rssfong@inet.polyu.edu.hk

查詢電話：2766 6739 (Ms. Shirley Fong)

下載報名表格: http://myweb.polyu.edu.hk/~rssfong/TKD/index

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

贊助： The Hong Kong Jockey Club Sports Medicine and Health Sciences Centre
香港賽馬會運動醫學及健康科學中心

康復治療科學系
免費健康講座

理工大學物理/職業治療師主講

日期	題目
27/02/2010(六)	膝關節的護理
06/03/2010(六)	如何協助書寫困難的學生? [2-3pm]
13/03/2010(六)	走出壓力及情緒低谷
20/03/2010(六)	如何選擇適合你的運動
27/03/2010(六)	鞋墊對處理足痛的重要性
10/04/2010(六)	注意你的體型、體態
17/04/2010(六)	OL常見的頸肩痛
24/04/2010(六)	健身氣功八段錦 [普通話]
08/05/2010(六)	辦公室保健運動
15/05/2010(六)	為何小孩子經常跌倒？ [附設免費學童平衡力評估，見下]
22/05/2010(六)	肌肉適能柔軟度及伸展運動

免費學童平衡力評估(6-14歲)

(每位約30分鐘, 務必致電預約)

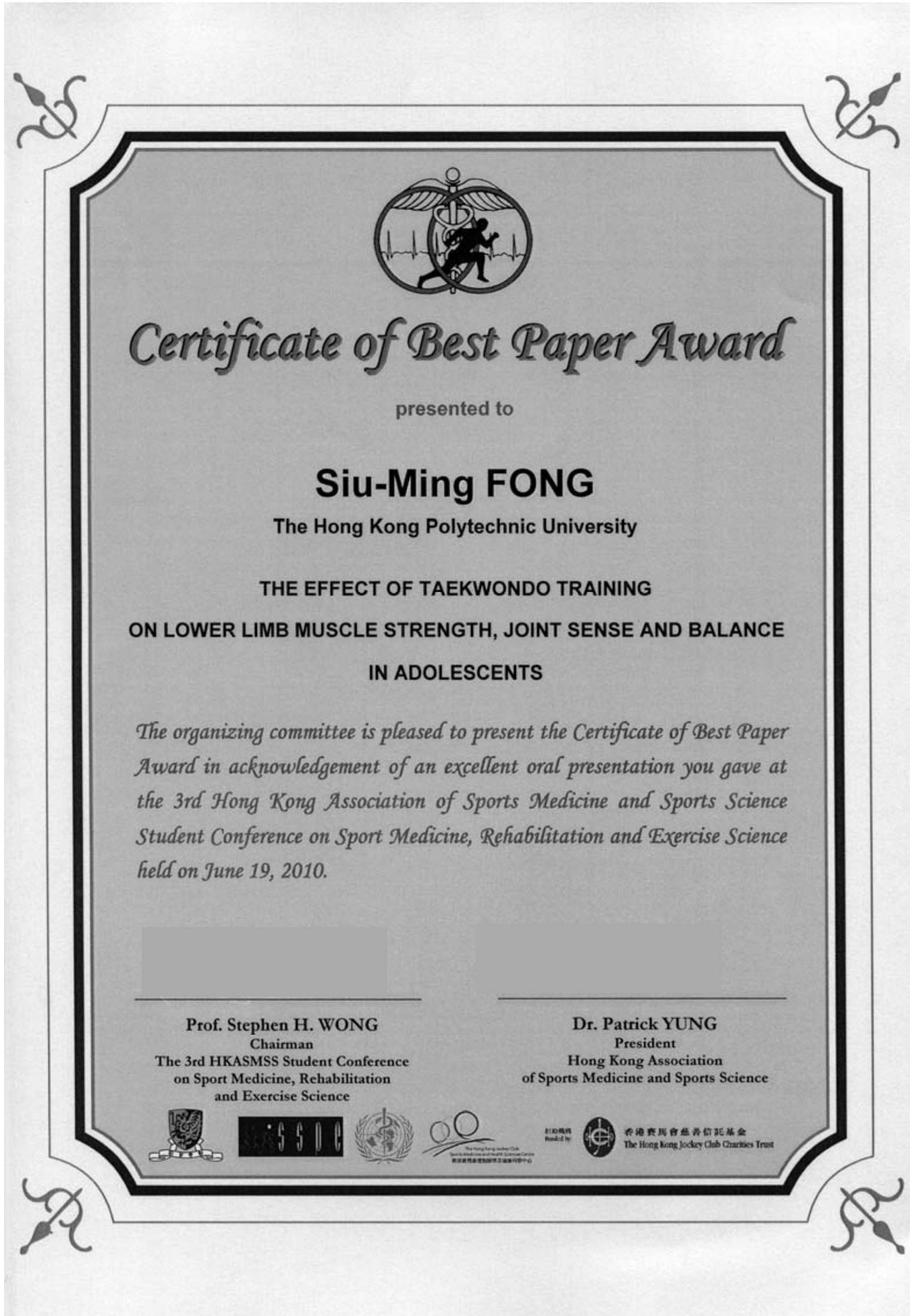
日期	題目	時間	地點
15/05/2010 (六)	學童平衡力評估	3:30 - 9pm	ST011
16/05/2010 (日)	學童平衡力評估	9am - 6pm	ST011

地點: 理大A座地下AG056室 (講座適用)
時間: 2-3:30pm
費用: 全免

名額有限 先到先得
敬請於網上預先登記 www.rehabclinic.org

* 除註明以外，所有講座均以粵語進行
* 除於講座開始前15分鐘仍有座位，無預約者則不能進場

Appendix VIII: Awards and certificates of conference presentations



Certificate of Best Paper Award

presented to

Siu-Ming FONG

The Hong Kong Polytechnic University

THE EFFECT OF TAEKWONDO TRAINING
ON LOWER LIMB MUSCLE STRENGTH, JOINT SENSE AND BALANCE
IN ADOLESCENTS

The organizing committee is pleased to present the Certificate of Best Paper Award in acknowledgement of an excellent oral presentation you gave at the 3rd Hong Kong Association of Sports Medicine and Sports Science Student Conference on Sport Medicine, Rehabilitation and Exercise Science held on June 19, 2010.

Prof. Stephen H. WONG Chairman The 3rd HKASMSS Student Conference on Sport Medicine, Rehabilitation and Exercise Science	Dr. Patrick YUNG President Hong Kong Association of Sports Medicine and Sports Science

Evidence Based Rehabilitation Medicine

Hong Kong Association of Rehabilitation Medicine

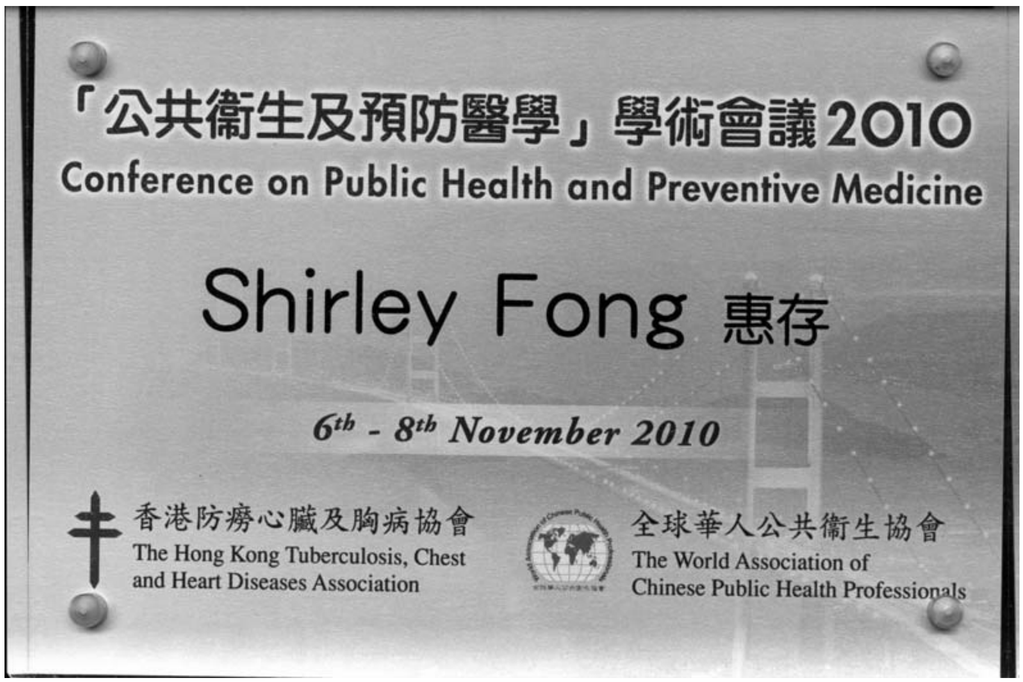
Best Free Paper Presentation

Winner

Annual Scientific Meeting, 26th November, 2011

Dr. Ernest Hon Ming MA

President, Hong Kong Association of Rehabilitation Medicine


「公共衛生及預防醫學」學術會議2010
Conference on Public Health and Preventive Medicine
Shirley Fong 惠存
6th - 8th November 2010
香港防癆心臟及胸病協會
The Hong Kong Tuberculosis, Chest and Heart Diseases Association
全球華人公共衛生協會
The World Association of Chinese Public Health Professionals

World Physical Therapy 2011

16th International WCPT Congress
20-23 June 2011 Amsterdam Holland

This is to certify that

S M Fong

presented

Research report poster display number RR-PO-303-9-Tue

CAN TAEKWONDO TRAINING SPEED UP THE DEVELOPMENT OF BALANCE AND SENSORY FUNCTIONS IN YOUNG ADOLESCENTS?

at the 16th International Congress of the World Confederation for Physical Therapy on

21 June 2011

WCPT President
World Confederation for Physical Therapy

Chair, International Scientific Committee
World Confederation for Physical Therapy

Ref: Tue-12:00-303

Appendix IX: News report on research findings

Apple Daily (2 August 2011)

兒童練跆拳道增平衡力

強筋健骼

隔周二刊出

你的孩子走路時會否容易跌倒？或是平衡能力遜於同齡小朋友？理大康復治療科學系一項最新研究顯示，有規律的跆拳道訓練能促進小朋友各個平衡系統的發展及應用，尤其是內耳前庭系統（vestibular system）。

刺激平衡系統發展

研究發現接受跆拳道訓練達一年或以上、年齡介乎 11 至 14 歲的小朋友，內耳前庭的平衡功能已達至成年人（18 至 23 歲）水平，即他們擁有較強的平衡能力，能在不平穩的地面或視覺受干擾情況下站立不倒，媲美成年人。

研究顯示一般沒練跆拳道、也無運動習慣的小朋友，內耳前庭平衡功能需至 15 歲才能發展完全，即平衡能力較習跆拳道的小朋友及成年人弱。

跆拳道是一種以腿擊為主的武術運動，練習時小朋友須在各種情況下保持平衡，例如單腳站立，或轉身踢腿時保持平衡，大腦及各個平衡系統因而得到較頻繁的刺激，並加速發展。

除內耳前庭平衡功能較佳外，長期練習跆拳道的小朋友，膝關節的本體感覺（knee joint proprioception）也較同齡小朋友佳，所以擁有較強的平衡能力。

總括研究結果，跆拳道能刺激小朋友大腦及各個平衡系統的發展、增強兒童及青少年的平衡能力。若你的小孩子平衡能力欠佳或缺乏運動，也許學習跆拳道是一個不錯的選擇。

撰文：理大康復治療科學系系主任吳賢發教授、曾偉男博士及方少萌
電郵查詢：rssfong@inet.polyu.edu.hk

Hong Kong Wushu & Art news (15 August 2011)

香港武林報

第 119-120 期

(不定期刊物)

網址：www.wushuart.com.hk

電郵：info@wushuart.com.hk

每期出版 1000 份

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跆拳道增平衡　Shirley Fong

(進行測試)

眾所周知，練習功夫能夠強身健體。〝理大康復治療科學系〞最近便進行了一項有關「跆拳道」的研究測試，研究人員發現，進行有規律的跆拳道訓練一百多個小時，便能促進小朋友 (六至九歲) 各個平衡系統的發展及應用，尤其是內耳前庭系統，進步達到 71.9 %。練習跆拳道的小朋友，擁有較強的平衡能力，能在不平穩的地上或視覺受干擾等情況下站立不倒。科學証明，練習跆拳道，真的能達到強健體魄之效。

(正接受訓練)

Apple Daily (4 October 2011)

強筋健骼

隔周二刊出

認識發展性協調障礙

「笨拙」也是病嗎？是的，若發現小朋友做事時「笨手笨腳」或「馬馬虎虎」，可能是患上「發展性協調障礙」症（Developmental coordination disorder）。也許你從未聽過這個病症，但根據衞生署的統計數字，現時約有5%至8%的兒童患有此症。

物理治療可改善

其實兒童「論盡」或有動作困難的問題已被醫學界廣泛研究，醫學專家在1994年，根據「美國心理學會精神功能失常診斷與統計手冊」及「世界衞生組織疾病之國際分級與相關健康問題」，將兒童出現動作困難之問題正式命名為「發展性協調障礙」。患有發展性協調障礙的小朋友，他們的動作協調能力較弱，身體平衡、肌肉力量、靈敏度等也遜於同齡的小朋友，因這些動作機能的問題，使他們在日常生活、學校課堂或參與體能活動時，遇到不少的障礙與挫敗，甚至影響學業表現或日常生活的活動。

幸好可透過適當的物理治療和體育活動，如練習跆拳道及體操等，有效改善這些小朋友的協調能力、體能、敏捷度與自信心。

此外，家長或老師也可嘗試在教導小朋友學習新的體能活動時，將動作分解為小部份教導，給予小朋友多些練習的時間，並多加提點，避免比賽形式的活動，以減低孩子遭受挫敗的機會。

撰文：理大康復治療科學系方少萌及曾偉男博士
電郵：rssfong@inet.polyu.edu.hk

Oriental Daily News (23 Nov 2011)

即時電視新聞 tv.on.cc 東方日報 2011年11月23日 星期三 A14

醫健

跆拳道改善動障童平衡

家長別以為子女失魂才會「論論盡盡」，行路經常搖晃或跌倒，若長期出現身體失衡情況，可能患動作協調障礙，受傷機會較正常小孩高。香港理工大學康復治療科學系全球首次發現，患動作協調障礙的小童接受跆拳道訓練三個月後，成功改善平衡力，耳水平衡功能更較前進步七成多，建議患者六歲起接受物理治療，同時選跆拳道作課外運動，效果更佳。

▣參與研究的兒童接受了三個月的跆拳道訓練。（受訪者提供）

動作協調障礙寫字難易仆親

▣患動作協調障礙的小童甚至執筆姿勢也不正確。

【本報訊】「執筆亂咁嚟、唔識綁鞋帶」都是動作協調障礙的病徵，理大康復治療科學系物理治療臨床導師方少萌指，近年確診患此症的學童不斷增加，但由於徵狀不明顯，兒童平均六歲才確診並接受物理治療。若學校老師或同學不了解，患者可能被誤以為智力有問題或太笨拙，遭同輩排斥。

本港約百分之六兒童確診患動作協調障礙。方少萌說，患者不論精細的動作或大動作的表現都不好。

方舉例表示，與協調性相關的大動作如接球、丟球、騎單車或跑步都有困難：「擺個波喺前面都踢唔中，跑步又好易仆親。」因此，大部分患者抗拒做運動，體形較胖。

患者手部肌肉也受影響，微細動作如執筆寫字、扣鈕或綁鞋帶都做不到：「同學唔知，咪以為佢好蠢，唔同佢做朋友。」

方又指，此類障礙屬先天性問題，幼童難以按病徵及早確診：「例如三、四歲小朋友，肌肉發展未咁好，單腳企得三、四秒都唔奇。」

大部分患者六歲前只能進行大肌肉、小肌肉及聽力等評估，至六歲才能確定患動作協調障礙。她說，患者病情不會惡化，但若不盡快接受物理治療，問題會持續終生。

▣參與研究的小童接受身體平衡測試，評估單腳站立的平衡能力。（受訪者提供）

動作協調障礙患者約八成會出現身體平衡困難，令到跌倒的風險更高及肌肉發展受阻；患者肌肉發育過程較同輩落後，易產生挫敗感及自信心低落。

理大康復治療科學系從本地兒童能力評估中心及醫院找來六十二名年齡介乎六至九歲的學童，安排其中廿一名有動作協調障礙的學童接受為期三個月，每天一小時的跆拳道訓練，包括學習前踢、側踢等各種招式，課後亦要在家中加強訓練；另外，分別有廿三名患者及十八名正常學童在三個月期間不接受跆拳道訓練。

練後耳水測試貼近正常

研究團隊於訓練前、後記錄了各學童的耳水平衡功能及單腳站立的平衡力。結果發現，有動作協調障礙的學童習跆拳道後，單腳站立的搖晃速度減慢百分之三十，耳水平衡功能測試發現改善約七成二，與正常小童的分數貼近；而沒學習跆拳道的患者，情況沒改進或惡化迹象。

負責研究的理大康復治療科學系物理治療臨床導師方少萌指，動作協調障礙患者確診後可每周進行一次感痛訓練及大肌訓練，以鍛煉對外來刺激的反應。

方認為，正接受治療、六歲或以上的動作協調障礙患者平衡力已發展到一定程度，建議配合跆拳道作課外活動，治療效果更佳，亦可令患者減少抗拒運動。

■記者戴碧怡

The SUN News (23 Nov 2011)

太陽報
2011.11.23 星期三
港聞7・醫知健 A18

醫知健

兒童練跆拳改善平衡力

◖**本報訊** 行路經常搖晃或跌倒，或長期出現身體失衡情況，可能患動作協調障礙，受傷機會較高。香港理工大學康復治療科學系全球首次發現，患動作協調障礙的小童接受跆拳道訓練三個月後，成功改善平衡力，耳水平衡功能更進步七成多，六歲起接受物理治療，同時選跆拳道作課外運動，效果更佳。

易生挫敗感損自信

動作協調障礙患者的肌肉發育過程較同輩落後，易產生挫敗感及自信心低落。理大康復治療科學系從本地兒童能力評估中心及醫院找來六十二名年齡介乎六至九歲的學童，安排其中二十一名有動作協調障礙的學童接受為期三個月、每天一小時的跆拳道訓練，包括學習前踢、側踢等各種招式，課後亦要在家中加強訓練；另外，分別有二十三名患者及十八名正常學童在三個月期間不接受跆拳道訓練。

研究團隊發現，有動作協調障礙的學童習跆拳道後，單腳站立的搖晃速度減慢百分之三十，耳水平衡功能測試發現改善約七成二，與正常小童的分數貼近；而沒學習跆拳道的患者，情況沒改進或有惡化迹象。

●學者建議兒童學習跆拳道，改善身體平衡問題。

動作協調障礙易被誤解

◖**本報訊** 理大康復治療科學系物理治療臨床導師方少萌指，近年確診患動作協調障礙的學童不斷增加，但由於徵狀不明顯，兒童平均六歲才確診並接受物理治療。若同學不了解，患者可能被誤以為智力有問題或太笨拙，遭同輩排斥。

本港約百分之六兒童確診患動作協調障礙。方說，患者不論精細動作或大動作的表現都不好。她舉例，與協調性相關的大動作如接球、丟球、騎單車或跑步都有困難，「擺個波喺前面都踢唔中，跑步又好易仆親。」患者手部肌肉也受影響，微細動作如扣鈕或綁鞋帶都做不到，「同學唔知，咪以為佢好蠢，唔同佢做朋友。」

Sing Tao Daily (12 Dec 2011)

改善學童動作協調障礙

理大首研跆拳道助平衡

兒童的平衡力是成長中其中一項重要發展，理工大學康復治療科學系研究團隊全球首次發現，患有動作協調障礙的學童，通過三個月有規律的跆拳道訓練，成功改善內耳前庭平衡能力，減少他們走路跌倒受傷的風險，有關研究亦已刊載至學術期刊《Elsevier》。

記者 曾愛芳

理大康復治療科學系助理教授曾偉男表示，現時本港有百分之六的學童患有動作協調障礙，大部分患者智力正常，但明顯地因身體平衡力不足，走路時較笨拙和容易跌倒受傷，同時由於不愛運動，體形會比同齡兒童肥胖。曾偉男聯同康復治療科學系系主任吳賢發及物理治療師方少萌，三年前開始研究利用運動，協助患有動作協調障礙的學童增加平衡力。

曾偉男指，今次研究對象主要是六至九歲的學童，理大康復治療科學系從本地兒童能力評估中心及醫院找來四十四名患有動作協調障礙的學童及十八名正常學童，當中安排二十一名患者接受跆拳道訓練，爲期三個月，「我們特別設計了一套跆拳道訓練，包括由熱身伸展，到前踢、側踢、後踢及轉踢各四十次，每天須要練習一小時。」另外二十三名患者及十八名正常學童，在三個月期間並沒有接受跆拳道訓練，作爲研究實驗對照組。

研究發現，患有動作協調障礙的學童在接受訓練後，他們的內耳前庭平衡能力明顯改善。經過動態平衡測驗儀的量度後，動作協調障礙患者的單腳站立搖晃速度減慢百分之三十，耳水平衡功能測試發現改善約七成二，與正常小童的分數接近。至於沒有接受跆拳道訓練的患者，平衡力差的情況並沒有惡化。

年紀小容易改善

理大物理治療師方少萌表示，研究最困難的地方是面對資源不足的問題，「由於大學資源有限，只能安排一定數量的學童參與研究。」她又表示，今次只集中於研究學童的平衡力，對於跆拳道對學童的肌肉能力及敏捷度，以及對九歲以上患有動作協調障礙學童的成效，要留待進一步的研究。

現時醫學界仍在研究動作協調障礙的成因，家長一般要等到六歲時才會發現子女出現動作協調問題。方少萌指，現時本地的評估時間一般須要較長的時間，故對於家境不太富裕的家庭而言，學童學習簡單的跆拳道招式，可改善他們的平衡力。她又提醒家長，學童年紀愈小愈容易改善毛病，如發現子女出現走路搖晃的情況，應趁黃金時期帶到中心進行有關評估。

■理大康復治療科學系助理教授曾偉男(左)及物理治療師方少萌(右)表示，跆拳道訓練可改善患有動作協調障礙的學童的平衡力，小圖為量度內耳前庭平衡力的動態平衡測驗儀。

伍明輝攝

iKid magazine (April 2012)

KIDBaby Photography_Chung & Wong Model_ 陸曉星 Text_ Winnie

平衡不好讀寫

無論是哪一個年代，小朋友最高興的總是到遊樂場遊玩，盪鞦韆、滑滑梯、搖搖馬等。原來這些設施不單讓小朋友舒展身心，對他們的前庭發展也有很大的幫助。但甚麼是前庭覺？對孩子的發展有何重要性呢？

維持身體平衡

前庭器或系統位在內耳，包括三個半規管系統及耳石器官，為身體提供「重力」與「空間」的感覺訊息，香港理工大學康復治療科學系物理治療臨床導師方少萌女士（Shirley）指前庭器對人來說是很重要的一種感官：「當我們處於移動的狀態時，前庭覺會不斷的將相關移動的訊息傳回腦部，提供腦部足夠訊息，以便調整身體，使身體維持在一個平衡的狀態。」前庭有助偵測頭部的移動，例如我們側身時頭部會自動回復垂直，這動作名為 Head Righting，是靠前庭管理的一項條件反射。此外，經由前庭系統，我們才能清楚知道身體各部位的位置、動作，還有身體與地心引力之間的相對關係。「假若我們在側身時不能保持平衡，往往便會容易跌倒。」

把幼童放在具彈性的健身球上，有助他們訓練前庭覺。

父母在家與孩子也可以玩一些旋轉遊戲，刺激孩子前庭發展。

於理工大學的康復治療診所內設有平衡測試儀，提供關於平衡的感覺和自主動作控制的客觀評估和訓練。

iKid magazine (April 2012) (continued)

有障礙

影響讀寫功能

除了前庭外，視覺系統也會幫助我們維持平衡。當頭部移動時，眼睛會向相反的方向運動，以使影像在視網膜上維持穩定。前庭覺、視覺與本體覺將資訊收集到我們腦部，再經小腦依據這些資訊，分析過濾哪一部分接收的訊息才是正確，例如應相信視覺訊息、前庭指揮我們的神經肌肉系統，維持身體平衡。如果其中一種感覺系統功能突然受損，或者其中兩種系統所收集到的資訊互相衝突時，腦部一時無法處理這訊息時，就會導致頭暈或者眩暈，同時身體失去平衡感。除了保持平衡，透過前庭視反射（Vestibulo-ocular reflex），前庭還幫助我們調節眼球運動，追縱移動中的物體。「所以如果小朋友的前庭發展不好，視覺追縱出現問題，便有可能出現讀寫障礙。」此外，不少學習功能障礙患者同時有前庭感覺問題，所以家長不應讓孩子整天臥床，否則容易導致孩子前庭發展不良。

前庭覺不良特徵

前庭覺不良可能有三種截然不同的表現，包括過敏、不足及區辨能力不良等。以下是不同表現的徵狀，若小朋友有三項或以上的特徵，家長便應注意。

1. 前庭神經過度敏感（hypersensitive）

怕高、討厭雙腳懸空、不愛玩遊樂場的大型設施（如鞦韆、攀爬架等）、動作慢不愛冒險、不喜歡爬樓梯、不愛體能性活動、排斥感官刺激、不愛頭被倒過來、容易暈眩（如：易暈車）。

2. 前庭神經反應能力不足（hyposensitive）

容易把數字或文字寫反、對於速度感和旋轉有很大的需求、熱愛冒險、常常愛從高處往下跳、平衡感差常跌倒、常不停地動來動去、很喜歡被翻轉或倒蔥的姿勢、常不小心撞翻物品或撞到家具；一些過度活躍的小朋友也會有這些問題。

3. 前庭神經區辨能力不良（Discrmination）

容易失去平衡、動作不協調顯得笨拙、肌肉張力低、有方向辨識的困難，經常迷路、在有相對運動時，搞不清楚是自己在動還是別人在動、常為雞毛蒜皮小事而緊張。

循序漸進

羅馬不是一天建成，小孩子的能力當然也不可能甫出生便發展完善。俗語說：「三抬頭六翻身九坐十二行」便是簡單概括了孩子的發展的里程碑，如果前庭發展不好，也許很遲還未懂得怎樣坐。不過 Shirley 指家長不用過分緊張，因為每位孩子的發展步伐不一樣。「例如十二個月孩子應該懂得行，但假若孩子十八個月還未懂得行，仍算正常。不過家長可在孩子嬰兒時期多給他們不同的刺激，因為環境的刺激可以令他們發展更好。」如果孩子仍未懂得行走，Shirley 建議家長可放嬰兒在搖籃、搖搖椅或健身球上，彈上彈下。「抱起孩子旋轉也可以，但要注意不可用力搖晃孩子的頭。」另外，遊樂場的韆鞦、繩網也是很好訓練前庭發展的場所。到孩子大一點，可以讓他們參與不同類型的運動如跑步、體操、溜冰或球類運動。「踢球時需要做一些平衡的動作，如單腳企；而接球時會訓練眼部的追縱能力，這些對孩子的前庭發展也有積極的幫助。」此外，Shirley 於去年曾做過一份研究，發現跆拳道也有助改善小朋友的前庭功能障礙。簡而言之，讓孩子多活動身心，總是有益的。

方少萌女士

香港理工大學康復治療科學系物理治療臨床導師

方女士於香港理工大學取得物理治療學學士學位以及衛生保健（物理治療學）碩士學位，在加入康復治療系之前，她在私營機構和兒科方面累積豐富的經驗。她特別關注之研究方向為兒童神經功能障礙和發育障礙的治療，同時對兒科運動亦感興趣。

4

Appendix X (Fong et al., 2011b)

Research in Developmental Disabilities 32 (2011) 2614–2623

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ELSEVIER

Motor ability and weight status are determinants of out-of-school activity participation for children with developmental coordination disorder

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A B S T R A C T

According to the International Classification of Functioning, Disability and Health model endorsed by the World Health Organization, participation in everyday activities is integral to normal child development. However, little is known about the influence of motor ability and weight status on physical activity participation in children with developmental coordination disorder (DCD). This study aimed to (1) compare motor performance, weight status and pattern of out-of-school activity participation between children with DCD and those without; and (2) identify whether motor ability and weight status were determinants of participation patterns among children with DCD. We enrolled 81 children with DCD (boys, $n = 63$; girls, $n = 18$; mean age, 8.07 ± 1.5 years) and 67 typically developing children (boys, $n = 48$; girls, $n = 19$; mean age, 8.25 ± 1.6 years). Participation patterns (diversity, intensity, companionship, location, and enjoyment) were evaluated with the Children Assessment of Participation and Enjoyment. Motor ability was evaluated with the Movement Assessment Battery for Children, second edition (MABC-2). Other factors that may influence participation such as age, gender, and body weight were also recorded. Analysis of variance was used to compare outcome variables of the two groups, and significant determinants of activity participation were identified by multiple regression analysis. Children with DCD participated in fewer activities (i.e., limited participation diversity) and participated less frequently (i.e., limited participation intensity) than their typically developing peers; however, companionship, location of participation, and enjoyment level did not differ between the two groups. Children in the DCD group demonstrated significantly worse motor ability as assessed by the MABC-2. Further, a greater proportion of children in the DCD group were in the overweight/obese category compared with their typically developing peers. After accounting for the effects of age and gender, motor ability and weight category explained 7.6% and 5.0% of the variance in participation diversity, respectively, for children with DCD. Children with DCD showed less diverse and less intense out-of-school activity participation than typically developing children. Motor impairment and weight status were independently associated with the lower participation diversity. Interventions aiming at improving participation for children with DCD should target weight control and training in motor proficiency. Further study is needed to identify other factors that may hinder participation in this group of children.

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1. Introduction

Based on the International Classification of Functioning, Disability and Health (ICF) model, participation in everyday activities and a variety of life situations is integral to normal child development and positively influences health, quality of life, and future life outcomes (Mandich, Polatajko, & Rodger, 2003; WHO, 2001). However, children with developmental coordination disorder (DCD) have motor difficulties that often restrict their ability to participate in typical activities of daily living (Jarus, Lourie-Gelberg, Engel-Yeger, & Bart, 2011).

DCD is a well-known motor-based problem that affects approximately 6% of children of primary school age (APA, 2000). Common symptoms include marked delays in achieving motor milestones, clumsiness, and poor balance, coordination, and handwriting (APA, 2000; Cermak & Larkin, 2002). These motor impairments also significantly interfere with the child's academic achievements and activities of daily living. DCD is diagnosed when these impairments cannot be explained by any medical or intellectual conditions (APA, 2000). Although enrolled in regular classrooms, children with DCD often experience difficulty participating in typical childhood activities and thus are more sedentary (Mandich et al., 2003).

A number of studies have examined participation patterns of children with DCD, but important domains such as skill-based and recreational activities have not been assessed (Cairney et al., 2005b; Cermak & Larkin, 2002; Chen & Cohn, 2003; Green et al., 2011; Mandich et al., 2003; Poulsen, Ziviani, & Cuskelly, 2006; Poulsen, Ziviani, & Cuskelly, 2007). Moreover, only one recent study by Jarus et al. (2011) used standardized measures to assess participation in a wide range of out-of-school activities among school-age children with and without DCD. In their study, children with DCD showed limited participation diversity, in which they engaged less frequently and chose activities that were quieter and more socially isolating compared with children without DCD (Jarus et al., 2011). However, this study included only children aged 5–7 years old. Studies with larger sample sizes and a wider age range are needed to more accurately detect differences in participation patterns between primary school-aged children with and without DCD.

According to the ICF model, many factors influence the participation level of an individual. These include personal factors (e.g., age, gender), environmental factors (e.g., family support), and physiologic impairments (e.g., motor deficits). To develop effective interventions for children with DCD, a better understanding of their participation patterns and the determinants of participation are needed. Previous studies have attempted to identify the clinical correlates of participation in children with DCD. Jarus et al. (2011) identified a positive relationship between motor ability and participation patterns in children with DCD; however, multivariate analysis could not be performed because of the relatively small sample size ($n = 25$). Therefore, the effects of potentially confounding variables (e.g., gender) were not taken into account. Previous research demonstrated that boys and girls tend to participate in different types of activities (Bult, Verschuren, Jongmans, Lindeman, & Ketelaar, 2001); therefore, it is important to use a larger sample size and take covariates into account when evaluating the relationship between motor ability and participation patterns in children with DCD.

Another important correlate of activity participation may be related to weight status. Because of deficits in physical functioning (Cairney et al., 2005b; Poulsen, Ziviani, & Cuskelly, 2008) and psychosocial functioning (i.e., low self-esteem, perceived competency) (Cermak & Larkin, 2002), children with DCD may be less inclined to participate in physical activities (Cairney et al., 2005b; Cermak & Larkin, 2002; Poulsen et al., 2008). This lower activity level may predispose children with DCD to obesity and cardiovascular disease. Indeed, children with DCD were found to have increased body fat and poor cardiorespiratory fitness (Cairney, Hay, Faught, & Hawes, 2005; Cairney et al., 2007; Cairney, Hay, Veldhuizen, & Faught, 2010; Cermak & Larkin, 2002; Faught, Hay, Cairney, & Flouris, 2005). A vicious circle of further physical deconditioning, increased body weight, and motor deficits may ensue. However, no study has yet examined the association between activity participation and weight status in children with DCD.

The objectives of this study were to (1) compare motor performance, weight status, and pattern of out-of-school activity participation between children with and without DCD; and (2) determine whether motor ability and weight status are associated with activity participation diversity among children with DCD.

2. Methods

2.1. Study design

This was a cross-sectional exploratory study.

2.2. Participants

Sample size calculations were based on a statistical power of 0.80 and alpha of 0.05 (two-tailed). According to Jarus et al. (2011), the Movement Assessment Battery for Children, second edition (MABC-2) percentile rank was 2.6 (standard deviation [SD] = 1.84) for the DCD group ($n = 25$) and 49.96 (SD = 26.63) for the control group ($n = 25$), which translates into a large effect size (2.51). For the Children's Assessment of Participation and Enjoyment (CAPE) total activity diversity and intensity scores, the effect sizes were medium to large (0.74–0.80). Therefore, assuming a medium to large effect size (0.74) and power of 0.80, the minimum sample size needed to detect a significant between-group difference in outcomes (objective 1) is 30 for each group (children with DCD and controls) (Portney & Watkins, 2009). Regarding the regression analysis (objective 2), Jarus et al. (2011) reported that the MABC-2 percentile showed fair to good correlation with various activity participation scores ($r = 0.29–0.64$) among children with DCD. Therefore, a minimum sample size of 65 for the DCD group would be required for multiple regression analysis with four predictors and an effect size of 0.20 (medium to large) (Portney & Watkins, 2009).

Children with DCD were recruited from a local hospital and the Child Assessment Centre, which is a major institution that provides assessment services for children in Hong Kong, by convenience sampling. A formal diagnosis of DCD was made by an interdisciplinary team at the Child Assessment Centre according to criteria of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR) (APA, 2000). To warrant a DCD diagnosis, the child had to demonstrate motor coordination substantially below that of the child's age (i.e., gross motor composite score < 42 as measured by the Bruininks–Oseretsky Test of Motor Proficiency) (Bruininks, 1978) that interfered with the child's academic performance and ability to carry out activities of daily living. Other inclusion criteria were neurological screening performed by a paediatrician to rule out other causes of motor deficits; age 6–12 years; enrolled in a regular classroom; and no intellectual impairment. Exclusion criteria were a formal diagnosis of emotional, neurologic, or other movement disorders; and significant musculoskeletal or cardiopulmonary conditions that could influence motor performance. As controls, children with normal development were recruited from the community on a volunteer basis. They were subject to the same inclusion and exclusion criteria set for the DCD group, except that they did not have any history of DCD.

2.3. Procedures

Approval was obtained from the human subjects ethics review subcommittee of the Hong Kong Polytechnic University and the Hospital Authority. The study was explained to all children and their guardians, and written informed consent was obtained. All data collection was performed by two experienced paediatric physical therapists. The procedures were conducted in accordance with the Declaration of Helsinki.

2.3.1. Demographic information

Basic demographic information was obtained by interviewing the children and their guardians. Relevant information such as medical history was also obtained. Height and weight of the participants were measured, and body mass index (BMI, kg/m^2) was calculated. The percentile value of BMI was used to define overweight and obesity using results of a local study conducted by Ng, Lam, Kwok, and Chow (2004), which set the cut-off values for obesity and overweight as the 97th and 90th percentiles, respectively, for Hong Kong children.

2.3.2. Motor ability

The MABC-2 is a standardized tool used to measure motor performance of children in three age ranges: 3–6 years, 7–10 years, and 11–16 years. The assessment consists of eight tasks that are divided into three domains: manual dexterity, aiming and catching, and balance. The raw score of each item was converted into the item standard score, and the component score, standard score, and percentile of each domain were derived from the item standard scores. In addition, the total test score, standard score, and percentile rank were derived. The percentile rank, which indicates the percentage of children in the standardization sample who obtained a score less than or equal to a given raw score, was used for analysis in this study (Henderson, Sugden, & Barnett, 2007). A score at or below the 5th percentile indicates significant motor difficulty; a score between the 6th and 15th percentiles indicates borderline motor difficulty that requires monitoring; and a score at or above the 16th percentile is regarded as normal (Henderson et al., 2007). MABC-2, which is commonly used to identify children with DCD, has demonstrated good test–retest reliability, inter-rater reliability, and criterion-related validity (Henderson et al., 2007).

2.3.3. Out-of-school time activity participation

The Children's Assessment of Participation and Enjoyment (CAPE) is a reliable and valid self-report measure of participation in outside school activities for children and youth aged 6–21 years (Imms, 2008). This tool was validated with 427 children (6–15 years old) with physical disabilities. Results demonstrated sufficient internal consistency, content validity, construct validity, and good test–retest reliability (King et al., 2006). This questionnaire includes both formal domains (more structured activities that require planning) and informal domains (less structured activities that require less planning), and five activity types, namely recreational, physical, social, skill-based, and self-improvement activities. The physical and skill-based activities generally require specific physical abilities, whereas the recreational, skill-based, and self-improvement activities involve skills that are transferable across the lifespan and are more important for lifelong participation. The 55 specific activities assessed with CAPE are presented in Appendix. CAPE quantifies the level of participation according to five dimensions: diversity, intensity, location, companionship, and enjoyment. The participation diversity score is a count of the activities in which the child has participated over the previous 4 months. Participation intensity is calculated by dividing the sum of item frequency by the number of possible activities in each activity type. The intensity score indicates participation frequency for a set of activities. Location of participation is scored on a 6-point scale: 1 = at home, 2 = at a relative's home, 3 = in the neighbourhood, 4 = at school but not during class, 5 = in the community and 6 = beyond the community. Median scores were determined for each activity type, with low scores indicating participation closer to home and higher scores indicating more community-based participation. Companionship (participation with others) was scored on a 5-point scale (1 = alone, 2 = with family members, 3 = with other relatives, 4 = with friends, and 5 = with other types or multiple types of people). Median scores were calculated, with lower scores indicating more solitary activities, and higher scores indicating more social engagement. Enjoyment was also measured on a 5-point scale ranging from 1 (not at all) to 5 (love it) (King et al., 2004).

An interview was conducted with each subject and guardian (face to face or by telephone) to complete the CAPE assessment. Participation in each of the 55 activities during the previous 4 months was recorded. The children were also given the opportunity to add other activities not specified in the CAPE.

2.4. Statistical analysis

Data analysis was performed using SPSS 17.0 (SPSS Inc., Chicago, IL, USA). A significance level of 0.05 (2-tailed) was adopted for all statistical tests. Descriptive statistics were used to describe all relevant variables. Normality of data was checked using the Kolmogorov–Smirnov test. Continuous variables (i.e., age, height, weight, BMI) were compared by independent *t*-test, and categorical demographic variables (i.e., gender, weight category) were compared by chi-square test.

Multivariate analysis of covariance (MANCOVA) was used to compare MABC-2 total percentile rank and CAPE scores of the seven types of activity (i.e., informal, formal, recreational, physical, social, skill-based, and self-improvement) between groups, with BMI as the covariate. The total diversity, intensity, companionship, location, and enjoyment scores were also compared by MANCOVA. These analyses were repeated after separating data collected from boys from that of girls. Results from these analyses showed the effects of group on all corresponding outcomes simultaneously and Bonferroni adjusted *p*-values to avoid an inflated type I error rates associated with multiple comparisons.

Pearson's correlation coefficients (for continuous variables) or Spearman's rho (for ordinal variables) were used to examine bivariate relationships between CAPE and MABC-2 scores and other variables among children with DCD. Multiple regression analyses were then performed to identify physical parameters that were predictors of CAPE total diversity score. Selection of predictor variables for regression analysis was based on both biological relevance and results of the bivariate correlation analysis. Age and gender were first entered into the regression model, as these factors may influence activity participation (Bult et al., 2011; Cairney, Hay, Veldhuizen, Missiuna, & Faught, 2010; Green et al., 2011). MABC-2 total percentile rank or weight category (ideal weight vs. overweight/obese) was then entered into the regression model. To avoid multicollinearity, the degree of association among the potential independent variables was checked.

3. Results

3.1. Demographic characteristics and motor performance

Demographic characteristics and motor abilities of the DCD group ($n = 81$) and control group ($n = 67$) are outlined in Table 1. The mean age and gender ratios of the two groups did not differ ($p > 0.30$); however, significant between-group differences were found in BMI, weight, and motor performance (MABC-2 percentile rank) ($p < 0.05$). Gender-specific analysis also revealed significant between-group differences in weight category and motor performance (Table 1).

3.2. Diversity of participation

MANCOVA results revealed a significant overall difference between the two groups in participation diversity, as reflected by the CAPE total diversity score (Table 2). Significant between-group differences were still detected when the data for boys and girls were analyzed separately. Analysis of activity categories showed that children with DCD participated in fewer informal, physical, social, skill-based, and self-improvement activities than their peers with normal development ($p < 0.05$), but participation in formal and recreational activities did not differ between groups (Table 2).

3.3. Intensity of participation

Children with DCD had significantly lower CAPE total participation intensity scores compared with children in the control group; however, results were similar when gender was taken into account. Further analysis revealed that children with DCD participated less frequently in all categories (i.e., informal, formal, recreational, physical, social, skill-based, and self-improvement activities) (Table 2).

3.4. Companionship during participation

Companionship measures did not differ significantly between the two groups (Table 2).

Table 1
Demographic characteristics and motor ability of the participants.

	DCD group [Mean (SD)]			Control group [Mean (SD)]		
	All (n = 81)	Male (n = 63)	Female (n = 18)	All (n = 67)	Male (n = 48)	Female (n = 19)
Age, years	8.07 (1.49)	8.06 (1.52)	8.11 (1.41)	8.25 (1.60)	8.38 (1.63)	7.95 (1.51)
Gender (boys/girls), n	63/18			48/19		
Height, cm	130.53 (11.87)	131.07 (12.11)	128.64 (11.13)	129.87 (10.41)	130.82 (10.58)	127.45 (9.81)
Weight, kg	33.09 (11.55)	33.23 (11.26)	32.63 (12.87)	30.33 (8.69)	31.04 (9.21)	28.53 (7.11)
Body mass index, kg/m^2	18.85 (3.72)[a]	18.76 (3.23)	19.13 (5.21)	17.65 (2.97)	17.77 (3.15)	17.35 (2.51)
Overweight and obese, n	24[c]	18[b]	6[a]	5	4	1
MABC-2 total percentile rank	11.55 (14.79)[c]	10.85 (14.03)[c]	14.03 (17.42)[c]	46.36 (24.54)	47.94 (26.04)	42.37 (20.36)
Co-morbidity						
Attention deficit hyperactivity disorder, n	9	7	2	0	0	0
Attention deficit disorder, n	9	7	2	0	0	0
Dyslexia, n	9	9	0	0	0	0
Asperger syndrome, n	5	5	0	0	0	0
Autism spectrum disorders, n	1	1	0	0	0	0

[a] $p \leq 0.05$.
[b] $p \leq 0.01$.
[c] $p \leq 0.001$.

3.5. Location of participation

Location of participation differed between the two groups for recreational activities only. Children with DCD were more likely than children in the control group to participate in recreational activities that were far away from their home ($p < 0.05$) (Table 2).

3.6. Enjoyment of participation

Enjoyment measure scores did not differ significantly between the two groups. Both groups of children enjoyed "pretty much" or "very much" the activities in which they participated (Table 2).

3.7. Relationships among demographic characteristics, motor ability, and participation pattern in children with DCD

Because only the total diversity and intensity scores differed significantly between groups, we focused on these two aspects of participation in the subsequent correlation and regression analysis. We did not split the DCD and control groups into gender subgroups in this analysis because the MANCOVA results revealed that boys and girls had similar patterns of participation (total diversity and intensity scores) (Table 2). We found that motor ability (MABC-2 percentile rank) was positively correlated with CAPE total diversity score in children with DCD ($r = 0.264$, $p = 0.017$). Specifically, motor ability was fairly correlated with participation diversity in formal ($r = 0.291$, $p = 0.008$), recreational ($r = 0.249$, $p = 0.025$), and skill-based activities ($r = 0.235$, $p = 0.035$), suggesting that the children with DCD who had higher motor competence participated in a greater variety of formal, recreational, and skill-based activities. Motor ability was not associated with the CAPE total intensity score ($p > 0.05$).

We also found that weight status category was negatively correlated with total CAPE diversity score ($\rho = -0.227$, $p = 0.041$) and recreational activity diversity score ($\rho = -0.224$, $p = 0.044$), indicating that overweight children tended to participate in fewer activities, particularly recreational activities. In contrast, weight category did not correlate with intensity of participation.

3.8. Determinants of diversity of activity participation in children with DCD

The variables that were significantly associated with diversity of activity participation in bivariate correlation analysis were used in subsequent multiple regression analyses for predicting CAPE total diversity score. Hierarchical multiple regression analysis was performed to identify the determinants of the total CAPE diversity score. After adjusting for age and gender, adding motor ability to the regression model accounted for 7.6% of the variance in the total CAPE diversity score ($F_{\text{change}1,77} = 6.326$, $p = 0.014$) (Table 3). Addition of weight status category explained another 5.0% of the variance in activity participation diversity ($F_{\text{change}1,76} = 4.344$, $p = 0.040$). The regression model overall explained a total of 12.8% of the variance in activity participation diversity, with motor ability and weight status category being significant determinants ($F_{(4,76)} = 2.793$, $p = 0.032$) ($p < 0.05$).

Table 2
Differential participation patterns in children with and without DCD.

Outcome	DCD group [Mean (SD)]			Control group [Mean (SD)]		
	All (n = 81)	Male (n = 63)	Female (n = 18)	All (n = 67)	Male (n = 48)	Female (n = 19)
Total activities						
Total diversity score	23.40 (6.74)[c]	23.57 (7.05)[a]	22.78 (5.64)[b]	27.94 (4.99)	27.23 (5.12)	29.74 (4.25)
Total intensity score	108.37 (28.67)***	109.27 (30.10)[b]	105.22 (23.49)[c]	133.76 (26.61)	129.10 (27.11)	145.53 (21.74)
Total companionship score	2.40 (0.37)	2.39 (0.38)	2.41 (0.35)	2.45 (0.30)	2.38 (0.27)	2.64 (0.32)
Total location score	2.90 (0.42)	2.92 (0.43)	2.83 (0.35)	2.91 (0.52)	2.91 (0.58)	2.91 (0.30)
Total enjoyment score	3.76 (0.36)	3.72 (0.37)	3.89 (0.33)	3.78 (0.35)	3.73 (0.36)	3.92 (0.28)
Informal activities						
Diversity score	18.88 (5.23)[c]	18.97 (5.38)[b]	18.56 (4.82)[a]	22.37 (4.06)	22.13 (4.34)	23.00 (3.28)
Intensity score	2.17 (0.56)[c]	2.18 (0.58)[a]	2.13 (0.50)[c]	2.64 (0.52)	2.58 (0.55)	2.78 (0.41)
Companionship score	2.05 (0.31)	2.04 (0.31)	2.08 (0.32)	2.11 (0.28)	2.06 (0.25)	2.22 (0.32)
Location score	2.58 (0.43)	2.61 (0.44)	2.51 (0.39)	2.54 (0.36)	2.54 (0.34)	2.54 (0.43)
Enjoyment score	3.81 (0.38)	3.77 (0.38)	3.97 (0.35)	3.83 (0.35)	3.76 (0.36)	3.98 (0.28)
Formal activities						
Diversity score	4.53 (2.23)	4.62 (2.41)	4.22 (1.44)[c]	5.57 (1.92)	5.13 (1.90)	6.68 (1.53)
Intensity score	1.42 (0.68)[b]	1.45 (0.73)	1.34 (0.48)[c]	1.88 (0.71)	1.72 (0.67)	2.29 (0.65)
Companionship score	3.77 (1.07)	3.76 (1.07)	3.79 (1.12)	3.83 (0.74)	3.73 (0.77)	4.08 (0.63)
Location score	4.18 (0.75)	4.24 (0.76)	3.97 (0.65)	4.12 (0.57)	4.13 (0.59)	4.10 (0.50)
Enjoyment score	3.59 (0.84)	3.60 (0.91)	3.58 (0.56)	3.64 (0.57)	3.60 (0.63)	3.74 (0.38)
Recreational activities						
Diversity score	7.22 (2.25)	7.29 (2.22)	7.00 (2.40)	8.01 (1.67)	8.10 (1.77)	7.79 (1.40)
Intensity score	3.08 (0.98)[a]	3.09 (1.00)[a]	3.03 (0.90)	3.55 (0.86)	3.59 (0.92)	3.48 (0.67)
Companionship score	1.84 (0.42)	1.84 (0.45)	1.85 (0.29)	1.86 (0.44)	1.78 (0.36)	2.08 (0.53)
Location score	1.89 (0.65)[b]	1.92 (0.69)[a]	1.76 (0.47)	1.72 (0.44)	1.71 (0.47)	1.74 (0.38)
Enjoyment score	4.04 (0.46)	3.99 (0.46)	4.22 (0.43)	4.01 (0.41)	4.00 (0.42)	4.04 (0.37)
Physical activities						
Diversity score	3.20 (1.96)[a]	3.32 (1.99)	2.78 (1.86)[a]	4.13 (1.61)	3.92 (1.61)	4.68 (1.53)
Intensity score	1.05 (0.68)[a]	1.09 (0.71)	0.92 (0.59)[a]	1.43 (0.68)	1.37 (0.71)	1.57 (0.59)
Companionship score	3.13 (1.33)	3.11 (1.29)	3.19 (1.51)	3.06 (0.85)	3.01 (0.90)	3.19 (0.72)
Location score	4.17 (1.29)	4.28 (1.21)	3.74 (1.52)	4.09 (0.76)	4.14 (0.76)	3.97 (0.75)
Enjoyment score	3.64 (1.12)	3.70 (1.02)	3.45 (1.45)	3.89 (0.61)	3.90 (0.66)	3.85 (0.48)
Social activities						
Diversity score	4.93 (2.14)[b]	4.92 (2.19)[a]	4.94 (2.04)[a]	6.16 (1.64)	6.06 (1.77)	6.42 (1.26)
Intensity score	1.74 (0.88)[b]	1.75 (0.92)	1.68 (0.79)[c]	2.22 (0.77)	2.06 (0.79)	2.62 (0.56)
Companionship score	2.46 (0.53)	2.46 (0.52)	2.49 (0.61)	2.57 (0.41)	2.55 (0.41)	2.64 (0.43)
Location score	3.10 (0.87)	3.14 (0.91)	2.96 (0.72)	3.09 (0.63)	3.10 (0.63)	3.07 (0.65)
Enjoyment score	3.80 (0.65)	3.76 (0.66)	3.99 (0.62)	3.94 (0.49)	3.86 (0.50)	4.15 (0.40)
Skill-based activities						
Diversity score	2.64 (1.60)[a]	2.59 (1.65)	2.83 (1.42)[b]	3.46 (1.60)	3.02 (1.51)	4.58 (1.26)
Intensity score	1.20 (0.76)[b]	1.17 (0.77)	1.33 (0.74)[a]	1.74 (0.88)	1.49 (0.81)	2.37 (0.71)
Companionship score	3.25 (1.34)	3.30 (1.38)	3.09 (1.21)	3.49 (1.10)	3.28 (1.16)	4.02 (0.71)
Location score	3.68 (1.24)	3.80 (1.27)	3.24 (1.03)	3.61 (1.43)	3.48 (1.60)	3.94 (0.81)
Enjoyment score	3.60 (1.40)	3.53 (1.55)	3.86 (0.57)	3.54 (0.90)	3.44 (0.98)	3.79 (0.62)
Self improvement activities						
Diversity score	5.42 (1.65)[a]	5.48 (1.69)	5.22 (1.52)	6.16 (1.72)	6.15 (1.68)	6.21 (1.87)
Intensity score	2.79 (0.76)[c]	2.82 (0.75)[b]	2.69 (0.80)[a]	3.29 (0.80)	3.27 (0.81)	3.34 (0.79)
Companionship score	2.13 (0.59)	2.13 (0.54)	2.13 (0.77)	2.06 (0.45)	2.11 (0.39)	1.96 (0.58)
Location score	2.81 (0.73)	2.78 (0.63)	2.91 (1.05)	2.83 (0.63)	2.90 (0.64)	2.64 (0.56)
Enjoyment score	3.36 (0.49)	3.35 (0.47)	3.38 (0.55)	3.34 (0.60)	3.21 (0.59)	3.67 (0.48)

[a] $p \leq 0.05$.
[b] $p \leq 0.01$.
[c] $p \leq 0.001$.

4. Discussion

4.1. Differential participation patterns of children with and without DCD

This study revealed that children with DCD participated in fewer activities than their typically developing peers. This difference was observed regardless of gender, particularly in informal, physical, social, skill-based, and self-improvement activities, which is consistent with findings from previous studies (Cairney et al., 2005b; Chen & Cohn, 2003; Jarus et al., 2011; Mandich et al., 2003; Poulsen et al., 2006, 2007a). For example, Jarus et al. (2011) reported that children with DCD (n = 25) participated in fewer physical, skill-based, informal, and total activities, as assessed by CAPE, compared with children without DCD (n = 25). Although the participation diversity of social and self-improvement activities did not differ significantly between the two groups, the partial eta square (η_p^2) values were 0.06–0.08, which indicate moderate effect sizes. The nonsignificant

Table 3
Multiple regression analysis of participation diversity in children with DCD.

Independent variables	R^2 change	Unstandardized regression coefficient (B)	95% Confidence interval	Standardized regression coefficient (β)	p
Age (year)		0.697	−0.367, 1.760	0.057	0.609
Gender (boys = 1, girls = 2)	0.03	−1.042	−4.498, 2.414	−0.075	0.496
MABC-2 total percentile rank	0.076	0.121	0.022, 0.220	0.280	0.014[a]
Weight status category (ideal weight = 1, overweight/obese = 2)	0.050	−3.592	−7.025, −0.160	−0.245	0.040[a]

[a] $p \le 0.05$.

between-group differences in these activity categories was likely due to the reduced statistical power related to the smaller sample size in their study compared with ours (81 and 67 children in DCD and control groups, respectively).

Consistent with the results reported by Jarus et al. (2011), we found that participation diversity in formal and recreational activities was similar between children with DCD and typically developing children, perhaps because these structured, nonphysical activities do not expose the children's motor deficits (Engel-Yeger & Kasis, 2010). However, the participation intensity of children with DCD was far lower than typically developing children. In fact, children with DCD participated less intensely in all activities (informal, formal, recreational, physical, social, skill-based and self-improvement activities) compared with children without DCD. Jarus et al. (2011) also reported that children with DCD showed lower intensity of participation in most types of CAPE activity ($p < 0.05$ or η_p^2 ranging from 0.05 to 0.16). A possible explanation for this finding may be that children with less efficient movement patterns expend more energy and therefore fatigue faster (Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006).

Self-perception of enjoyment is important because it is associated with decisions concerning whether to continue to participate in activities (Cairney et al., 2007). We found that both group of children "pretty much" or "very much" enjoyed the activities in which they participated. Although children with DCD participated in fewer activities and the level of engagement was lower, they still enjoyed participating in the activities they selected. This finding is consistent with that of Jarus et al. (2011). In contrast, younger children with DCD (4–6 years old) and their parents reported a lower level of enjoyment while participating in play, leisure, social, and educational activities (Bart, Jarus, Erez, & Rosenberg, 2011). These findings suggest that older children with DCD (6–12 years old in our study and 5–7 years old in the study of Jarus et al.) may choose activities in which they have a higher likelihood of success and enjoyment based on their past experience. It is therefore important to encourage children's enjoyment of a variety of activities starting at a very young age.

Although previous studies (Jarus et al., 2011; Poulsen, Ziviani, Cuskelly, & Smith, 2007) reported that children with DCD felt a sense of loneliness and tended to engage in solitary activities, we found that children with and without DCD demonstrated similar patterns of companionship or participation with other people. In contrast, the children in our DCD group tended to participate in activities with family members or relatives, similar to the controls. The discrepancy in results between studies might be explained by cultural and parental influences. Since western cultures emphasize on independence of the child while Asian cultures emphasize on parental warmth (Kim & Wong, 2002; Rubin & Stewart, 1996). The parents in this study may thus be more inclined to accompany their children in the outside school activities. Further research should consider the role of culture and parenting style in determining participation companions.

We found that activity locations were also similar between the two groups. Children with DCD might even travel further to participate in recreational activities that are suited to their needs and interests. This information is encouraging because it suggests that children with DCD do not experience limited community access.

4.2. Determinants of participation diversity in children with DCD

Consistent with the findings of Jarus et al. (2011), who reported that motor ability (MABC-2 percentile) was positively correlated with CAPE participation diversity, our study confirmed that motor proficiency was a significant determinant of activity participation diversity in children with DCD. This factor accounted for 7.6% of the variance in activity participation diversity after controlling for age and gender. Children with lower MABC-2 percentile ranks participate in fewer types of activities. Previous studies in children aged 8 to 10 years also found that motor proficiency, as determined by the Bruininks–Oseretsky Test of Motor Proficiency Short Form, explained 8.7% of the variance in physical activity (Wrotniak et al., 2006). A possible explanation for these findings is that children with greater motor proficiency (close to 15th percentile in MABC-2) are better at activating and sequencing movement patterns in formal, recreational, and skill-based tasks and may therefore have more opportunities to participate in varied activities (Wrotniak et al., 2006). In addition, children with higher motor proficiency may have higher self-efficacy (Cairney, Hay, Faught, Wade, et al., 2005), perceived freedom in leisure activity (Poulsen, Ziviani, & Cuskelly, 2007), and enjoyment during activities (Cairney et al., 2007). They may therefore choose to participate in a wider range of activities compared with other children with DCD. In contrast, children with DCD with very low motor ability may participate in fewer activities, including physical activities (Cairney et al., 2005b; Cairney et al., 2010b; Chen & Cohn, 2003; Engel-Yeger & Kasis, 2010; Green et al., 2011; Jarus et al., 2011; Mandich et al., 2003; Poulsen et al., 2008; Wrotniak et al., 2006), further decreasing opportunities to practise skills and leading to activity deficits and a developmental skill-learning gap (Wall, 2004).

Similar to previous studies (Cairney et al., 2005a, 2007; Faught et al., 2005), we found that a higher proportion of children with DCD tended to be overweight/obese than children without the disorder. Further, weight status category was a significant determinant of activity participation diversity in this group of children. Being overweight or obese may make it more difficult for children with DCD to participate in activities (especially recreational activities), due to reduced physical fitness and the social stigma associated with obesity (Puhl & Latner, 2007). Reduced activity, in turn, may further increase body fat and increase the risk of coronary vascular disease, thus triggering a vicious cycle of inactivity and deterioration of health (Faught et al., 2005). Thus inclusion of various activities, including physical activities, is necessary to prevent disease and enhance overall health in children with DCD. However, motivating overweight children with DCD to participate in different types of activity may be a challenge. Previous studies have provided insight into psychological factors affecting activity participation in this group of children. Cairney et al. (2005a,b, 2007) suggested that lower self-efficacy largely (28%) accounts for inactivity in children with DCD, whereas body fat explained only a small proportion (5.7%) of the variance in participation in the present study. Clinicians may consider developing separate exercise classes for children with DCD (e.g., aerobic exercise classes) to avoid ridicule from typically developing children, improve self-efficacy, provide motivation to participate in other activities (Cermak & Larkin, 2002), and improve physical fitness.

4.3. Clinical implication

Motor impairments and overweight/obesity experienced by children with DCD limit activity participation, which in turn may affect the health and well being of these children (Mandich et al., 2003). Interventions should aim to prevent the vicious circle of activity avoidance, poor motor performance and physical fitness, and decreased participation in all activities. Interventions for children with poor motor ability and physical fitness should be made available in the community and after-school facilities along with more opportunities to participate in a variety of activities. In addition, the activity or training intensity must be sufficient to improve the children's health.

4.4. Limitations and consideration for future studies

Some limitations of this study need to be addressed in future work. First, these data are cross-sectional and causal inferences based on the results can be made but not tested. Second, our regression model accounted for only 12.8% of the variance in activity participation. Many other personal, familial, and environmental factors are associated with children's activity participation diversity (e.g., children's communication skills and social competence, leisure interests and preferences, family circumstances, socioeconomic backgrounds, and environment setting) (Jarus et al., 2011; King et al., 2006). These factors should also be examined in future studies.

5. Conclusions

This study shows that out-of-school activity participation in primary school-aged children with DCD is less diverse and intense than that of typically developing children, regardless of gender. Motor impairment and weight status are significantly associated with the deficit in participation diversity in this group of children. Interventions directed at improving participation for children with DCD should target training on motor proficiency and weight control. Further study is needed to identify other factors that hinder participation in this group of children.

Declaration of interest

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

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Appendix A. Appendix

Table A1.

Table A1
Activities assessed by The Children's Assessment of Participation and Enjoyment.

Recreational (12 items)	Physical (13 items)	Social (10 items)	Skill-based (10 items)	Self-improvement (10 items)
1. Doing puzzles	1. Doing martial arts	1. Talking on the phone	1. Swimming	1. Writing letters
2. Playing board or card games	2. Racing or track and field	2. Going to a party	2. Doing gymnastics	2. Writing a story
3. Doing crafts, drawing or coloring	3. Doing team sports	3. Hanging out	3. Horseback riding	3. Getting extra help for schoolwork from a tutor
4. Collecting things	4. Participating in school clubs	4. Visiting	4. Learning to sing (choir or individual lessons)	4. Doing a religious activity
5. Playing computer or video games	5. Bicycling, in-line skating or skateboarding	5. Entertaining others	5. Taking art lessons	5. Going to the public library
6. Playing with pets	6. Doing water sports	6. Going to the movies	6. Learning to dance	6. Reading
7. Doing pretend or imaginary play	7. Doing snow sports	7. Going to a live event	7. Playing a musical instrument	7. Doing volunteer work
8. Playing with things or toys	8. Playing games	8. Going on a full-day outing	8. Taking music lessons	8. Doing a chore
9. Going for a walk or a hike	9. Gardening	9. Listening to music	9. Participating in community organizations	9. Doing homework
10. Playing on equipment	10. Fishing	10. Making food	10. Dancing	10. Shopping
11. Watching TV or a rented movie	11. Doing individual physical activities			
12. Taking care of a pet	12. Playing non-team sports			
	13. Doing a paid job			

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