The Hong Kong Polytechnic University

The Department of Rehabilitation Sciences

'Performance of

a dynamic reach-and-grasp task

in Children with Developmental Coordination Disorder'

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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 material previously published or written, 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.

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ABSTRACT

Introduction: Most of the published data in children with developmental coordination disorder (DCD) examined time and force factors separately, and with force control examined in a static setup. These findings had limitations in explaining their poor performance in sport activities that involve the control of both speed and force. Since playing is an essential domain in the life of children and boys have shown a higher prevalence of DCD than girls, the setup of this study was specially designed to simulate a dynamic ball game, which boys are most commonly involved in. The objective of this study was to investigate the performance of a dynamic reach-and grasp task in children with DCD when compared with a group of healthy children at similar age. We examined the successful rate of completion of the dynamic reach-and grasp task in children with DCD. We also studied whether children with DCD required a longer reaction and movement time as well as greater peak force and rate of force production than healthy children. We further explored whether these children had difficulties in adjusting their time and force to a change of weight and speed of the target.

Methods: Twelve healthy children (mean age: 7.8 ± 0.6 years old) and seventeen children with DCD (8.1 ± 0.6 years old) were instructed to use their dominant hand to grasp a toy car, which was allowed to slide down from a slanted board of adjustable slope. All subjects were tested in 4 conditions with different combinations of slope (8° or 15°) and weight (no-weight-added and weight-added), 5 trials for each condition. The sequence of testing conditions was randomized. Reaction time, movement time, peak force and rate of force production were recorded. These variables were analyzed using two-way repeated measures analysis of variance (ANOVA) with group (DCD and control) as the 'between' factor, and slope (8° and 15°) and weight (no-weight-added and weight-added) as 'within' factors. Pearson product-moment correlation coefficient was calculated to establish associations among movement time, peak force and rate of force production. Within-subject standard deviations were calculated to investigate the variations in reaction time, movement time and peak force. A significance level of 0.05 was employed for all analyses.

Results: The testing procedure was found reliable with the Intraclass Correlation Coefficients of test-retest reliability valued above 0.83 for reaction time, movement time and peak force. Healthy children completed all trials of reach-and-grasp task successfully. However DCD group failed in 118 out of the total of 340 test trials, i.e. 34.7%, with the highest failure rate found in the fastest condition. The 3 most common failure reasons were ‘Child picked the toy car up at the wrong spot’, ‘Toy car ran off the board without being picked up’ and ‘Child pressed down the toy car to stop it but did not pick it up as instructed’.

Within the successful trials, DCD group had much more within-subject variability in the movement time than control group among the 4 conditions. DCD group took significantly longer reaction times than control group in all 4 conditions ($p<0.05$), but both groups did not adjust their reaction time in response to change in weight or slope. DCD group tended to use longer movement times than control group, although these differences did not reach a significant level. Both groups used significantly shorter movement time when the slope was increased ($p<0.05$). Regarding the peak force, DCD group used greater force than control group even when grasping a static toy car, although the difference did not reach a significant level. They used significantly greater peak force than healthy children when grasping a moving toy car ($p<0.01$). Both groups increased their peak force significantly when the slope was increased ($p<0.01$). For the rate of force production, there was no between-group difference, and both groups tended to increase their rate of force production when the slope was increased although not to a significant level. In both healthy and DCD groups, their movement time was inversely correlated to their rate of force production.

Discussions: Children with DCD appeared to have difficulty in adjusting time and force to complete a dynamic reach-and-grasp task, therefore they had a high failure rate to complete the task in this study. To reach and grasp the toy car successfully, children had to rely on visual information to plan, initiate and monitor the motor response. Children with DCD might have visual perceptual problems, which led to inaccurate prediction of the toy car's motion and planned an inaccurate action. Hence they failed many trials by grasping the toy car at a wrong site. Their high failure rate might also be related to their slowness in developing the capacity to process proprioceptive input and to effectively integrate visual and proprioceptive information. Therefore they required a longer time to plan and to execute the movement. When time was limited; they could not pick up the toy car before it ran off the track.

Regarding the prolonged reaction time, children with DCD might have longer tracking delay in detecting the temporal and spatial information about the toy car, and a longer time was required to process and translate this information to plan for an appropriate response. The high within-group variability for the movement time reflected that they had ineffective feed-forward and feedback control for the on-going movement. In the present study, movement time was subdivided into ‘reach time’ and ‘grasp time’. There was a trend of prolonged movement time in children with DCD, and the ‘grasp time’ showed the similar trend of difference between the two groups. It was possible that the prolonged MT in successful trials was contributed by the prolonged ‘grasp time’, i.e. the time between initial contact of the toy car to a secured grasp. The trend of prolonged ‘grasp time’ could be related to their inaccurate proprioceptive sensory system. Therefore, they required longer time to collect information on the weight of the toy car to produce the required force, and information on the position of the fingers involved in the grasp so as to refine the shape of the hand grasp. It might also be related to their ineffective integration between the sensory and motor systems.

Children with DCD used significantly greater force than healthy children to pick up the moving toy car. They could have impaired kinaesthetic perception and sensory-motor integration, therefore, they compensated by increasing the peak force.

In successful trials, children with DCD could decrease movement time, increase peak force and increase rate of force production when the slope was increased in a similar manner as those of control subjects. But the high failure rate in the DCD group reflected that their adjustment ability was not as effective as that of the control group.

Conclusions: The result of this study confirmed that children with DCD were less effective in performing a dynamic reach-and-grasp task with a failure rate of 34.7%. In successful trials, they used significantly longer reaction time and larger peak force, and tended to use longer movement time to perform the fine-tuning phase of the task. They could adjust their movement time, peak force and rate of force production in response to change of slope of the slanted board, hence the speed of the toy car. Findings of this study suggested that their poor performance in sport activities could be related to their prolonged time to plan, prolonged and inconsistent time to fine-tune the motion, excessive force to grasp, and inefficient rate of force production. They could adjust their motion time in a crude reaching phase and their force output in response to a change in speed of the target but were not as effective as the healthy children. This was causing a lot of their failure in a dynamic reach-and-grasp task. In order to improve their performance in dynamic sport activities, training program with timely and quantified feedback may be useful to speed up their reaction time, movement time and to optimise their force output with a greater consistency.

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LIST OF ABBREVIATION

APA	American Psychiatric Association
BOTMP	Bruininks-Oseretsky Test of Motor Proficiency
BMS	Between-subjects mean square’
CAS	Child Assessment Service
DCD	Developmental Coordination Disorder
EMS	Error mean square
g	Gram
HKCAS	Hong Kong Child Assessment Service
ICC	Intraclass Correlation Coefficient
ICD	International Classification of Diseases and Related Health Problems
kg	Kilogram
kg/s	Kilogram per second
MABC	Movement Assessment Battery for Children
ms	Millisecond
m/s	Metre per second
MT	Movement time
NA	Not applicable
No.	Number
PF	Peak force
RT	Reaction time
SD	Standard deviation
WHO	World Health Organization
yr.	Year

Chapter 1 Introduction

Developmental motor problems were first discussed by Collier as early as 1900 (Ford, 1996). Collier used the term “congenital maladriotness” to describe the developmental motor problems evidenced in children. Since then various terms were used to describe these motor problems. Orton (1937) used “developmental apraxia” and “abnormal clumsiness” to distinguish them from any other developmental motor disorders caused by pyramidal, extra pyramidal or cerebellar dysfunction. Neurologists used terms ‘developmental apraxia and agnosia’ (Walton, Ellis & Court, 1962), ‘developmental apraxic and agnostic ataxia’ (Gubbay, 1975), ‘minimal cerebral dysfunction’ (Wigglesworth, 1963), ‘minimal brain dysfunction’ (Clements, 1966) and ‘minimal cerebral palsy’ (Kong, 1963) to explain these motor coordination or motor planning difficulties with the etiology of minor brain damage. Walton (1962) explained that the problems of these ‘clumsy children’ were a consequence of poor motor skills instead of being naughty or due to low intelligent level.

In 1960s, these problems were accounted by some researchers as a consequence of perceptual deficits and perceptual-motor dysfunctions (Ayres, 1960, 1965; Brenner, Gillman, Zanwill, & Farrell, 1967), with remedial education and perceptual-motor programs developed accordingly (Frostig, 1968; Kephart, 1960). By the 1980s and 1990s, ‘developmental dyspraxia’ became frequently and widely used by neurologists to describe these motor learning or planning problems (Denckla, 1984; Denckla & Roeltgen, 1992). This term was also used by therapists (Cermak, 1985; Missiuna & Polatajko, 1995; Szklut, Cermak, & Henderson, 1995) and neuro-pyschologists (Dewey, 1995). Some explained the motor planning problems of these children as a difficulty in integrating sensory information from the body (Ayres, 1980; Cermak, Trimble, Coryell & Drake, 1991), while others explained them as difficulties in motor sequencing and selection (Ayres, 1989; Miyahara & Mobs, 1995).

1.1 Definitions of Developmental Coordination Disorder (DCD)

In 1994, a consensus meeting was held in London, Ontario, Canada (Polatajko, Fox & Missiuna, 1995). It was finally agreed by a group of internationally recognized multidisciplinary researchers who worked with children with motor clumsiness to use the term ‘developmental coordination disorder’ (DCD) as described by the American Psychiatric Association (APA) in DSM-IIIR (APA, 1987) and revised in DSM-IV (APA, 1994). Another diagnostic system, the World Health Organization (WHO, 1992a, 1992b, 1993) International

Classification of Diseases and Related Health Problems (ICD-10), used the term 'specific developmental disorder of motor function' to refer to children with DCD, developmental dyspraxia, or the clumsy child syndrome.

Due to the classification in these manuals, DCD is now recognized as a specific entry, a separable developmental disorder of motor skills that requires diagnostic, etiological, and remedial attention in its own right.

According to DSM-IV, the diagnostic criteria of DCD are as follows (APA, 1994):

- Performance in daily activities that require motor coordination is substantially below the expected level for the chronological age and measured intelligence. This may be manifested by marked delay in achieving motor milestones, e.g. sitting, crawling and walking.
- Dropping things, 'clumsiness', poor performance in sports, or poor handwriting is commonly seen.
- Academic achievement or activities of daily living is significantly interfered.

- 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.
- If mental retardation is present, the motor difficulties are in excess of those usually associated with it.
- The manifestations of this disorder vary with age and development. For example, younger children may display clumsiness and delay in achieving developmental motor milestones, e.g. walking, crawling, sitting, tying shoelaces, buttoning shirts and zipping pants. Older children may display difficulties with the motor aspects of assembling puzzles, building models, playing ball games, and printing or handwriting.

1.2 Etiology

There is no single factor that causes DCD; the underlying etiology for DCD is still unclear (Wall et al, 1990) and probably heterogeneous (Gubbay, 1975). One of the major reasons is due to great inconsistencies in diagnostic criteria adopted by different researchers. A review of 176 publications on DCD found that there was little consistency in the diagnostic procedures in identifying children with DCD, hence making it hard to reach an overall conclusion on the underlying etiological factors (Peters, Barnett & Henderson, 2000). Advances in structural and functional imaging of the brain indicated that extensive areas of brain are involved in the planning and performance of motor actions (Rizzolatti, Luppino & Matelli, 1998; Willingham, 1998; Rowe & Frackowiak, 1999). Various causes of DCD were investigated, and a wide range of approaches was adopted to identify the underlying causes of the difficulties experienced by children with DCD (Barnett, Kooistra & Henderson, 1998).

Some studies found that these children had a number of mild neurological signs than age-matched control group (Henderson & Hall, 1982; Lundy-Ekman, Ivry, Keele & Woollacott, 1991). The most commonly identified neurological signs were poor coordination (poor performance on tests of ‘finger to nose’, ‘heel to knee’, finger pursuit, rapid individual finger movements, or rapid alternating movements), abnormal gait (awkwardness when walking, walking on toes or heels, running or hopping), poor position sense, nystagmus, strabismus, astereognosis, abnormal reflex, mirror movements and poor tactile finger recognition (Nichols & Chen, 1981). Dewey and Wilson (2001) speculated that DCD is part of the continuum of cerebral palsy. Although the etiological significance of these neurological signs remains unclear and their occurrence generally lacked localizing value (Touwne, 1990), it had been suggested that the presence of the above-mentioned neurological signs might provide some indications of neurological impairment (WHO, 1996). Knuckey, Apsimon & Gubbay (1983) noticed that 50% of children with severe developmental clumsiness (in contrast to 9% in control group) showed abnormal computerized tomography scan of ventricular dilatation, peripheral atrophy and parenchymal disruption.

Orton (1937) suggested that developmental disorders in praxis and gnosis might result in motor skills deficits that were different from those arising from pyramidal, extra-pyramidal or cerebellar dysfunction. Walton (1962) hypothesized that clumsiness was related to cerebral disorganization in a neuro-physiological rather than an anatomical sense. It was the result of poorly organized pathways concerned with the recognition of tactile and other sensory stimuli, or poor organization of skill movement. A meta-analysis of fifty studies on children with DCD found that their greatest deficiencies were in visual-spatial processing, followed by deficiencies in kinesthetic and cross-modal processing (Wilson & Mckenzie, 1998). This finding supported the postulation that clumsiness was linked to deficits in different perceptual processing such as visual or kinesthetic perception (Hoare, 1994; Laszlo & Bairstow, 1983; Lord & Hulme, 1988; Mon-Williams, Wann & Pascal, 1999; Wilson & Mckenzie, 1998). Other studies proposed that clumsiness was due to defects in motor organization (Henderson, Rose & Henderson, 1992; Lundy-Ekman et al., 1991; Williams, Woollacott & Ivry, 1992), or related to deficits in both perceptual processing and motor organization (Hoare, 1994; Smyth & Glencross, 1986; Smyth & Mason, 1997).

DCD was frequently associated with a greater incidence of perinatal complications especially jaundice, low birth weights, prematurity or overdue (Johnston, Short & Crawford, 1987). Longitudinal follow-up of preterm or low birth weight children revealed a higher risk of DCD (Fox & Lent, 1996; Marlow, Robert & Cooke, 1993; Holsti, 2002). Hoare (1991) also reported that children with coordination problems had higher incidence of complicated pregnancy, premature birth, breech birth, use of forceps, cesarean section, and vacuum extraction, comparatively lower birth weight, jaundice, ventilation therapy, and other risk factors.

With the findings of 20% to 30% of DCD group versus 4% in the control group had a familial feature with positive family history, it was possible that clumsiness or developmental apraxia had a genetic predisposition (Gubbay, 1975, 1978; Johnston et al., 1987; Hoare, 1991). Kaplan, Wilson, Dewey & Crawford (1994) reported a subtype of reading disability associated with deficits in motor coordination and balance, and reported there was a factor of inheritance. Stordy (2000) also suggested a genetic predisposition as the common basis for comorbid dyslexia and DCD. This investigator further found that a problem with fatty acid conversion was linked to both disorders. DCD also reported to have a high incidence of co-morbidity with attention-deficit/hyperactivity disorder. Mervis, Robinson & Pani (1999) found that DCD might have genetic links to visual spatial construction. A better understanding of the subtypes of DCD might lead to earlier identification of children with DCD and better-targeted interventions.

Different studies examined and described DCD from different perspectives. Findings of these studies could suggest heterogeneous underlying causes of DCD. There were no definitive anatomical changes in the brain to explain sensory and/or motor deficits observed in children with DCD. Since DCD has a wide range of etiology, health professionals from different streams would choose the areas relevant to their own expertise, so that they could contribute to an effective intervention for these children with DCD.

Chapter 2 Literature review

According to DSM-IV, the prevalence of DCD was estimated to be 6% in the age range of 5-11 years and 5-8 % of all regular school-aged children (APA, 1994). However, some investigators estimated the prevalence was as high as 22 % (Kadesjo & Gillberg, 1999; Keogh, 1968; Wright & Sugden, 1996). No prevalence has been reported for the children population in Hong Kong. Estimating the prevalence of DCD is difficult because there are no clear definition and diagnostic criteria for DCD (Cermak & Larkin, 2002). Since the motor problems of children with DCD are heterogeneous, no "gold standard" test or screening measure can be used solely to confidently identify the problem. In many cases, the percentile cut-offs of standardized tests for identification of children with DCD were arbitrarily set (Sugden & Keogh, 1990). It is because using a cut-off point to determine the percentage of children with DCD would have an essential implication on the demand of service, and therefore it was never unified internationally. For example, Henderson and Sugden (1992) used the 15^{th} percentile in the Movement Assessment Battery for Children (MABC). Gubbay (1975) diagnosed 6% of his sample of school children as clumsy, as this proportion was reported by either the children themselves or their caretakers as having significant motor problems. The criteria used in Hong Kong Child

Assessment Service (HKCAS) for diagnosis of DCD were report of gross motor functional problem (APA, 1994) on the CAS-DCD functional checklist (Appendix III), and 'gross motor composite standard score' in the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) equals or less than 42 (Crawford, Wilson & Dewey, 2001), or score in the Movement Assessment Battery for Children (MABC) below 5th percentile (Henderson & Sugden 1992; Crawford et al., 2001; Chan, Ng, Lin, Leung, Poon, Ng & Tsang, 2004). Other than using the cut-off point of standardized tests, factors that could influence prevalence rates were methods of assessment. Some had used questionnaires e.g. the checklist of the Movement Assessment Battery for Children completed by teachers (Henderson & Sugden, 1992) and the Developmental Coordination Disorder Questionnaire completed by parents (Wilson, Kaplan, Crawford, Campbell & Dewey, 2000) to identify children with DCD. The more teachers and parents know about DCD, the more effective they will be in completing the questionnaires. Cultural differences also affect the prevalence since children or their caretakers from different countries could find different degrees of motor problems as significant.

Many studies showed a higher prevalence of DCD in boys than girls (Gubbay, 1978; Henderson & Hall, 1982; Kadesjo & Gillberg, 1999; Keogh et al, 1979; Sovik & Maeland, 1986). However, the ratios reported were not unified. Taylor (1990) reported a ratio of 3:1. Missiuna (1994) found a ratio of 5 male children to 1 female child being referred by teacher for movement difficulties. A recent survey by the HKCAS reported that the male to female ratio was around 3 to 4: 1 (Chan, 2006). This may be due to greater caretaker concerns over boys' than girls' motor skill (Gubbay, 1978). It may also be due to a higher rate of behavioral problems for boys who have motor coordination problem would present with difficulty in school. This made them easier to be identified for further evaluation (Barnhart, Devenport, Epps & Nordquist, 2003). On the other hand, when the girls were identified with motor clumsiness, they usually had significantly poorer motor coordination than that of the boys (Revie & Larkin, 1993). This implied girls would need to exhibit more severe movement difficulties in their daily livings than boys in order to be identified as having DCD.

Although no prevalence rate was reported in Hong Kong, if we applied the prevalence rate of 6% found by the American Psychiatric Association (1994), it was estimated that each year 33000 school-aged children would be diagnosed as having DCD and would require intervention programs. In recent years, more children were reported to be clumsy and were brought to the attention of the HKCAS of the Department of Health. These children requested to have comprehensive assessment and appropriate treatment. The awareness of DCD among health professionals in Hong Kong has also increased notably (Chan, 2006). Further sub-division of DCD into gross or fine motor domain was found in HKCAS. Out of the 94 children diagnosed with DCD at HKCAS, 65% had gross motor coordination affected (Chan, Ng, Lin, Leung, Poon, Ng & Tsang, 2004). Unfortunately, most of these motor problems remain as they grow up but would be manifested differently according to the changing motor demands in their activities of daily livings or in sport appropriate for their age (Geuze & Borger, 1998; Cantell, Smyth & Ahonen, 1994; Losse et al., 1991).

2.1 Standardized clinical tests

Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) and Movement Assessment Battery for Children (MABC) are the two standardized tests commonly used by clinicians or researchers to assist in identifying children with DCD (Crawford, Wilson & Dewey, 2001; Henderson & Sugden, 1992). BOTMP is an individually administered test that assesses the motor functioning of children from $4^1/_2$ to $14^1/_2$ years old (Appendix I). It has eight subtests comprising 46 separate items totally. The 8 subtests are: running speed and agility, balance, bilateral coordination, strength, upper-limb coordination, response speed, upper-limb speed and dexterity, and visual-motor control. This test provides a comprehensive index of motor proficiency as well as separate measures of both gross and fine motor skills. Children who have their ‘gross motor composite standard score’ in this test of less than 42 are considered as having lower than average motor function (Crawford et al., 2001). Children who score between 38 and 41 are in 12th to 22nd percentile. Children who score between 32 and 37 are in the 5th to 11th percentile. Children who score below 32 are in the lowest 4 percentiles (Bruininks, 1978).

MABC is also an individually administered series of motor tasks to be tested in a standardized way (Appendix II). In this test, eight motor tasks are tested for each age group, from 4 to 12 years of age. These eight motor tasks cover three functioning areas: dynamic balance, manual dexterity and ball skills. A total impairment score of this test between the 5th and the 15th percentile suggests a borderline motor difficulty. A score below the 5th percentile is indicative of a definite motor problem (Henderson & Sugden, 1992).

2.2 Clinical Presentation

Since children with DCD form a heterogeneous group (Hoare, 1994), there is no typical DCD signs and symptoms. Hence, not all children with DCD show the same clinical picture. Some children may experience difficulties in a variety of areas while others may only have problems with specific activities. There are different subtypes of DCD manifesting different profiles. The disorders mainly involve fine and / or gross motor coordination but the extent of involvement varies. The course of the disease is variable. The particular pattern of motor disabilities also varies with age. In some cases, lack of coordination continues through adolescence and adulthood (APA, 1994). The recognition of DCD usually occurs when the children first attempt tasks such as holding a knife and fork, buttoning clothes, running or playing ball games. Developmental motor milestones may be delayed. The young children may be awkward in general gait pattern, being slow in learning to run, hop, and go up and down stairs. They tend to drop things, to stumble, to bump into obstacles and are often poor at ball games (WHO, 1996). They often demonstrate movements that are inaccurate and lacking in fluency (Chan, 2006). They demonstrated ‘slowness of movement’ in studies of both reaction time and movement time (Henderson & Sugden, 1992; Van der Meulen, Denier van der Gon., Gielen, Gooskens & Willemse, 1991). They seem having difficulties selecting the best motor response for a task (Van Dellan & Geuze, 1988) and may repeat motor tasks in the same way regardless of repeated failed experience with that task (Chan, 2006). William (2002) summarised that children with DCD had significantly longer reaction time, movement time or response time, difficulty with timing control, difficulty with force control, increased variability of performance on a wide variety of motor tasks, and inability to adapt quickly to changes in movement demands.

For a normal child, playing is an important ingredient in his / her life. However play skill is closely related with motor skill, especially in boys. Children with DCD usually require more effort and frequently face repeated failure when acquiring new motor skills; therefore, they are always upset with their own performance. In fact, some children with DCD were observed to have socio-emotional behavioral problems (WHO, 1996). Their poor motor skills will cause them having a lower self-perceived competence in sport skills, hence avoidance to participate in physical games and leisure pursuits (Cantell et al., 1994). As a result, they cannot socialize effectively with peers of their age, particularly on the playground. They are usually left out, teased or bullied by peers (Chan, 2006). Due to their decreased confidence level, they prefer to either play with younger playmates or go off on their own. They usually have less social hobbies and pastimes than a comparison group of typical peers. Eventually they are more susceptible to become introverts and judge themselves as less competent not just physically but also socially, and are anxious when compared with their peer group (Schoemaker & Kalverboer, 1994).

Since most children with DCD will not outgrow their motor problems, adolescents with DCD will continue to experience difficulty with sports and any new motor tasks (Cermak, 1991). They tend to avoid group sports activities; in which ball games are the most commonly avoided ones. Eventually, they usually have lower self-perceptions in active aspects of their physical selves e.g. sport competence. The lack of competence in one area is usually being generalized to other domains, and finally results in low self-esteem or perception of global self-worth (Harter, 1987; Skinner & Piek, 2001; Larkin & Parker, 1997). As a secondary consequence of lower global self-worth in children with DCD, they will learn to become helpless and unrealistic when they set goals for themselves

(Henderson, May & Umney, 1989). Apart from the lower global self-worth, some of them may develop social problems (Johnston et al., 1987; Geuze & Borger, 1998), affective problems (Henderson & Hall, 1982; Schoemaker & Kalverboer, 1994), and psychiatric problems (Gillberg, 1989). If no appropriate intervention were attained, the situation would get worse as they grow older. Anxiety was significantly higher for the adolescent DCD group compared to their younger counterparts (Cantell, 1998). Many of them have high risk of being bullied by their peers and have few friends (Henderson & Hall, 1982). Moreover, they were also more prone to behavioral problems that varied from bullying to legal offences (Losse, Henderson, Elliman, Hall, Knight & Jongmans, 1991). Therefore, appropriate training to improve their motor skills is important and will have a significant effect in all aspects on their long-term development.

2.3 Clinical management

Since little is understood about the etiology of the disorder (Ayyash & Preece, 2003) and with their heterogeneous clinical presentation (Gubbay, 1975), one would expect that there would not be one single factor causing DCD. As a result, clinicians used different approaches and interventions for managing this group of clients in order to meet their diverse and unique needs. Paediatricians help to screen out other medical condition according to the diagnostic criteria of DSM-IV (APA, 2000). Medication was rarely used except that in one study where Richardson & Montgomery (2005) introduced dietary supplement of fatty acid, but no effect was found on their motor problem. Clinical psychologists help in confirming their cognitive functioning level and to look after the secondary consequence in emotional and behavioral aspects. The intervention program for improving their motor coordination problem is mainly conducted by physiotherapists (for the gross motor domain), and occupational therapists (for the fine motor domain). The approaches commonly used by therapists can be broadly categorized into 'bottom-up' or 'top-down' approaches (Chan, 2006).

'Bottom-up' approaches are based on the assumption that if the foundational motor skills are developed, motor skills will emerge and performance in tasks will be improved. It is based on the hierarchical theories of motor control, which advocates that remediation of underlying process deficits will result in improved motor function. The methods frequently used in this approach were sensory integration, process-oriented treatment and perceptual motor training (Chan, 2006). 'Top-down' approaches focus on cognitive strategies for skill acquisition and use of problem-solving skills to improve motor performance (Mandich, Polatajko, Macnab & Miller, 2001). These approaches assume that motor requirements for any task are variable and motor control for a task is more efficient when the child understands what is expected. Emphasis is placed to assist child to identify, develop and utilize cognitive strategies to manage daily tasks. These approaches suggest that motor learning results from interaction of the child with the task and the environment, and the context in which motor behavior occurs also greatly affects the quality of the motor behavior. Examples are task-specific intervention and cognitive approaches (Barnhart et al., 2003; Chen, Tickle-Degnen & Cemak, 2003; Mandich, Polatajko & Rodger, 2003; Ward & Rodger, 2004).

However, when comparing previous studies using either 'bottom-up' or 'top-down' approach, no one approach or combination of approaches was found superior to another in improving motor skills. No single method of bottom-up approach was shown to be reliably better than no treatment at all (Mandich et al., 2001). In addition, no previous study has provided any suggestion for DCD intervention program that could improve motor skills such as in sport activities, that is important to develop children's global self-worth, especially for the male group.

2.4 Motor deficits in children with DCD

Despite normal intelligence and normal findings on conventional neurological examination, children with DCD demonstrate poor or below age level ability in performing skilled and coordinated tasks (Gubbay, 1978). Reach-to-grasp is one of the most frequently performed activities in daily livings (Wang & Stelmach, 2001). However, skilled upper-limb movement is one of the most common difficulties experienced by children with DCD (Williams, Fisher & Tritschler, 1983). They usually drop things, or tip over utensils or cutlery on meal-table (ICD-10). According to data collected by Hong Kong Child Assessment Services (HKCAS), 90 % of children that were diagnosed with DCD in gross motor domain had poor upper limb coordination (Chan et al., 2004). Their performance in the subtest of upper limb coordination of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) was particularly poorer than that in the other subtests. This subtest involves a lot of throw-and-catch skills. The difficulty in this subtest reveals their poor performance in sport activities. They commonly have difficulty in bouncing ball, dribbling ball along obstacle, or throwing and catching ball. When dribbling ball, they usually push the ball downward too quickly and with too much force irrespective to the specific rebounding course of the ball. When throwing a ball to a target, they either throw it too gently hence missing the target, or too forcefully that cause it to rebound too fast to be caught. All these activities require an effective control of speed and force. However, children with DCD were found to have poor perception of sensory inputs (Grimley & Gordan, 1977) to discriminate weight and/or speed of objects. Consequently, they always responded much slower than their peers in time-constraint tasks and had poor control of force output (Smyth & Glencross, 1986). Their ability to control speed and force of movement are believed to be inadequate and need further improvement. These motor deficits of speed and force control are more apparent when one is required to participate in open sport activities, such as catching an approaching ball or hitting a Ping-Pong ball in table tennis game. Therefore, these children rarely participate in racquet ball games, such as tennis, badminton or ping-pong ball games, that are age-appropriate activities for the older client group. Inability to participate in these games and activities will hinder both their physical and social development, in turn, the perception of global self-worth (Harter, 1987; Skinner & Piek, 2001; Larkin & Parker, 1997).

These skilled arm movements are characterized by precise control of voluntary movement initiation, execution and completion (Williams et al., 1983). In order to better understand their problems in this aspect, previous studies had extensively investigated the clinical problems of speed and force control in children with DCD. Several parameters including failure rate, reaction time, premotor time, movement time and peak force, were commonly measured to reflect the effectiveness of motor control in those children. However, most of the published data examined time and force control separately. For instance, some studies examined their reaction time to a visual moving target or to kinaesthetic stimulus (Henderson & Henderson, 1992; Raynor, 1998; Smyth, 1996); or force control in a static set-up (Pereira, Landgren, Gillberg & Forssberg, 2001). Skilled upper limb tasks are frequently affected in children with DCD, and these tasks require an interaction of speed and force. Examination of these 2 parameters would be helpful to understand their difficulties in performing some play activities such as “catching a ball” which requires a reach-and-grasp action.

2.4.1 Failure rate

Lefebvre and Reid (1998) found that when viewing a video that depicted softball trajectories, children with DCD required more viewing time and more visual information to predict the path of the ball. They also made much more mistakes than the control group in predicting the location of the ball. These investigators suggested that children with DCD had less ability to make accurate prediction based on visual information than normal children due to their visual perceptual problems. This may explain why they have difficulty in catching or dribbling ball, and had greater difficulty to hit an approaching ball in racquet ball games.

Some researchers were interested in performance of children with DCD in response to other sensory input. Williams et al. (1992) compared the effect of auditory sensory input on the failure rate of performance between children with or without DCD. In this study, children with DCD were asked to tap their index finger in time with a series of 50-ms auditory tone spaced at 550-ms intervals and continued to tap at the same rate after the auditory tone had stopped. They found that the failure rate for children with DCD was more than double of that of the control group when performing tasks that required timed movements. Apart from the ability of DCD children to react to simple visual or auditory signal, no published data has reported their ability to react to both visual and spatial stimuli, i.e. the ability required in ball games.

2.4.2 Reaction time (RT) and movement time (MT)

Many previous studies investigated RT using various methods of measurements. Anson (1992) defined RT as the time required for the most rapid volitional response an individual could make. This definition included both phases of planning and motor execution. Weiss (1965) adopted a similar understanding and fractionated reaction time into central (premotor) and peripheral (motor) time components. He defined premotor time as the period between presentation of the stimulus and arrival of the efferent neural impulse at the muscle responsible for initiating the response, and measured this duration by the first appearance of electromyographic signals. This premotor time included the stimulus identification, response selection, and the response programming stages. The motor time component was defined as the time required to complete the motion task. Raynor (1998) also defined reaction time as the sum of premotor time and motor time. Williams (2002) defined RT differently and measured RT as the process of planning without the motion part included. It was actually the premotor time according to the fore-mentioned definition. By this definition, RT reflects the speed and accuracy of processing sensory information, e.g. visual, auditory or proprioceptive senses, and the effectiveness of translating that process into plan of action and the initiation of an overt response.

Smyth & Glencross (1986) examined the RT of children with DCD in response to kinaesthetic or visual sensory input. In the first part of their study, a sudden passive arm movement, which acted as a proprioceptive stimulus, was applied to either the left or right arm of the children. During the test, vision of the arm movement was occluded by a curtain located on either side of the subject. The subject was instructed to respond by pressing a thumb-held micro switch after detecting the proprioceptive stimulus from either left or right arm. In the second part of this study, visual stimulus from two lamps set on either side of the subject was used to replace the proprioceptive stimulus used in the first part. These investigators found that children with DCD had longer RT in response to proprioceptive stimulation than the control group by more than 100 ms. No significant between-group difference was detected in response to visual stimulation. These researchers suggested that the prolonged RT might be due to their slowness in processing kinaesthetic or motion information.

Similar to the setup used by the previous study, Smyth (1996) extended the study using simple and choice RT paradigm. Similarly, both of the subject's forearms were suspended in a horizontal position by cuffs placed at the wrists and one of the arms was made to fall suddenly by the investigator. For 'simple RT task', subjects had to respond by operating the switch held in the dominant hand, when either arm was released. For 'choice RT task', arm was released in random order.

Subjects were required to respond to the release of dominant arm by operating the switch held in the dominant hand. No response was required to the release of the non-dominant arm. This study also found that DCD group had significantly longer RT than the control group. The mean RT for choice tasks was also significantly longer than that for simple tasks by 229 ms. However, the difference in RT between choice and simple tasks was similar for both DCD and control groups. Therefore, Smyth postulated that the significantly longer RT in DCD group was due to a prolonged time for processing kinaesthetic information but not due to difficulties in choosing the appropriate response. The slowness in processing kinaesthetic information could explain why children with DCD always move their arms clumsily and inaccurately in ball games.

Instead of testing the RT in the arm, Raynor (1998) found that children with DCD required a longer premotor period by 16.4% when they were asked to kick their leg forward in response to a light flash in a sitting position. Raynor (1998) proposed that there might be due to delays in the central processing time, i.e. time for stimulus registration and coding process, and/or the response programming stage. This might explain partly why children with DCD responded slower than their normal peers in a kicking activity in sitting position.

MT records the time taken to execute a movement with the planning stage excluded. It is an indirect indicator of efficiency of the child's motor control system (Henderson et al., 1992).

Henderson & Henderson (1992) was the first study that investigated motor response with differentiation of RT and MT. They examined the RT to aim at visual signals. The visual signal was given as a green arrow appearing on the computer screen and pointing to either a large or small sized target key. Prior to this aiming task, children were instructed to press the 'start key' with their dominant index finger. When the green arrow appeared on the computer screen, children had to respond by releasing the 'start key' and reached their arm forward to press on the targeted key. RT was calculated as the interval from the onset of green arrow to the release of the 'start key'. MT was calculated from release of 'start key' to depression of the 'targeted key'. Henderson & Henderson (1992) found that children with DCD had significantly longer RT than the control group by 41 ms. They also found that the MT was also significantly prolonged in the DCD group, by 102 ms in response to the large-sized target and by 203 ms in response to the small-sized target. The variability of MT was also significantly greater than that in the control group when performing this aiming task in response to the moving visual target. Therefore, from findings of fore-mentioned studies, it is postulated that the prolonged RT and MT, and inconsistent MT in children with DCD could result in poor performance in sport activities. A study that examines these parameters in a simulated sport activity would be useful in elucidating motor control in children with DCD.

In Raynor's study (1998) when children were asked to kick their leg forward in response to a light flash in a sitting position, the motor time of DCD group was also significantly longer than control group by 9.2%, and this motor time would be equivalent to the MT defined by Henderson & Henderson (1992).

2.4.3 Force control

Peak force (PF) is the maximal force used to successfully perform a task. The adjustment in its value reflects how effective a child uses the sensory information to monitor the motion performed (Case-Smith & Weintraub, 2002).

Pereira et al. (2001) measured the isometric fingertip peak forces applied in a static grip to hold objects of different surface texture (covered with sand paper or silk to change the friction between the fingers and the object) and of different weight (altered by adding masses to it). This study confirmed that children with DCD used excessive grip force when lifting static object with a precision grip.

Two other studies examined both time and force control. Lundy-Ekman et al. (1991) focused on the consistency of force production rather than the maximum force output generated. Subjects were asked to produce a series of isotonic movements to target forces. Initially they were given feedback so that they could adjust their force output to match with the target force. Afterward, the isotonic movements were made without feedback; and the consistency of force output during this phase was measured. Temporal measure such as the duration of the force pulses that they could maintain was obtained to evaluate the possible trade-off between time control and accuracy control. They found that children with DCD could reach the targeted force but were not able to maintain the force for a long period of time. They suggested that these children had more deficit in timing rather than force control.

Pitcher, Piek & Barrett (2002) also studied both timing and force control in children with attention-deficit / hyperactivity disorder and DCD. In that study, each subject was instructed to reach out the tested arm to produce 20 five-tap sequences on the tapping key as soon as a green light was seen. Results of that study revealed that children with a dual diagnosis of attention deficit hyperactivity disorder and DCD took a significantly longer time to react to the green light and demonstrated a higher level of peak force output. The investigators believed that these higher force output and slower response time were associated with their motor dysfunction. That was the only study that investigated both RT and PF output. Response time, as defined in that study, included both the planning stage and motor execution stage i.e. the reaching out to the tapping key and the tapping motion. It could not distinguish whether the longer response time was due to poor attention that causing a delayed planning or it was due to prolonged time for motor execution, or due to both. Moreover, this study examined children with attention deficit hyperactivity disorder and DCD but not children with pure DCD. The performance of children with DCD would be better understood if the subjects included had DCD only.

2.5 Clinical application and objectives of the present study

Some of the previous studies examined the RT of children with DCD in responding to simple proprioceptive, visual or auditory signals. Some studied the MT of children in executing simple motor responses such as tapping or pointing tasks. Some tests were performed in a static task situation. However, in activities of daily livings or sport activities, children have to process a combination of senses, and the motor response has to be executed spontaneously with respect to the environmental spatial, temporal and force demands. Therefore, none of the previous studies could adequately explain the poor performance of children with DCD in real life situations.

Since play is an essential domain in the life of children and that boys have a higher prevalence than girls diagnosed with DCD (Gubbay, 1978; Henderson & Hall, 1982; Kadesjo & Gillberg, 1999; Keogh, Sugden, Reynard & Calkins, 1979; Sovik & Maeland, 1986), further study is required with the testing setup simulated to a game which is popular among boys, i.e. ball game. The handgrip of the motor task in this study was made resembling the handgrip used in a ball game. Motor skills required in ball games usually involve both temporal and spatial challenges. Therefore the present study was designed to investigate both time and force control. In the present study, the motor response was separated into planning phase - represented by RT, and motor execution phase - represented by MT. RT provides important information about the speed and accuracy of sensory information processing, the translation of that processing into a plan of action, and the initiation of an overt response (Williams, 2002). MT measures the duration of movement execution and can be viewed as an indirect indicator of the efficiency of the motor system function (Williams, 2002). PF of the handgrip and the rate of force production were also measured. By examining RT and MT as well as force control ability, we might be able to find out why clinically they were always too slow to secure a grasp of an approaching ball. We could find out whether it was due to their slowness in planning or in executing the motion. A lot of time they might already have their hand at the right spot but were applying wrong force that eventually they squeezed the ball out of the hand instead of grasping it effectively. And they always used inappropriate force to serve a ball. The study of their force control could explain whether it was their accuracy of force amplitude, their rate of force production or their consistency of force output that had caused their failure. As indicated in some pervious studies that children with DCD had high failure rate in completing simple task, and the variability of their performance were also greater than control subjects, the current study also explored their performance in these aspects in order to further explore the possible cause for their repeated failure and inconsistent performance in acquiring new dynamic reach and grasp task.

The present study aimed to investigate how children with DCD controlled their response time, i.e. both RT and MT, and force output when reaching out the arm to grasp a moving target with the dominant hand, when compared with healthy children of similar age. The second objective was to investigate whether the children could adjust their response time and force output according to the variation of weight and speed of targets.

Results of this study could contribute to our understanding of the possible underlying factors that affecting children with DCD in controlling grip force and response time during an open task that involves upper-limb coordination skills. The findings will provide scientific background for the design of effective treatment intervention to improve their motor skills especially in ball games for this group of children.

Chapter 3 Methodology

3.1 Study Design

The study was carried out in three phases (Fig. 3.1). In *Phase I*, the testing equipment and test procedure were developed and reliability test was conducted for this initial setup. In *Phase II*, the reliability of the instrument and testing procedure of the final setup was established. In *Phase III*, the main study was performed to investigate the difference between children with DCD and healthy children in the performance of a dynamic reach-and-grasp task using the final setup.

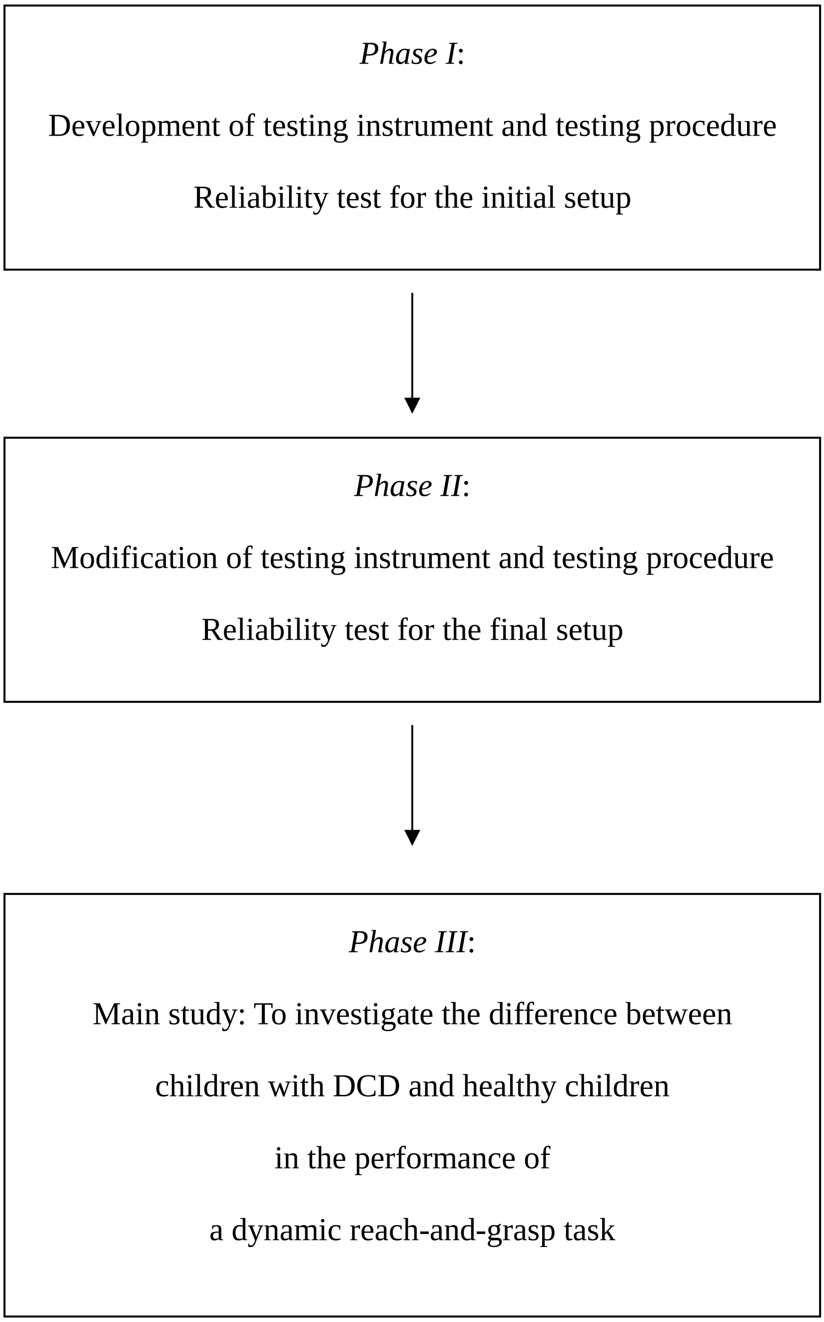


Figure 3.1 Study design

3.2 Subject

Two groups of children were recruited. The DCD group comprised children with DCD diagnosed at Child Assessment Services. The control group comprised healthy children recruited by convenient sampling method, and from local community centres and church communities.

3.2.1 Inclusion criteria

For the DCD group, children were diagnosed with DCD by Child Assessment Service with their ‘gross motor composite standard score’ in the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) being less than 42 (Crawford et al., 2001). Children who had scores below 32 were in the lowest 4 percentiles; scores between 32 and 37 were in 5-11 percentiles; and scores between 38 and 41 were in 12-22 percentiles (Bruininks, 1978). In addition to the scores obtained by this standardized test, all these children were reported to have gross motor functional problems (APA, 1994) as indicated on the CAS-DCD Functional Checklist (Appendix III). For the control group, children were reported by their caregivers as not having any gross motor functional problem.

3.2.2 Exclusion criteria

Children with the following problems would be excluded from the study:-

1. Healthy children who had limited range of upper limb movement, visual problem, problem in understanding and following commands that would affect their ability to follow instructions of the testing procedure.
2. Children diagnosed with DCD, but had limited range of upper limb movement, visual problem, poor sitting balance, or problem in understanding and following commands that would affect their ability to follow instructions of the testing procedure.

3.2.3 Number of subject

Table 3.1 shows the demographic data of children recruited from *Phase I* to *III*. In *Phase I*, fourteen healthy children with mean age 7.3 ± 1.0 years old and sixteen children with DCD with mean age 7.9 ± 0.54 years old were recruited to develop an instrument to examine a dynamic reach-and-grasp task. The DCD group, with the ‘gross motor composite standard score’ in BOTMP ranged from ‘less than 20’ to 41, was recruited to have pilot trial of this initial setup of the testing instrument and procedure. Only the healthy group participated in examining the test-retest reliability of testing procedure of this instrument.

Since the value of Intraclass Correlation Coefficients were not satisfactory (Table 4.1 in p.63), the instrument and testing procedure were modified and the test-retest reliability of the final setup was re-assessed in Phase II.

In *Phase II*, five healthy children with age ranging from 7.4 to 15.5 years old were recruited. They completed the test-retest reliability test for the testing procedure of the final setup of testing instrument. In *Phase III*, twelve healthy children (mean age 7.8 ± 0.6 years old) and seventeen children (mean age 8.0 ± 0.6 years old) newly diagnosed with DCD at a child assessment center, Hong Kong Department of Health, with 'gross motor composite standard score' in the BOTMP ranging from 'less than 20' to 41, were recruited to investigate the difference between children with DCD and healthy children in the performance of a dynamic reach-and-grasp task. The study was carried out right after their diagnosis before any training was provided to these children with DCD. Independent t-tests indicated no significant difference for age between children with DCD and healthy subjects (p = 0.554).

Table 3.1 Demographic data of subjects participated in *Phases I, II* and *III*

	No. of children		Mean age ± SD (yr.)	
	Control group	DCD group	Control group	DCD group
Phase I	14	16	7.3 ± 1.0	7.9 ± 0.5
Male	10	15	7.8 ± 1.0	7.9 ± 0.6
Female	4	1	6.6 ± 0.5	8.1
BOTMP score				
< 32		10		
32-37		5		
38-41		1		
Phase II	5	NA	10.6 ± 3.6	NA
Male	2	NA	11.0 ± 4.0	NA
Female	3	NA	10.0 ± 4.2	NA
Phase III	12	17	7.8 ± 0.6	8.1 ± 0.6
Male	9	14	7.5 ± 0.3	8.0 ± 0.6
Female	3	3	8.2 ± 0.4	7.8 ± 1.0
BOTMP score				
< 32		11		
32-37		4		
38-41		2		

3.3 Instrumentation

The main objective of the present study was to examine the response time and force output when performing a dynamic reach-and-grasp task in children with DCD. In order to increase the applicability of the study outcome, an instrument was developed to simulate a ball catching game. The task required subjects to grasp a target when it was in motion simulating a dynamic situation.

3.3.1 Phase I

There was a toy car weighed 180g. In some testing trials a weight of 160g was added in its trunk to increase its total weight to 340g. Initially, a spherical lens-cleaning pump was used as a grasp target to simulate a ball. It was mounted on top of the toy car and the children were instructed to grasp the pump. A pressure transducer, with an overall accuracy up to ± 5.7% was used to detect a change in pressure when the pump was grasped. It was found during pilot trials that some healthy children picked up the pump merely by applying frictional force against the cover of the pump since the cover was hard and thick. In addition there was a rim around the central part of the pump that would cause a variation in the recorded pressure according to site of force application. Subsequently a 4-inch diameter thin ball was used to replace the pump. The same pressure transducer was used to detect a change in pressure when the ball was grasped.   Figure 3.2 shows the initial setup.

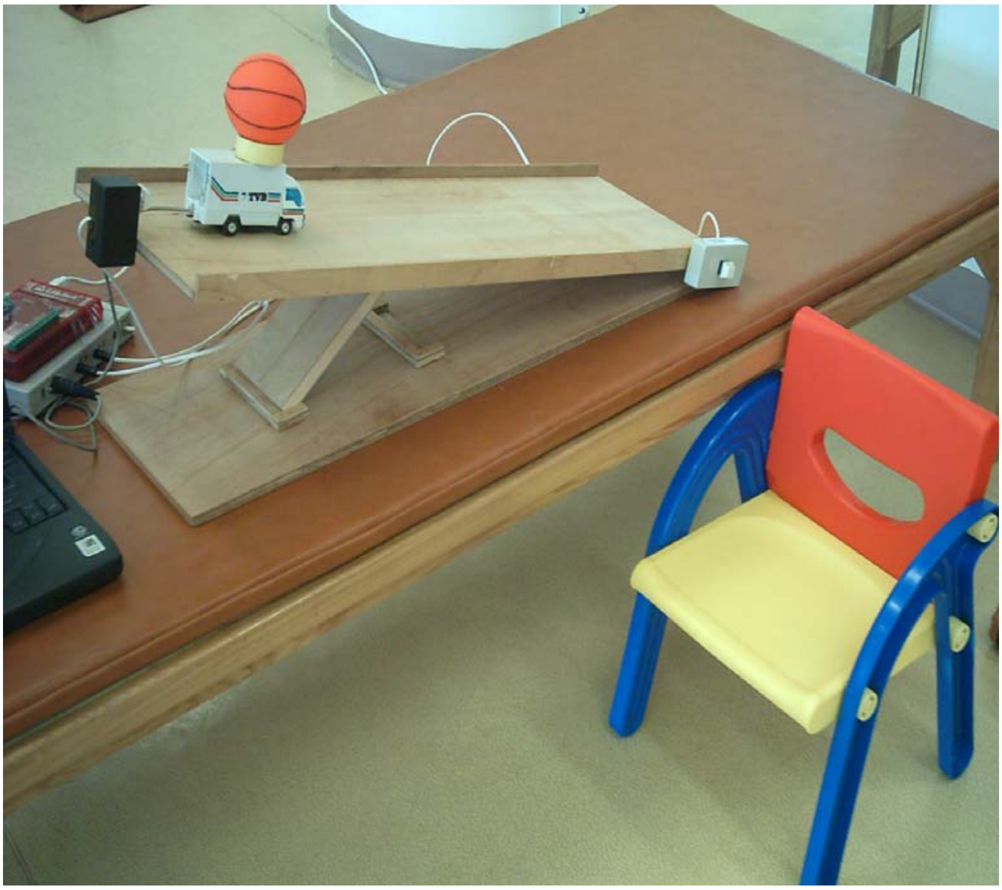


Figure 3.2 The initial setup in *Phase 1*. The slanted board had a button attached on its top against which the toy car was pressed against before it was allowed to slide down. Another button was attached on the bottom of the slanted board. The child was asked to press that bottom button with dominant thumb before the reaching-out action. The toy car had a 4” ball attached on its top. The chair with back support was located adjacent to the table.

To create a dynamic situation the toy car was allowed to slide down from a slanted board. The slanted board was built to have its slope adjustable between 15° and 25° to vary the speed of the toy car. A button was mounted on the top of the slanted board. The toy car was held by the investigator to press against that button. When the investigator opened the hand, the car would be released and slid down the slanted board. Another button was mounted on the bottom of the slanted board, against which the child initially had to press with his / her dominant thumb. The slanted board was supported on a low table of 45 centimeters high. A chair with back support of 26 centimeters high was placed adjacent to the low table for the child to sit on.

Reliability test was performed on RT, MT and peak pressure of control group in the reach-and-grasp task using this initial setup. The ICC values of the reliability test were not satisfactory partly because of the following instrumental problems:-

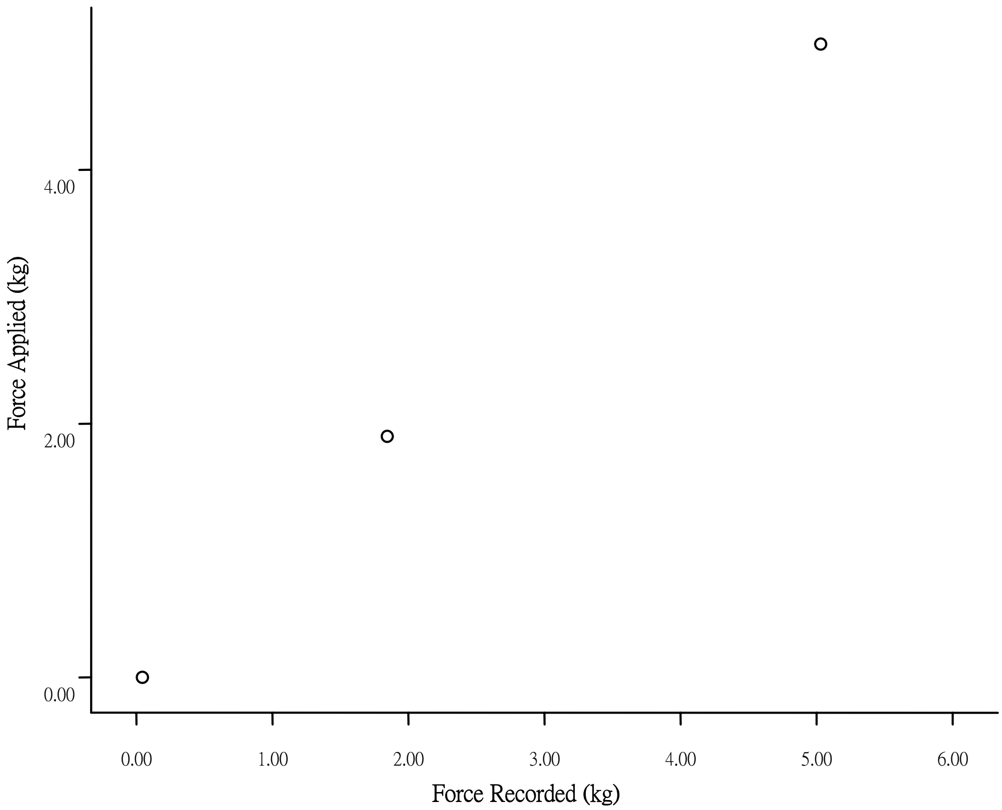
1. It was revealed during calibration that there was leakage at the attachment between the ball and the car. That greatly affected the reliability of data collected.
2. The wheels of the toy cars were found worn out and the sliding-down-speed of the toy cars was found inconsistent.

3.3.2 Phase II and III

In the final setup, a load cell that measured the applied force was used to replace the ball and the pressure transducer. The load cell was calibrated on 13th August 2004 by the supplier and was suggested by the supplier to be re-calibrated one year after. When it was calibrated on 28th April 2005, a consistent ratio between given force and measured force was recorded (Table 3.2). The accuracy was found to be above 95%. Pearson's product moment correlation coefficient was calculated to establish the correlation between applied force and recorded force, with $r = 1.000$ and $p = 0.014$, and that was considered to be satisfactory. The use of load cell improved the accuracy of data collection, and technically, a load cell was also easier than a ball to be attached to the toy car.

Table 3.2 Force recorded in calibration done in April 2005

Force applied (kg)	Force recorded (kg)	Error (%)
0	0.044	4.4
1.9	1.844	2.9
4.99	5.031	0.8



Because of the reasons explained in 3.3.1, a load cell was installed inside the trunk of the toy car to measure directly the grasp force applied by the child when picking up the toy car and to measure the time the applied force took to reach its peak value. Figure 3.3 shows the toy car with the load cell installed in the final instrumental setup. Furthermore, to eliminate the inconsistent sliding-down speed of the toy car discovered in *Phase I*, a track of linear bearing was mounted on the slanted surface. A plate was then mounted on the track to which the toy car was seated on. This plate allowed the toy car to slide down along the track with a consistent speed and pathway. After this track was made, the toy car was found sliding down on the slanted board with a much faster speed. To make it manageable for children with DCD, the adjustable angles of the slanted board was decreased from 15° and 25° to 8° and 15°. The reliability of this final setup was established in *Phase II*, and therefore this set up was used in the main study.

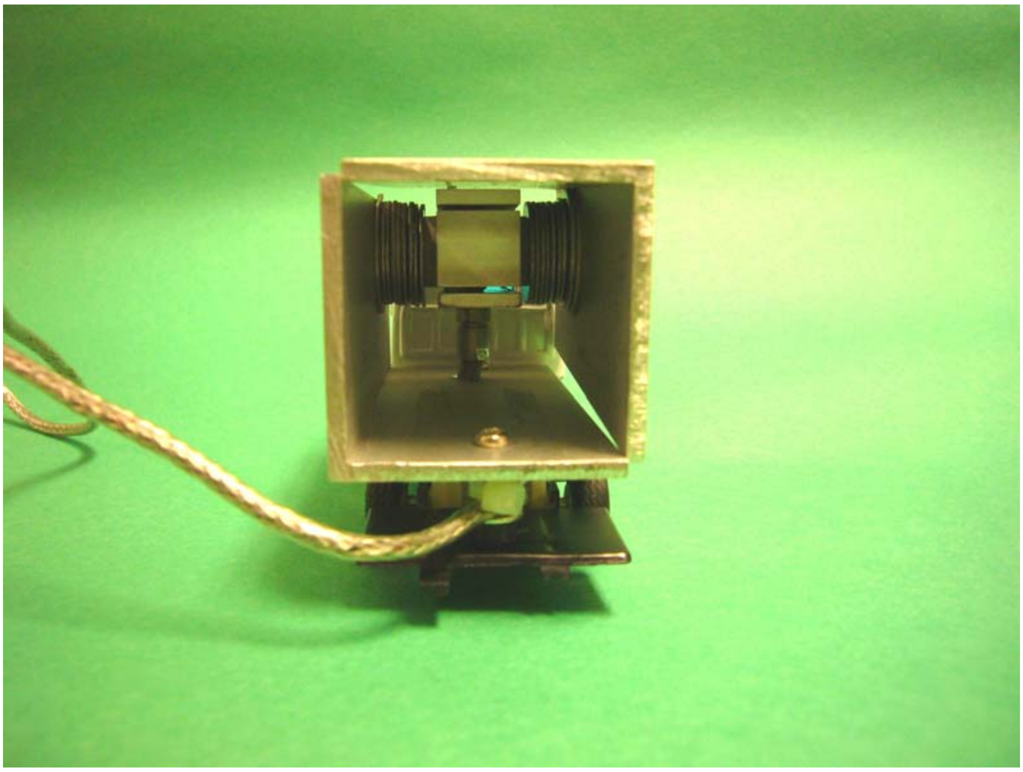


Figure 3.3 The toy car with load cell installed inside its trunk in the final instrumental setup.

3.4 Testing Procedures

The proposal of the study was reviewed and approved by the Department Research Committee of Rehabilitation Sciences, The Hong Kong Polytechnic University. The research study was also approved by the Consultant Paediatrician of Child Assessment Service, Department of Health. The personal particulars of these children were collected and informed consents (Appendix IV) were obtained from their parents prior to their participation in this study.

For the group of healthy children, the test trials were administered in a premise chosen by the children for their convenience. For the group of children with DCD, the test trials were carried out at two child assessment centres. The environmental factors of the testing areas, e.g. quietness and lighting, etc were controlled to be as similar as possible.

The hand dominance of these children was determined by asking them to perform an overhand throw. The hand used to throw was determined as the dominant hand (Bruininks, 1978). In case the children used either hand to throw, the hand that had better performance was determined as the dominant hand. When either hand performed similarly, the children were asked to show which hand they used to brush their teeth and to comb their hair. The hand used would be determined as the dominant hand (Bruininks, 1978). For consistent comparison, all children recruited in *Phase III* were having (R) hand as their dominant hand.

During the test, the child was seated on a chair of 26 centimeters high with back support. A low table of 45 centimeters high was placed next to the chair with the side of the table adjacent to the side of the child's dominant hand to ensure the best arm reaching performance. The slanted board was placed on the low table close to the child with the child facing the top end of the slanted board. Figure 3.4 shows the final instrumental setup. Figure 3.5 presents the sequence of the reach-and-grasp task in the main study.

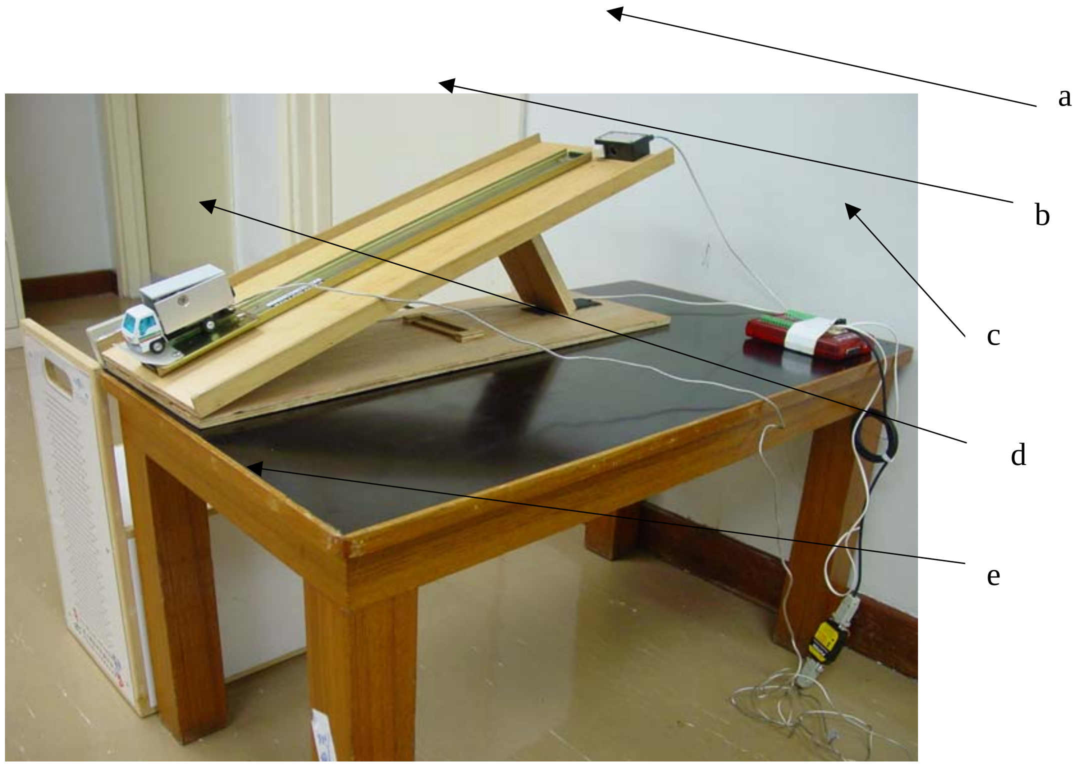
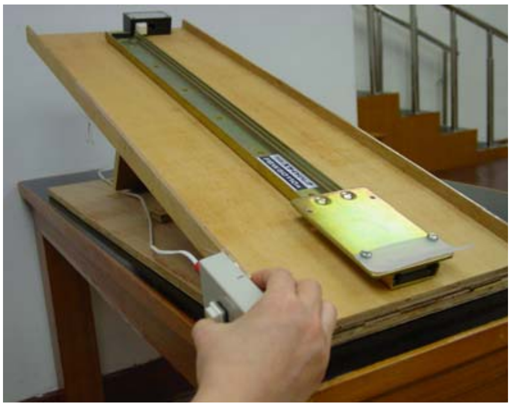
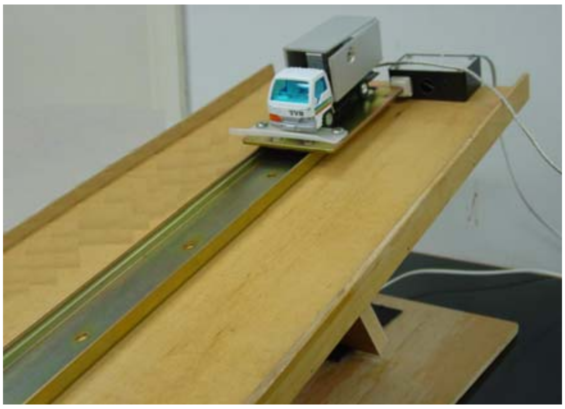


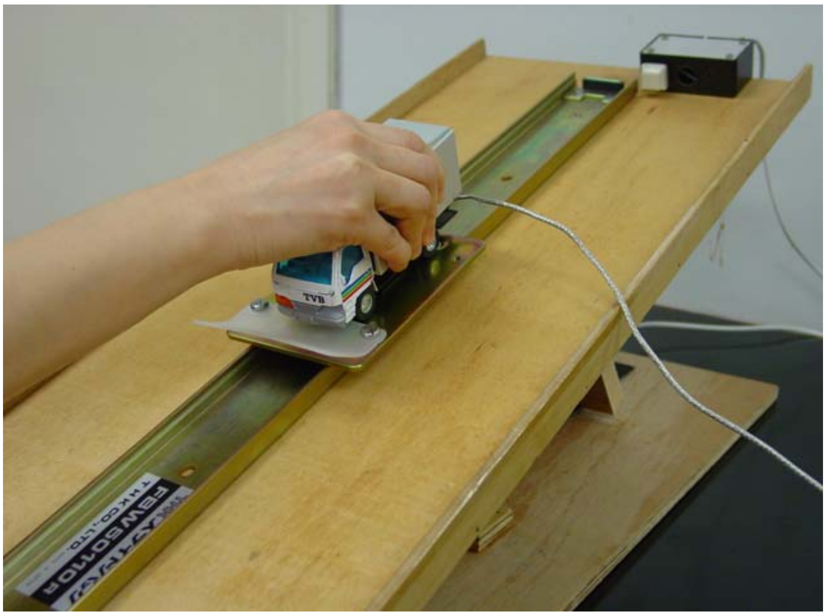
Figure 3.4 The final setup used in the main study showing the (a) top button, (b) linear bearing track, (c) programmable input-output controller, (d) plate which allowed the toy car to sit on, (e) chair with back support





a. Child held on to the bottom button with the dominant thumb.

b. The toy car, which was attached onto the plate, was held by the investigator's hand (not shown in the figure). The plate was pressed against the top button before it was allowed to slide down.



c. Once the child saw the toy car being allowed to slide down, he / she reached out the dominant hand to grasp the toy car.

Figure 3.5 The sequence of the reach-and-grasp task

3.4.1 Phase I

All subjects were instructed to perform a reach-and-grasp task in both static and dynamic manner. At the beginning of the test session, the child was shown how to grasp the ball attached to the top of the toy car in order to lift the toy car off the surface. The child was then asked to pick up each static toy car (180g and 340g) for 5 times in a randomized sequence. The pressure used to pick up the toy car was recorded as the baseline pressure used in a static condition.

For the dynamic test trials, the toy car was held by the investigator to press against the button mounted on the top of the slanted board. The child was asked to press the button that was mounted at the bottom of the slanted board with his / her dominant thumb. When the investigator opened the hand to let go the toy car, it started to slide down the slanted board. The child was instructed that once he / she saw the toy car sliding down the slanted board, he / she had to release his / her thumb from the bottom button, to reach that same arm forward and to grasp the ball that was attached on the top of the toy car in order to lift the toy car off the board as soon as possible. The toy car was allowed to slide down from the top of the slanted board in one of the following 4 conditions:-

W_0S_{15}: toy car with no weight added; slope of 15°

W_AS_{15}: toy car with weight added; slope of 15°

W_0S_{25}: toy car with no weight added; slope of 25°

W_AS_{25}: toy car with weight added; slope of 25°

The proper handgrip of picking up the toy car in a dynamic situation was demonstrated once. The children were allowed to practise once for each condition before test trials commenced. Each child was asked to perform 5 trials for each condition, with a total of 20 test trials. The sequence of the trials was randomized to eliminate the learning effect. The whole process took about 20 minutes. Children were reminded to pay full attention to the toy car before it was allowed to slide down to minimize inattentive effect. The control group repeated the test once within a period of 7 days for establishing the test-retest reliability of the testing procedure.

3.4.2 Phase II

Because of the reasons explained in 3.3.1, a load cell was attached inside the trunk of the toy car to measure the grasp force directly and the toy car was placed on the plate mounted on the linear bearing track. Every child was instructed to perform the reach-and-grasp task in both static and dynamic manner. Prior to the static test, the child was shown how to grasp the sides of the trunk of toy car in order to lift it off the surface. The child was then asked to pick up each static toy car (180g and 340g) for 5 times in a randomized sequence. The force used to pick up the toy car was recorded as the baseline force used in a static condition.

After the static test, the child was instructed to perform the dynamic reach-and-grasp task. At the beginning of each trial, the plate that supported the toy car was pressed against the button mounted on the top of an adjustable slanted board (of slope 8° and 15°) by the investigator until the investigator initiated the release. The child was instructed that once he / she saw the toy car sliding down the slanted board, he / she had to release his / her dominant thumb from the bottom button, to reach and grasp the sides of the trunk of the toy car with that same hand, and to lift the toy car off the board as soon as possible.

The slopes of the slanted board were decreased to an adjustable 8° or 15° because after the linear bearing track was attached on the slanted board, the toy car was found sliding down the slanted board with a much faster speed. To make it manageable for children with DCD, the adjustable angles of the slanted board was decreased from 15° & 25° to 8° & 15°. The toy car was slid down from the top of the linear bearing track on the slanted board in one of the following 4 conditions in a randomized manner:-

W_0S_8: toy car with no weight added; slope of 8°

W_AS_8: toy car with weight added; slope of 8°

W_0S_{15}: toy car with no weight added; slope of 15°

W_AS_{15}: toy car with weight added; slope of 15°

As it was reflected in *Phase I* that children with DCD had much higher failure rate in the last 4 of the 20 test trials, the 20 test trials were administered in 2 sessions with a resting period of 5 minutes in-between. The whole testing procedure was completed in about 25 minutes. The testing procedure was repeated once within a period of 7 days in healthy group to establish the test-retest reliability of the testing procedure.

3.4.3 Phase III

Every child was instructed to perform the reach-and-grasp task in both static and dynamic manner. The testing procedure was the same as that in *Phase II*.

3.5 Steps taken to ensure confidentiality of data

All information concerning subjects' identities and all data concerning their performance were kept in confidence. They were only accessible to the investigator of the study. Names of these children would not be disclosed in any published report.

3.6 Data reduction

A programmable input-output controller was used to capture the triggered signals during the course of the test trial. It was attached to the button on the top of the slanted board and the button on the bottom of the slanted board as well as to the load cell inside the trunk of the toy car to record the time taken and force applied during the performance of the reach-and-grasp task. Figure 3.6 shows the connections of the programmable input-output controller to the computer, the 2 buttons on the slanted board and the load cell inside the trunk of the toy car.

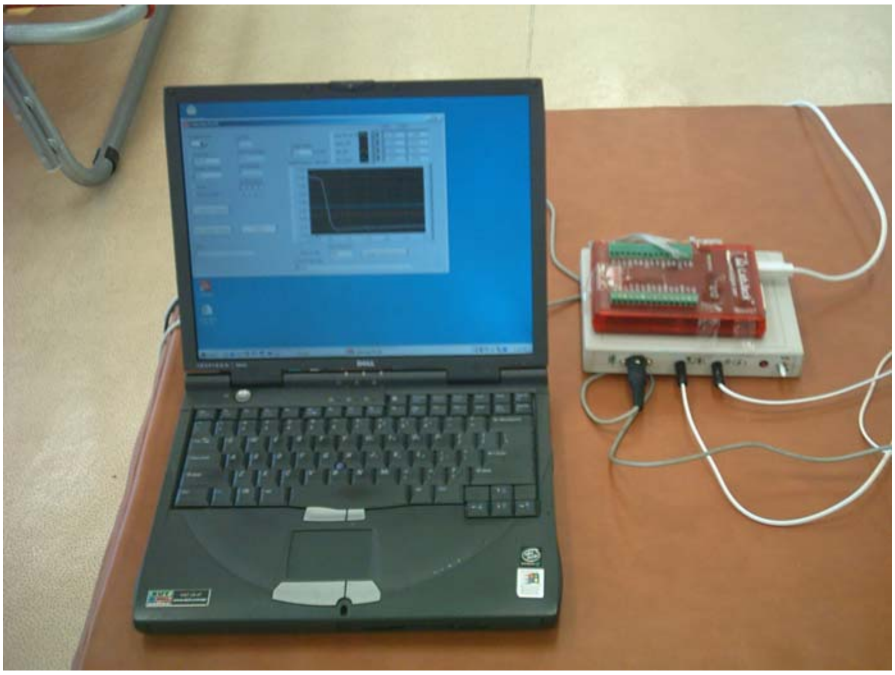


Figure 3.6 a. The programmable input-output controller was attached to the computer.

Figure 3.6 b. The programmable input-output controller was attached to the 2 buttons on the slanted board and the load cell in the trunk of the toy car.

3.6.1 Reaction time (RT) and movement time (MT)

The plate that supported the toy car was pressed against the button mounted on the top of the slanted board by the investigator until the investigator initiated the release. The instant of separation from the top button was registered as T_0. The instant at which the dominant thumb of the child left the bottom button on the slanted board was registered as T_1. The instant at which the force registered by the load cell increased to a value that exceeded 2 standard deviations of the baseline force, denoting the initial force generated by the child at the beginning of the grasp, was registered as T_2. The instant at which the force registered by the load cell reached its peak value was registered as T_3.

T_0	=	car off time
T_1	=	thumb off time
T_2	=	time recorded when the force equal to baseline force plus 2 SD
T_3	=	time recorded at peak force
T_1 - T_0	=	RT (time required to plan an action after perceiving information from external stimuli)
	=	the time period from the instant the toy car started to slide down the slanted board till the instant the child released the bottom button to initiate a grasping action of the toy car
T_3 - T_1	=	MT (time required to execute the planned reach-and-grasp action)
	=	the time period from the instant the child released the bottom button to initiate a grasping action of the toy car until the instant the grasp of the toy car was secured

T_2- T_1	=	reach time (time required to reach out to initially grasp the toy car)
	=	the time period from the instant the child released the bottom button to initiate a grasping action, i.e., child generated a grip force of baseline force plus 2 standard deviations
T_3- T_2	=	grasp time (time required to secure the grasp of the toy car)
	=	the time period from the instant the child generated an initial force to the instant that the child generated the peak force to secure the grasp of the toy car

3.6.2 Peak force (PF) and rate of force production

The mean value of 100 force data registered by the load cell before T_1 was registered as the baseline force, F_1. The force generated at T_2 was registered as F_2, which denoted the initial force that the children exerted at the beginning of the grasp. The force generated at T_3 was registered as F_3, which denoted the peak force children exerted to secure the grasp of the toy car. Figure 3.7 summarizes the RT, MT and PF measurements.

F_1	=	baseline force
F_2	=	baseline force plus 2 SD
	=	the initial force
F_3	=	PF
F_3 - F_2	=	difference between peak and initial force
$(F_3-F_2) / (T_3-T_2)$	=	rate of force production

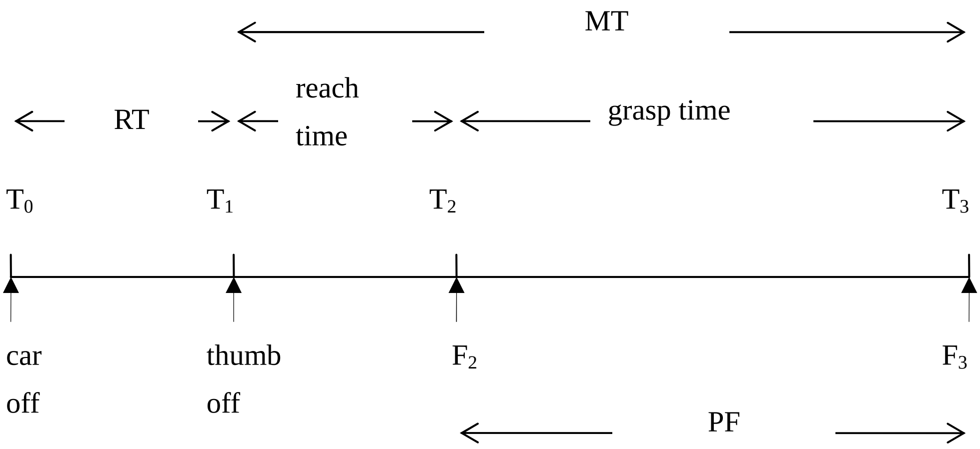


Figure 3.7 Summary of RT, MT and PF

3.7 Data analysis

In order to test the reliability of the testing procedure using the instrumental setup, the data collected in *Phase 1* for the initial setup, and *Phase 2* for the final setup were analyzed using ‘two way mixed model’ intraclass correlation coefficients (ICC) with respect to their reaction time, movement time and peak force. The reliability of the setup was considered satisfactory if the ICCs of the data collected were above 0.75 (Portney, 2000).

For the main study, the failure rate and reasons for failure performance were analyzed by descriptive method (Fig. 4.1 & 4.2). Variables including RT, MT, PF and rate of force production were analyzed using a two way repeated measures analysis of variance (ANOVA) with the group (DCD and control) as the 'between' factor, and weight (no-weight-added and weight-added) and slope (8° and 15°) as 'within' factors. When an interaction was found, post hoc t-test was used to determine the real difference after stratification. Pearson product-moment correlation coefficient was calculated to establish the correlation between different variables. Within-subject standard deviation was calculated to investigate the variation in the performance of subjects. A significance level of 0.05 was employed for all analyses.

Chapter 4 Results

4.1 Reliability test of Phase I: the instrument and testing procedure for the Initial setup

Fourteen healthy children participated in the test-retest reliability test. Table 4.1 shows the 'two way mixed model' ICC values of RT, MT and peak pressure for healthy children performing the reach-and-grasp task using the initial setup. The ICC values for RT for conditions W_0S_{15}, W_AS_{15} and W_0S_{25} were very small or even negative. The ICC values for MT ranged from 0.820 to 0.943 in all four conditions. The ICC values for peak pressure were above 0.84 in conditions W_0S_{15} and W_AS_{15}. However, the ICC values for peak pressure were 0.726 and 0.565 respectively in conditions W_AS_{25} and W_0S_{25}, which were lower than satisfactory (Portney, 2000). Since some ICC values were lower than 0.75, the initial setup could not be considered as reliable. Therefore a few modifications were made in the instrument and the testing procedures.

Table 4.1 Two way mixed model ICC values of RT, MT and peak pressure for the reach-and-grasp task in Phase I

	W_0S_{15}	W_AS_{15}	W_0S_{25}	W_AS_{25}
Reaction time	0.061	-1.078	-1.770	0.843
Movement time	0.889	0.912	0.820	0.943
Peak pressure	0.882	0.842	0.565	0.726

ICC = Intraclass Correlation coefficient

W_0S_{15} = toy car with no weight added, slope of 15°

W_AS_{15} = toy car with weight added, slope of 15°

W_0S_{25} = toy car with no weight added, slope of 25°

W_AS_{25} = toy car with weight added, slope of 25°

4.2 Reliability test of Phase II: the instrument and testing procedure for the final setup

In *Phase II* a loadcell, that measured the applied force directly, was used to improve the accuracy of data collection. A track of linear bearing was mounted on the slanted surface to maintain a consistent speed and pathway for the sliding-down toy car. The adjustable angles of the slanted board were decreased to 8° and 15° to make it manageable for children with DCD. Finally, 5 healthy children with a larger age range were recruited for the reliability test. Table 3.2 shows the ICC values of RT, MT and Peak force (PF) for healthy children during performance of the reach-and-grasp task using the final setup of instrument. For all testing conditions, the ICC values for RT ranged from 0.838 to 0.967. The ICC values for MT ranged from 0.880 to 0.972, and those of the PF ranged from 0.958 to 0.973.

Since all ICC values were well above 0.75 that was used as an indicative value of good reliability (Portney, 2000), the reliability of the final setup of instrument and testing procedure was established. The final setup was used in *Phase III*, the main study, to investigate the difference between DCD group and control group in force control and response time.

Table 4.2 Two way mixed model ICC values of RT, MT and PF in the reach-and-grasp task in Phase II

	Static condition		Dynamic condition			
	W_0	W_A	W_0S_8	W_AS_8	W_0S_{15}	W_AS_{15}
RT	-	-	0.838	0.956	0.875	0.967
MT	-	-	0.928	0.893	0.972	0.880
PF	0.959	0.953	0.967	0.967	0.958	0.973

ICC = Intraclass Correlation coefficient

W_0 = toy car with no weight added

W_A = toy car with weight added

W_0S_8 = toy car with no weight added, slope of 8°

W_AS_8 = toy car with weight added, slope of 8°

W_0S_{15} = toy car with no weight added, slope of 15°

W_AS_{15} = toy car with weight added, slope of 15°

4.3 Main study

4.3.1 Sliding speed of car in each condition

Table 4.3 shows the maximum speed of the toy car in each condition. The maximum speed in each condition was measured at the instant when the toy car reached the bottom of the slanted board. The highest speed was in condition W_AS_{15} and the slowest speed was in condition W_AS_8. This further indicated that within a constant slope, there was only a small change in speed with respect to a variation in the weight of the toy car. On the other hand, the change in speed was more obvious with a change in slope when the weight of the toy car being kept constant.

Table 4.3 Maximum speed of toy car in each condition

	Top speed (m/s)
W_0S_8	0.890
W_0S_{15}	1.075
W_AS_8	0.771
W_AS_{15}	1.112

W_0S_8 = toy car with no weight added, slope of 8°

W_AS_8 = toy car with weight added, slope of 8°

W_0S_{15} = toy car with no weight added, slope of 15°

W_AS_{15} = toy car with weight added, slope of 15°

4.3.2 Failed trials

All healthy children in the control group managed to grasp the toy car in all 240 trials of their group (12 children x 4 conditions x 5 trials for each condition). On the contrary, DCD group had a high rate of failed grasp. They failed in 118 out of the total 340 trials, i.e. 34.7% of the trials (17 children x 4 conditions x 5 trials for each condition).

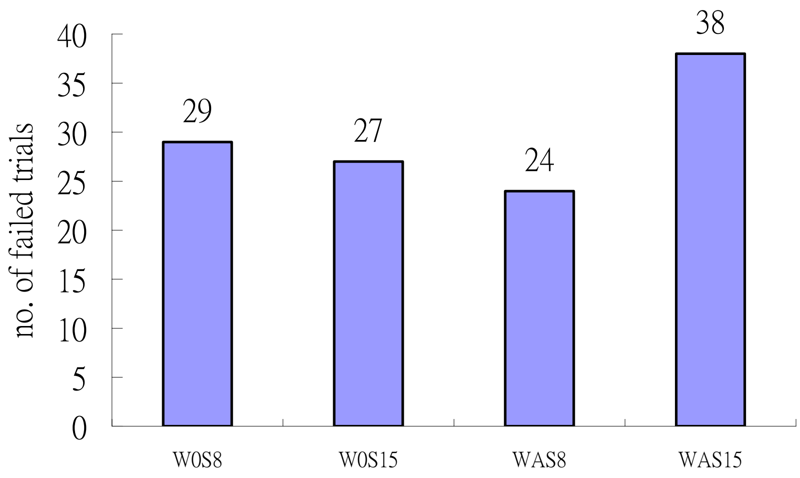


Figure 4.1 No. of failed grasp in each condition by DCD group

(85 test trials in each condition)

Figure 4.1 shows the number of failed grasp in each condition in the DCD group. The highest failure rate was found in condition W_AS_{15}, i.e., 38 out of 85 trials (44.7%). In this condition, the toy car was slid down the slanted board with its maximum speed at 1.112 m/s (Table 4.3). This speed was the highest among all the four conditions. The failure rate was the lowest in condition W_AS_8, i.e., 24 out of 85 trials. This condition had the lowest maximum speed, 0.771 m/s, among the four conditions.

Between the two conditions of steepest slope, W_0S_{15} and W_AS_{15}, although there was only minimal difference in the speed of the car, with weight added, the failure incidence was greatly increased from 27 to 38 out of 85 trials. On the contrary, between the two conditions of gentle slope, W_0S_8 and W_AS_8, with weight added, the failure incidence decreased from 29 to 24 out of 85 trials.

4.3.2.1 Reasons for failed grasps

Figure 4.2 shows the reasons for failed grasp in DCD group for the 4 conditions. According to the observations, children with DCD failed to grasp the toy car due to the following reasons:

1. Child was not pressing the ‘start” button before reaching out to pick up the toy car, hence the starting time of the movement could not be recorded.

2. Child did not reach hand out at all to reach for the sliding toy car.

3. Child could not reach the toy car before it ran off the board.

4. Child used wrong hand to pick up the toy car.

5. Child pressed down the toy car to stop it but did not pick it up as instructed.

6. Child picked up the toy car but could not grasp it at the designated spot as instructed.

7. Child dropped the toy car after picking it up.

The most common reason for failed grasp was ‘6’ - Picked the toy car up at the wrong spot (45 out of 118). The second common reason was ‘3’ - Toy car ran off the board (34 out of 118) and the third one was ‘5’ - Pressed down the toy car to stop it but did not pick it up as instructed (19 out of 118). In only 4 out of 118 failed trials, children with DCD failed to secure the grasp by dropping it (Figure 4.2).

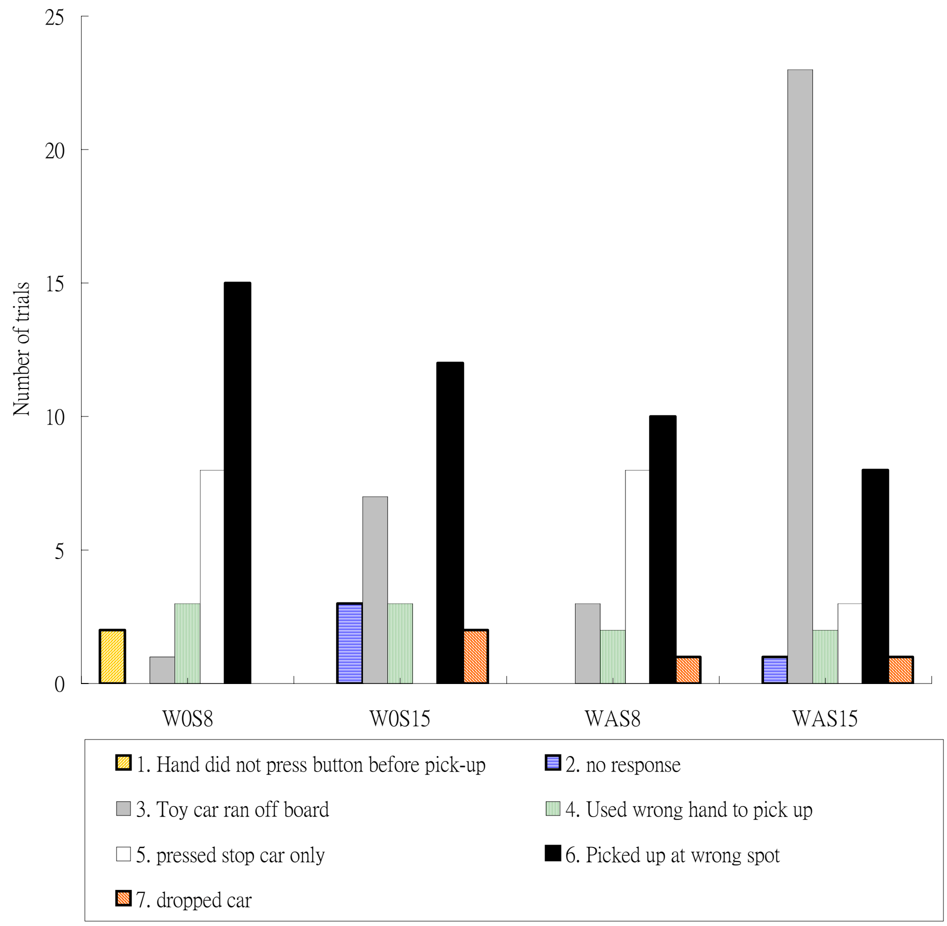


Figure 4.2 Reasons for failed grasp in DCD group (total: 118 failed trials)

In the fastest condition W_AS_{15}, the main reason of failure was ‘3’ - Toy car ran off the board before child could reach it. The second common reason was ‘6’ - Picked the toy car up at the wrong spot. The opposite occurred in the slowest condition W_AS_8, the most common reason was ‘6’ - Picked the toy car up at the wrong spot’. The second common reason was ‘3’ - Toy car ran off the board before child could reach it.

4.3.3 Successful trials

4.3.3.1 Within-subject variability

The variation of performance of each subject in each condition was reflected by the within-subject standard deviation. The within-subject standard deviation was divided by the group mean to show the within-subject variability. Table 4.4 shows the means, within-subject standard deviation and the within-subject variability of RT, MT, and PF between control group and DCD group for the 4 conditions.

Regarding RT, there were only small differences in within-subject variability between the two groups. DCD group had higher variation than control group except in the 2 conditions with no added weight, W_0S_8 and W_0S_{15}. Regarding MT, DCD group had higher within-subject variability than control group in all 4 conditions. The largest difference was found in the fastest condition W_AS_{15}, with the within-subject variability of DCD group being 2.75 times of that of the control group. Regarding PF, only small differences in within-subject variability were detected between the two groups. DCD group had lower within-subject variability than control group in all 4 conditions.

Table 4.4 Mean, within-subject SD and within-subject variability of RT, MT and PF of control group and DCD group for the 4 conditions

	Control			DCD		
	Mean	Within - subject SD	Within-subject variability (%)	Mean	Within - subject SD	Within-subject variability (%)
Reaction time (ms)						
W_0S_8	284.7	80.3	28%	331.2	73.5	22%
W_AS_8	283.3	52.9	19%	327.5	78.8	24%
W_0S_{15}	281.7	61.1	22%	300.6	57.2	19%
W_AS_{15}	287.5	72.3	25%	321.6	96.5	30%
Movement time (ms)						
W_0S_8	578.5	111.6	19%	677.1	259.1	38%
W_AS_8	591.5	223.1	38%	796.6	389.1	49%
W_0S_{15}	469.5	61.3	13%	545.5	127.5	23%
W_AS_{15}	495.8	99.7	20%	512.1	279.4	55%
Peak force (N)						
W_0S_8	11.96	4.80	40%	16.86	5.19	31%
W_AS_8	12.84	4.70	37%	18.23	5.98	33%
W_0S_{15}	16.07	5.19	32%	20.48	5.10	25%
W_AS_{15}	15.48	5.29	34%	19.21	5.49	29%

W_0S_8 = toy car with no weight added, slope of 8°

W_AS_8 = toy car with weight added, slope of 8°

W_0S_{15} = toy car with no weight added, slope of 15°

W_AS_{15} = toy car with weight added, slope of 15°

4.3.3.2 Reaction time (RT)

Table 4.5 shows the comparison of RT between control group and DCD group in all 4 conditions. Children with DCD were found to use a significantly longer RT than healthy children by 18.9 ms to 46.5 ms in all conditions ($p = 0.036$). Within each group, there was no significant change in their RT with regard to factor ‘weight’ or ‘slope’ among the 4 conditions.

Table 4.5 Comparison of RT between control group and DCD group in all 4 conditions

RT (ms)	Control	DCD	Between-group p value
W_0S_8	284.7 ± 63.9	331.2 ± 60.9	0.036*
W_AS_8	283.3 ± 41.6	327.5 ± 45.7	0.036*
W_0S_{15}	281.7 ± 45.9	300. 6 ± 36.4	0.036*
W_AS_{15}	287.5 ± 48.7	321.6 ± 65.6	0.036*
Within-group p value			
Weight	0.444	0.444	
Slope	0.154	0.154	

Values shown are means ± standard deviations

W_0S_8 = toy car with no weight added, slope of 8°
W_AS_8 = toy car with weight added, slope of 8°
W_0S_{15} = toy car with no weight added, slope of 15°
W_AS_{15} = toy car with weight added, slope of 15°

* p <0.05

Interaction
weight x group $F_{(1,24)} = 0.184$, $p = 0.672$
slope x group $F_{(1,24)} = 2.385$, $p = 0.136$
weight x slope x group $F_{(1,24)} = 0.223$, $p = 0.641$

Within-group difference
weight $F_{(1,72)} = 0.605$, $p = 0.444$
slope $F_{(1,72)} = 2.164$, $p = 0.154$

Between-group difference $F_{(1,24)} = 4.914$, $p = 0.036$

4.3.3.3 Movement time (MT)

Children with DCD tended to use a longer MT than healthy children by 16.3 ms to 205.1 ms, but these differences did not reach a significant level (Table 4.6). Within each group, there was no significant change in their MT with regard to the factor 'weight'. However, significant difference was found in MT among the 4 conditions for the factor 'slope'. With an increase in angle of the slope, there was a significant reduction in MT within each group (p = 0.011). When the slope was increased from 8° to 15°, healthy children shortened their MT by 18.8% and children with DCD by 19.4% in W_0 conditions. For W_A conditions, healthy children shortened their MT by 16.2% and children with DCD by 35.7%.

Table 4.6 Comparison of MT between control group and DCD group in all 4 conditions

MT (ms)	Control	DCD	Between-group *p* value
W_0S_8	578.5 ± 72.3	677.1 ± 300.8	0.091
W_AS_8	591.5 ± 153.1	796.6 ± 646.4	0.091
W_0S_{15}	469.5 ± 46.7	545.5 ± 68.3	0.091
W_AS_{15}	495.8 ± 48.8	512.1 ± 117.8	0.091
Within-group *p* value			
weight	0.487	0.487	
Slope	0.011*	0.011*	

Values shown are means ± standard deviations

W_0S_8 = toy car with no weight added, slope of 8°
W_AS_8 = toy car with weight added, slope of 8°
W_0S_{15} = toy car with no weight added, slope of 15°
W_AS_{15} = toy car with weight added, slope of 15°

* $p < 0.05$

Interaction	
weight x group	$F_{(1,26)} = 0.090$, $p = 0.766$
slope x group	$F_{(1,26)} = 1.048$, $p = 0.316$
weight x slope x group	$F_{(1,26)} = 0.614$, $p = 0.441$
Within-group difference	
weight	$F_{(1,35)} = 0.498$, $p = 0.487$
slope	$F_{(1,35)} = 7.644$, $p = 0.011$
Between-group difference	$F_{(1, 26)} = 3.092$; $p = 0.091$

4.3.3.4 Reach Time

The MT was further divided into reach and grasp time. ‘Reach Time’ measured the duration between the child’s letting go of the button to reach out and the instant of initial contact with the toy car. Results showed no significant difference between control group and DCD group in their ‘reach time’ (Table 4.7). Within each group, there was no significant change in their ‘reach time’ with regard to the factor ‘weight’. However, significant difference was found in reach time among the 4 conditions for the factor ‘slope’ (p = 0.000). With an increase in angle of the slope, there was a significant reduction in ‘reach time’ within each group. For W_0 conditions, healthy children shortened their ‘reach time’ by 22.7% and children with DCD by 18.4% when the slope was increased from 8° to 15°. For W_A conditions, healthy children shortened their ‘reach time’ by 10.7% and children with DCD by 16.5% when the slope was increased from 8° to 15°.

Table 4.7 Comparison of 'reach time' between control group and DCD group in all 4 conditions

Reach Time (ms)	Control	DCD	Between-group *p* value
W_0S_8	401.2 ± 68.4	406.6 ± 68.9	0.682
W_AS_8	390.5 ± 475.4	369.8 ± 44.3	0.682
W_0S_{15}	310.0 ± 32.3	331.9 ± 46.9	0.682
W_AS_{15}	348.8 ± 79.4	309.1 ± 44.1	0.682
Within-group *p* value			
weight	0.112	0.112	
Slope	0.000**	0.000**	

Values shown are means ± standard deviations

W_0S_8 = toy car with no weight added, slope of 8°
W_AS_8 = toy car with weight added, slope of 8°
W_0S_{15} = toy car with no weight added, slope of 15°
W_AS_{15} = toy car with weight added, slope of 15°

** p <0.01

Interaction	
weight x group	$F_{(1,24)} = 18.790$, $p = 0.168$
slope x group	$F_{(1,24)} = 0.000$, $p = 0.997$
weight x slope x group	$F_{(1,24)} = 0.506$, $p = 0.484$
Within-group difference	
weight	$F_{(1,24)} = 2.722$, $p = 0.112$
slope	$F_{(1,24)} = 118.091$, $p = 0.000$**
Between-group difference	$F_{(1, 24)} = 0.172$, $p = 0.682$

4.3.3.5 Grasp Time

Table 4.8 shows the comparison of ‘grasp time’ between control group and DCD group in all 4 conditions. ‘Grasp time’ measured the duration between the moment of initial contact with the toy car and the instant when the peak force was reached and the grasp was secured. Children with DCD tended to use a longer ‘grasp time’ than healthy children (by 12.8 ms to 55.6 ms). However those differences did not reach a significant level. Within each group, there was no significant change in their ‘grasp time’ with regard to the factors ‘weight’ or ‘slope’ among the 4 conditions.

Table 4.8 Comparison of 'grasp time' between control group and DCD group in all 4 conditions

Grasp Time (ms)	Control	DCD	Between-group *p* value
W_0S_8	177.3 ± 28.5	216.5 ± 176.4	0.089
W_AS_8	201.0 ± 120.2	216.8 ±105.7	0.089
W_0S_{15}	159.5 ± 21.1	213.7 ± 71.6	0.089
W_AS_{15}	147.3 ± 60.2	202.9 ± 128.6	0.089
Within-group *p* value			
weight	0.396	0.396	
Slope	0.127	0.127	

Values shown are means ± standard deviations

W_0S_8 = toy car with no weight added, slope of 8°
W_AS_8 = toy car with weight added, slope of 8°
W_0S_{15} = toy car with no weight added, slope of 15°
W_AS_{15} = toy car with weight added, slope of 15°

Interaction	
weight x group	$F_{(1,24)} = 0.524, p = 0.476$
slope x group	$F_{(1,24)} = 1.073, p = 0.311$
weight x slope x group	$F_{(1,24)} = 0.377, p = 0.545$
Within-group difference	
weight	$F_{(1,24)} = 0.747, p = 0.396$
slope	$F_{(1,24)} = 2.500, p = 0.127$
Between-group difference	$F_{(1, 24)} = 3.145, p = 0.089$

4.3.3.6 Peak Force

Table 4.9 shows the comparison of PF between control group and DCD group when grasping a static toy car. Even when grasping a static toy car, children with DCD tended to use a force greater than healthy children although those differences did not reach a significant level. A larger between-group difference was detected when grasping a lighter toy car. DCD group exerted a larger force than the control group by 44.8% and 37.5% respectively for W_0 and W_A conditions.

In performing a dynamic reach-and-grasp task, children with DCD were found to use significantly greater PF than healthy children (by 3.72 N to 5.39 N $p = 0.002$, Table 4.9). Within each group, there was no significant change in their PF with the factor ‘weight’ but significant change was found in their PF with the factor ‘slope’. With an increase in angle of the slope, there was a significant increase in PF within each group ($p = 0.001$). In W_0 conditions, healthy children increased their PF by 34.4% and children with DCD by 21.5% when the slope was increased from 8° to 15°. In W_A conditions, healthy children increased their PF by 20.6% and children with DCD by 5.3% when the slope was increased from 8° to 15°.

Table 4.9 Comparison of PF between control group and DCD group in static conditions and the 4 conditions

PF (N)	Control	DCD	Between-group *p* value
Static conditions			
W_0	6.57 ± 4.9	9.51 ± 3.92	0.087
W_A	8.62 ± 4.02	11.86 ± 7.15	0.166
Dynamic conditions			
W_0S_8	11.96 ± 3.82	16.86 ± 3.92	0.002*
W_AS_8	12.84 ± 3.63	18.23 ± 4.80	0.002*
W_0S_{15}	16.07 ± 3.43	20.48 ± 3.23	0.002*
W_AS_{15}	15.48 ± 4.41	19.21 ± 4.02	0.002*
Within-group *p* value			
weight	0.677	0.677	
Slope	0.001*	0.001*	

Values shown are means ± standard deviations

W_0 = toy car with no weight added
W_A = toy car with weight added
W_0S_8 = toy car with no weight added, slope of 8°
W_AS_8 = toy car with weight added, slope of 8°
W_0S_{15} = toy car with no weight added, slope of 15°
W_AS_{15} = toy car with weight added, slope of 15°

* p <0.01

Interaction	
weight x group	$F_{(1,26)} = 0.017$, $p = 0.896$
slope x group	$F_{(1,26)} = 0.379$, $p = 0.544$
weight x slope x group	$F_{(1,26)} = 0.815$, $p = 0.376$
Within-group difference	
weight	$F_{(1,35)} = 0.178$, $p = 0.677$
slope	$F_{(1,35)} = 15.892$, $p = 0.001$
Between-group difference	$F_{(1, 26)} = 11.585$; $p = 0.002$

4.3.3.7 Rate of force production

Table 4.10 shows the comparison of rate of force production between control group and DCD group in all 4 conditions. To succeed the grasp, children with DCD had to perform with a faster rate of force production than healthy children by 15 to 108.58 N/s. However those differences did not reach a statistically significant level. DCD group also performed with a larger standard deviation in rate of force production especially in the fastest condition W_AS_{15}. Within each group, there was no significant change in their rate of force production with regard to the factor 'weight'. When the slope increased, there was a trend of increase in rate of force production within each group (p = 0.065). In W_0 conditions, healthy children increased their rate of force production by 46.6% and children with DCD by 28.4% when the slope was increased from 8° to 15°. In W_A conditions, healthy children increased their rate of force production by 58.9% and children with DCD by 138.1% when the slope was increased from 8° to 15°.

Table 4.10 Comparison of rate of force production between control group and DCD group in all 4 conditions

Rate of force production (N/s)	Control	DCD	Between-group *p* value
W_0S_8	69.78 ± 27.44	91.34 ± 44.69	0.267
W_AS_8	74.58 ± 29.89	95.35 ± 7.18	0.267
W_0S_{15}	102.31 ± 25.77	117.31 ± 84.28	0.267
W_AS_{15}	118.48 ± 51.06	227.07 ± 436.30	0.267
Within-group *p* value			
Weight	0.314	0.314	
Slope	0.065	0.065	

Values shown are means ± standard deviations

W_0S_8 = toy car with no weight added, slope of 8°
W_AS_8 = toy car with weight added, slope of 8°
W_0S_{15} = toy car with no weight added, slope of 15°
W_AS_{15} = toy car with weight added, slope of 15°

Interaction	
weight x group	$F_{(1,24)} = 0.523$, $p = 0.476$
slope x group	$F_{(1,24)} = 0.571$, $p = 0.457$
weight x slope x group	$F_{(1,24)} = 0.652$, $p = 0.427$
Within-group difference	
weight	$F_{(1,24)} = 1.058$, $p = 0.314$
slope	$F_{(1, 24)} = 3.744$; $p = 0.065$
Between-group difference	$F_{(1,24)} = 1.290$, $p = 0.267$

4.3.3.8 Correlation among MT, PF and rate of force production

There was no significant correlation between MT and PF used in either group (Table 4.11). For control group, there was moderate to good inverse correlation between MT and rate of force production in all conditions except W_0S_{15}. For DCD group, there was moderate to good inverse correlation between MT and rate of force production in all conditions except W_AS_{15}. The inverse correlation implies that with a decreased MT, there was a significant increase in the rate of force production.

Table 4.11 Correlation among MT, PF and rate of force production in control group and DCD group

	ICC			
	PF		Rate of force production	
	Control	DCD	Control	DCD
MT				
W_0S_8	-0.486	-0.307	-0.586	-0.724
	(0.109)	(0.230)	(0.045*)	(0.001**)
W_AS_8	-0.120	0.370	-0.664	-0.517
	(0.710)	(0.143)	(0.019*)	(0.034*)
W_0S_{15}	-0.063	0.169	-0.474	-0.815
	(0.845)	(0.531)	(0.120)	(0.000**)
W_AS_{15}	0.027	-0.070	-0.718	-0.514
	(0.934)	(0.805)	(0.009**)	(0.050)

* $p < 0.05$ ** $p < 0.01$

4.4 Summary

The final setup of instrument and testing procedure was proven to be reliable for measuring RT, MT and PF in the reach-and-grasp task. The ICC values ranged from 0.838 to 0.967 for RT, ranged from 0.880 to 0.972 for MT and ranged from 0.958 to 0.973 for PF.

All healthy children successfully performed the reach-and-grasp task in all 240 trials. Children with DCD failed 118 out of the total 340 test trials. They had the lowest failure rate in condition W_AS_8 (24 out of 85 trials) and highest failure rate in the fastest condition W_AS_{15} (38 out of 85 trials). The most common reasons for the failed trials were ‘Child picked the toy car up at the wrong spot’, followed by ‘Toy car ran off the board’ and ‘Child pressed down the toy car to stop it but did not pick it up as instructed’.

DCD group had similar within-subject variability as those of control group in RT and PF. However, they had much higher variability than those of control group in MT in all 4 conditions.

Children with DCD took a significantly longer RT than healthy children in all conditions. Within each group, there was no significant adjustment in their RT among the 4 conditions.

Children with DCD tended to use a longer MT than healthy children. However, that difference did not reach a significant level. Within each group, there was a significant decrease in MT when the slope was increased. When MT was split into ‘reach time’ and ‘grasp time’, no significant difference was found between the two groups in their ‘reach time’. But within each group, there was a significant decrease in ‘reach time’ when the slope was increased. Children with DCD tended to use a longer ‘grasp time’ than healthy children, although that difference did not reach a significant level. Within each group, there was no significant change in ‘grasp time’ with regard to change in ‘weight’ and ‘slope’.

When children were instructed to grasp a static toy car, children with DCD used a force greater than that of healthy children although the difference did not reach a significant level. DCD children used a significantly greater PF than healthy children to grasp the moving toy car. Within each group, when the slope was increased, there was a significant increase in the PF.

For the rate of force production there was no significant difference between control group and DCD group. Within each group, there was a trend of increase in rate of force production when the slope was increased.

In both control group and DCD group, MT was inversely correlated to their rate of force production. For control group, the correlations reached significant levels except in the condition W_0S_{15}. For DCD group, the correlations reached significant levels except in the fastest condition W_AS_{15}.

Chapter 5 Discussions

5.1 Characteristics of subjects

The 17 children recruited for DCD group in the main study were diagnosed with DCD by Hong Kong Child Assessment Service (Department of Health) using the cut-off point of less than 42 in the ‘gross motor composite standard score’ of BOTMP (Crawford et al., 2001). Eleven of them had scores below 32, i.e. in the lowest 4 percentiles with very poor gross motor coordination, 4 of them had scores between 32 and 37, i.e. in the 5-11 percentiles with poor gross motor coordination, and 2 of them had scores between 38 and 41, i.e. in 12-22 percentiles with below average gross motor coordination (Bruininks, 1978). In addition to the scores obtained by this standardized test, all these children were reported to have gross motor functional problems (APA, 1994) as indicated on the CAS-DCD Functional Checklist (Appendix III). Since the majority of children recruited for the DCD group, i.e. 11 out of 17, had very poor gross motor coordination, the findings of this study could be applied to those children with DCD of severe level. The age group of 7 to 8 was selected since this was the age group commonly referred for physiotherapy assessment and rehabilitation planning in HKCAS. The age of children recruited in previous studies varied but were mostly within the range from 6 to 9 years old (Henderson et al., 1992;

Williams et al., 1992; Symth, 1996; Raynor, 1998; Pitcher et al., 2002). Therefore the findings in this study could be compared to those previous studies.

5.2 Reliability of the setup

5.2.1 The initial setup in Phase I

In *Phase I*, the testing instrument and procedure for the performance of a reach-and-grasp-task were developed. Reliability tests on RT, MT and PF were performed in a group of healthy children using that initial setup. The ICC value of 0.75 or above was used as an indicative value of good reliability (Portney, 2000).

In order to enhance the reliability of the testing procedure, the environmental factors of the test venues, e.g. quietness and lighting, etc, were controlled to be similar in both healthy and DCD groups. Clear and standardised instructions and demonstration were given before test trials. The testing procedures were also standardised for all subjects. Children were reminded to pay full attention to the toy car before it was allowed to slide down to minimize inattentive effect on the stability of their performance. To make sure they understood the testing procedure, children were allowed to practise grasping of the static toy car once and the moving toy car once for each condition before test trials. The dominant hand was used to perform the grasp to ensure the best performance. To diminish the effect of inconsistent performance, five test trials were performed for each condition. These test trials were performed in a randomized sequence among the four conditions to eliminate learning effect.

For the initial setup, the ICC values for MT were well above 0.75 in all 4 conditions. That reflected that the initial instrument and testing procedure were reliable for investigating MT（Portney, 2000). However, the ICC values were very low and even of negative value for RT in 3 out of 4 conditions. The ICC values for PF were above 0.75 in 2 conditions with gentle slope, W_0S_{15} and W_AS_{15}, but were lower than 0.75 in the 2 conditions of greater slope, W_0S_{25} and W_AS_{25}. It reflected the instrument and the testing procedure needed further improvement for investigating RT and PF.

Several reasons contributed to that unsatisfactory level of reliability. First, in this initial setup, the force applied by the child was measured indirectly by a change of pressure inside the ball that was attached to the top of the toy car. Later in Phase I, leakage was noticed at the junction between the ball and the toy car, therefore the change of pressure detected would be smaller than the actual force produced and was unreliable. Secondly, after the toy car had repeatedly slid down from the slanted board, the wheels of the toy car had worn out. That led to inconsistent speed and irregular sliding path of the toy car. Thirdly, ICC value equals 'between-subjects mean square' (BMS) minus 'error mean square' (EMS), divided by BMS. When subjects' performance is too homogenous, the variability among subjects' scores is too low, the value of BMS would be insignificant, and the ICC values would become lower or even negative（Portney, 2000). Therefore, a large variability among subjects' scores is required to demonstrate reliability. In our pilot study, the performance of healthy children was found to be very homogenous. This could be reflected by the small SDs of RT in all 4 conditions especially in the 3 conditions, W_0S_{15}, W_AS_{15} and W_0S_{25}. That explained why we obtained low and even negative ICC values in those 3 conditions.

5.2.2 The final setup in Phase II

To improve the reliability of the initial setup, some modifications were made to the instrument and testing procedure in the final setup. Firstly, the ball was dismounted from the top of the toy car and a load cell was installed inside the trunk of the toy car. That allowed a direct measurement of the force applied on both sides of the trunk when the toy car was picked up. The load cell was calibrated by the supplier right before its delivery and one year after its installation, a consistent ratio between given force and measured force was found. Secondly, to eliminate the inconsistent sliding-down speed and irregular path of the toy car, a track of linear bearing was mounted on the slanted surface. A sliding plate was mounted on the track. The toy car was seated on this plate to slide down in order to compensate for the worn-out wheels. As a result the sliding-down speed and sliding path were consistent in all test trials. After the track of linear bearing was mounted, the sliding-down speed became much faster and unmanageable for the DCD group. Therefore, the original adjustable angles of the slanted board, 15° and 25°, were decreased to 8° and 15° to make it manageable for children with DCD. Thirdly, a rest period of 5 minutes was allowed in the middle of the 20 test trials of the final setup. It was because DCD group was found to fail more in the latter part of the test trials of *Phase I* probably due to tiring effect. Fourthly, the age range of healthy subjects recruited for the reliability test was widened to decrease the homogeneity of performance.

Using this final setup to establish the test-retest reliability of the testing procedure, the ICCs were all well above 0.83 for RT, MT and PF. As the ICCs were all above 0.75, the reliability of the testing procedure was established

(Portney, 2000). This final setup was used in the main study for examining the difference between DCD group and control group in the performance of the dynamic reach-and-grasp task.

5.3 Main study

5.3.1 Failure rate

The zero failure rate of control group indicated that the task was well within the grasping ability of healthy children in that age group. On the contrary, the high failure rate of 34.7% in the DCD group indicated that children with DCD had great difficulty to perform this dynamic reach-and-grasp task, which required adjustment of space, force and time. Williams et al. (1992) found that the failure rate for children with DCD was more than double of that of control group (20% vs. 9.9%) when performing tasks that required timed movements. In their study, children were asked to tap their index finger in time with a series of 50-ms auditory tone spaced at 550-ms intervals and continued to tap at the same rate after the auditory tone was stopped. In comparison with the present study, the task used in the study by Williams et al. (1992) was simpler. In Williams's study, the tapping motion only involved the control of movement of finger joints. In the present study, the reach-and-grasp motion involved the control of movement of the whole arm and hand. In Williams's study, the temporal judgment was simpler as there was only one rhythm to be copied. In the present study, the temporal judgment was more demanding as the toy car was slid down in 4 different speeds. In Williams's study, there was no judgement of space and force as required in the present study. Therefore, in the present study, the failure rate of DCD group (34.7%) was much higher than that of their study. However, the control group in our study completed all test trials successfully while the control group in Williams's study failed by 9.9%. That reflected that the performance of 'memorising-and-imitating consistent rhythm' task was difficult even for healthy children. Lefebvre and Reid (1998) found that when viewing a video that depicted softball trajectories, children with DCD required more viewing time and more visual information to predict the path of the ball. Still they made much more mistakes than the control group in predicting the location of the ball although no data on the percentage was reported. Lefebvre and Reid (1998) suggested that due to their visual perceptual problems, children with DCD were less able to make accurate prediction based on visual information than normal children. In the present study children had to rely on the visual information to plan, initiate and monitor the motion response. If children with DCD had visual perceptual problems, prediction of toy car's motion would be slower and inaccurate, resulting in a high failure rate.

In the present study, children had to integrate the visual information on the spatial and temporal condition of the toy car with the proprioceptive information on the weight of the toy car. Wann et al. (1998) found that when children with DCD were placed in a perceived-to-be swinging room, they tended to respond to the visual information by falling, staggering or swaying in the direction of the room to compensate for the visually perceived but non-existent body sway. This observation suggested that children with DCD were more reliant on visual input and less on proprioceptive information than control group in regulating their postural controls. Wann et al. (1998) proposed that children with DCD were slow in developing the capacity to process proprioceptive input and to effectively integrate visual and proprioceptive information. If weakness in the integration of visual and proprioceptive information on postural control could be carried over to voluntary motor control, a small number of failed trials in DCD group would be due to inaccurate assessment of the weight of the toy car, leading to the dropping of toy car after picking it up (Fig. 4.2).

5.3.1.1 Speed factor on failure rate

The highest failure rate, 38 out of 85 trials, was found in the fastest condition W_AS_{15}. The lowest failure rate, 24 out of 85 trials, was found in the slowest condition W_AS_8. This suggested that inadequate time allowed was an important contributing factor for the failure of children with DCD in that dynamic grasp task. In those failed trials, children with DCD could have been too slow to postulate a reaction, which could be manifested by their prolonged RT even in successful trials. The time they took to plan might be longer than the entire time allowed. Those children might also have planned an inaccurate action, which would be manifested by grasping the toy car at a wrong site. Even with an accurately planned action, they might have taken a long time to execute the action. That prolonged MT might be longer than the entire time allowed. The combination of prolonged RT and MT would further increase the risk of failing the trial. In the faster conditions, time might not be enough for children with DCD to build up adequate force. The rate of force production required for a secure grasp had been too demanding for them, especially in the fastest condition W_AS_{15}, resulting in the highest failure rate of 38 out of 85 trials. Therefore, in some trials of that condition, they failed to produce adequate force to grasp the car and the car was dropped. In other trials they failed to produce the required force within the allowed time, and therefore they grasped the car crudely but not on the right spot. Since the motion required to be planned and executed in all four conditions was basically the same, when the lowest failure rate was found in the condition of slowest speed W_AS_8, the factor of inadequate time allowed for motor planning and execution appeared to be more predominant than the inaccuracy of planning and execution.

5.3.1.2 Weight factor on failure rate

Between the two conditions of gentle slope, hence slower speed, i.e. W_0S_8 and its weight added counterpart W_AS_8, DCD group had their failure incidence decreased from 29 to 24 out of 85 trials. One possible explanation could be that the slowing down of speed of the toy car from 0.89 m/s to 0.771 m/s by the added weight had provided more time for the reception and processing of the proprioceptive information and / or more time for execution of the planned motion. The increased weight could also have increased the proprioceptive input and made it easier for the child to plan for the required force to secure the grasp. Exaggerated kinaesthetic information provided by a heavier object was suggested to be beneficial for children with DCD because of their known deficits in kinaesthetic perceptual function (Laszlo, Bairstow, Bartrip, & Rolfe, 1988;

Smyth, 1994; Johnston et al., 1987). Their deficient kinaesthetic perceptual function included a disrupted ‘input’ stage of information processing that involved perceptual processes such as registration, integration and interpretation of sensory information (Wilson & Mckenzie, 1998) or deficits in kinaesthetic acuity or prolonged kinaesthetic reaction time (Smyth & Glencross, 1986).

Between the two conditions of steeper slope, hence faster speed, W_0S_{15} and W_AS_{15}, adding weight increased the speed of the toy car slightly from 1.075 m/s to 1.112 m/s. It also greatly increased the failure incidence in DCD group from 27 to 38 out of 85 trials. It appeared that when time was limited, heavier weight would contribute to their failed performance. Although the added weight would give children more proprioceptive inputs to plan for the required force, the heavier weight also demanded these children to produce a greater force to secure the grasp. When time was limited, children with DCD would not be fast enough to build up the required greater force. Therefore, they either failed to produce adequate force by dropping the toy car or failed to produce the required force fast enough that they could only grasp the toy car crudely but not on the right spot.

5.3.2 Reasons for failed trials

The most common reason was ‘Picked toy car up at the wrong spot’. In those failed trials children had planned the motion and attempted to pick up the toy car but not according to instruction. That was the major reason of failure in conditions of gentle slope, W_0S_8 and W_AS_8. That could be due to inaccurately planned motion and / or wrong execution of the planned motion. According to the Fitts’ law, which is one of the most robust law to explain phenomena in motor control, the duration of a given movement is constrained by the required accuracy of the movement (Wilson, Maruff, Ives & Currie, 2001). When children with DCD had to complete a task within a very short time that was inadequate for them, they would trade off the accuracy of their grasp for time. In those trials, they might have taken a similar length of time as that of the control subjects, but they failed to meet the accuracy demand of the task by grasping the toy car on the wrong position. Those failed trials could also be due to imprecision of control and inaccurate end point differentiating response (Henderson et al. 1992).

The second most common reason was ‘Toy car ran off the board’. In those failed trials children were too slow to reach the toy car at all before it ran off the board. This could be due to prolonged RT and / or MT. If we applied the Fitts’ law of speed-accuracy trade off, children with DCD might want to reserve the accuracy of the movement by using longer response time, but failed by an inability to finish the grasp within the time allowed. As that was the major reason of failure in condition of highest speed $W_AS_{15,}$ that showed that in extreme time-constrained situation, prolonged RT and / or MT became the major reason for failure. In 4 test trials of the two faster conditions W_0S_{15} and W_AS_{15}, children with DCD did not generate any motor response at all. That was either due to prolonged RT required to finish the mental planning or the children were too shocked by the speed of the toy car that no motor response could be initiated.

The third most common reason was ‘Pressed to stop the toy car but did not pick it up’. Similar to ‘Picked toy car up at the wrong spot’, that could be due to inaccurate motor planning and / or wrong execution of planned response. That was the second major reason of failure in conditions of gentle slope W_0S_8 and W_AS_8. Their proprioceptive deficit demanded prolonged MTs to fine-tune the motion. Eventually they could only reach the toy car but did not have enough time to pick it up at all.

In 4 out of 118 failed trials, children with DCD picked up the toy car but failed to secure the grasp by dropping it. That indicated that inadequate force was generated. Those could be due to their slowness in building up the force required or inaccurate estimation of the weight of the toy car resulted from their deficient proprioceptive sensory system (Hill and Wing, 1998). A secure grasp depended very much on the appropriate grasping force in relation to the weight of the toy car. With inadequate kinaesthetic sensory or judgment of the weight, even though they managed to reach the toy car, they still might not produce adequate force to pick it up or would drop it after picking up. The small percentage of failure of this kind indicated that force control might not be a major factor causing failure performance in that reach-and-grasp task. Our findings concerted with the suggestion raised by Lundy-Ekman, Ivry, Keele & Woollacott (1991) that timing control deficit would lead to more pervasive deficits in movement control than force control deficit would. In the present study, force control in children with DCD was further investigated in data collected from their successful grasps. These findings are discussed in section 5.3.6.

5.3.3 Within-subject variability

Clinically children with DCD tended to perform more inconsistently than healthy children. One of the objectives of the present study was to find out which parameter(s) among RT, MT or PF was / were the contributing factor(s).

Results of the present study showed that regarding RT, the within-subject variability between the two groups was quite similar. This suggested that children in each group did not differ in consistency in their planning performance within each condition. This might be due to the simplicity of the task of the present study. The motor strategy to be planned was very straightforward.

Regarding MT, children with DCD had much greater variation than healthy children in all 4 conditions. Children with DCD were known to have difficulty in learning novel motor tasks, executing new motor skills and generalizing learned motor skills (Goodgold-Edwards & Cermak, 1990). Each time they perform a repeated task, they will treat it as a fresh start. Very little and slow learning effect will be accumulated from previous attempts (Goodgold-Edwards & Cermak, 1990). That could explain their high variability in MT when executing the same reach-and-grasp motion in each condition in the present study. The high variability could also be related to their weak feed-forward and feedback control. Their poor performance in feed-forward or anticipatory control was more obvious in challenging task such as tracking a target that moved in an unpredictable way (Van der Meulen et al., 1991). Rösblad & von Hofsten (1994) also suggested that children with DCD had less developed anticipatory control strategies than healthy children. In their study, children were instructed to pick beads from one cup and carry them to another cup with visual information about the performing hand only, while visual information regarding the cups and beads was hidden from them by a curtain. They could only collect this information from the reflected image of a mirror. Children with DCD were found to move much slower than control group. The researchers suggested that children with DCD had to rely heavily on feedback control, this increased their execution time and also made their performance more varied.

Their high variation in MTs in the present study might also be due to ineffective feedback control during on-going movement. Henderson et al (1992) found that normal children moved rapidly in the early phase of a projectile movement, and then slowed down efficiently and accurately in the final phase to fine-tune the grasp onto the target. But children with DCD had to move slower, more inconsistently and less accurately at the end point due to inefficient and immature motor control. Other studies suggested that children with DCD required multiple steps when generating fast movement (Forsstrom & von Hofsten, 1982; Schellekens, Scholten & Kalverboer, 1983). They had to complete the demanded dynamic task with ‘jerky’ and ‘staccato’ movement in a series of short and segmented steps. Those jerky movement patterns led to slowness of building up adequate force, variability of performance, and diminished the accumulating learning effect on the accuracy of task execution. They either decelerated too early or too late, or stopped at the wrong spot, especially in a limited time situation (Forsstrom & von Hofsten, 1982; Schellekens, Scholten & Kalverboer, 1983). That could also explain why in the present study children with DCD performed inaccurately such as 'picked toy car up at the wrong spot' or 'pressed down the toy car to stop it but did not pick it up as instructed'.

William, Huh & Burke (1998) examined electromyographic activity of arm muscles when performing a simple unilateral reaching movement to either near or far targets. Those investigators found that children with DCD exhibited a slower and inconsistent onset latency of antagonist neuromuscular activities as well as varied and prolonged duration of agonist neuromuscular activities. Children with DCD were also found to have difficulty in establishing the timing of movement and the sequencing of synergies of movement (Blanche 1998). As a result, these children took a significantly longer and more varied MT than the control group.

In the present study, DCD group always had a higher variability in MT than their healthy counterparts across all conditions. That difference reached a maximum of 2.75 times in the fastest and heavier condition W_AS_{15}. In that condition, children were demanded to complete the movement within the shortest time. The heavier weight also demanded a greater force, hence a greater rate of force production. With all those demands, the motor control became too difficult for children with DCD. They could have exhibited weak anticipatory control; ineffective feedback system to monitor motor control during on-going movement; slow and inconsistent onset latency of antagonist neuromuscular activities as well as varied and prolonged duration of agonist neuromuscular activities. As a result they performed the task with prolonged and varied MTs, and exhibited high failure rate. Healthy children on the other hand could produce consistent motor output. Therefore they were able to secure the grasp in all trials.

Regarding PF, the difference in within-subject variability between the two groups was only small and the variations in DCD group were even slightly lower than that of the control group in all 4 conditions. Children with DCD produced significantly greater PF than control group in each condition. The force produced in the limited number of successful trials was much greater than the optimal force required. It could be the maximum force output that children with DCD could produce in each condition. The accuracy of force production was traded off for speed as suggested by Fitt's law. Any inconsistent PF produced would have led to failed grasp, and those PFs were not included for analysis.

5.3.4 Reaction time (RT)

RT reflected the speed and accuracy of processing sensory information, the effectiveness of translating that process into plan of action and the initiation of an overt response (Williams, 2002). In the present study, RT was measured from the moment the toy car started to slide down the slope until the child released the button at the bottom of the slope. This duration represented the time required by the child to postulate a movement plan of grasping the toy car in the brain in response to visual stimulus that provided temporal and spatial information about the toy car.

Children with DCD took a significantly longer RT than healthy children by 18.9 ms to 46.5 ms ($p < 0.05$). That indicated that children with DCD required more time than healthy children to plan for an action in response to an external visual stimulus. The finding in the present study was similar to that of Henderson et al. (1992) who found that when pressing a key after seeing a green arrow pointing toward a target, children with DCD took significantly longer RT (by 41 ms) than normal children. They postulated that the cognitive process in time estimation was not the major factor contributing to the difference in RT. The significant longer RT was due to their inconsistent time taken to process information and to plan for an action. Since the reach-and-grasp task in the present study was straightforward and would not require high level of cognitive time estimation, therefore the significantly longer RT would likely be due to the latter reason, i.e. inconsistency in time taken to process information and to plan for an action. The longer RT found in the present study would also be related to the delay in detecting visual stimuli about the temporal and spatial change in the environment. Children with DCD were reported to have longer tracking delay which required processing and translating temporal and spatial information into a plan of action, and then to initiate an appropriate corrective response (Henderson et al., 1992; Van der Meulen et al., 1991). Previous studies indicated that the difference in RT was even more significant and varied in a challenging task such as performing an asymmetrical bilateral reach where coordination between two arms was required (William et al., 1998).

Within each group, the RT did not differ among all four conditions. That suggested that children in each group used similar duration to plan the reach-and-grasp action in response to the visual stimulus irrespective to the change in speed and position of the moving target among the four conditions. Unlike the challenging asymmetrical bilateral reach performed in the study by William et al. (1998), the dynamic reach-and-grasp task in the present study was simple and all four conditions were very similar in nature. Although there was some variation among tasks in terms of speed and weight, the movement pattern to be planned was basically the same. In the planning process, the degree of difficulty among the four conditions would not be very different. Therefore, no extra time was required to plan for a minor change in movement strategy.

5.3.5 Movement time (MT)

In the present study, MT measured the duration from the moment the child started to execute the planned motion until the grasp of the toy car was secured. It included both the first phase, the ‘reach time’ when the reach-and-grasp action was guided by visual information on the speed and position of the toy car; and the second phase, the ‘grasp time’ when the child had collected some proprioceptive information regarding the weight of the toy car through physical contact with the toy car. The MT reflected the total time required to complete movement execution and was an indirect indicator of efficiency of the child's motor control system (Henderson et al., 1992).

In the present study, DCD group showed a trend of using a longer MT to grasp the toy car than healthy children in all 4 conditions although the difference did not reach a significant level. That agreed with the well-known fact that children with DCD used longer MT and their motor control was inefficient and immature (Missiuna & Polatajko, 1995). Their motor control became worse when speed demand increased (Henderson et al., 1992). Since the MT in the present study included both phases of movement, in order to find out the main contributing factor to this trend of prolonged MT, examination of their performance in each phase separately was required.

In the first phase, visual information on the temporal and spatial position of the toy car was required to bring the hand to an accurate direction and distance to pick up the toy car. Perception of the size and the shape of the trunk of the toy car were also needed to shape the hand in anticipation of contact with the toy car. To increase the applicability of the outcome of this study, a toy car of a particular size was chosen to simulate a ball that children of this age group usually play with in their leisure sport activities. The performance of that phase was reflected by the ‘reach time’. In that phase, visual information was needed to make on-going correction in the course of the movement. During development, children change from a probing strategy where they rely on feedback control to an anticipatory strategy in which they can pre-plan actions to be performed (Forssberg, 1998). As children grow up, their dependency on visual feedback during ongoing movement decreases (Cermak & Larkin, 2002). Van der Meulen et al. (1991) found that children with DCD have less developed ability for anticipatory control. Smyth (1991) also suggested that longer MT of children with DCD were related to their difficulty with execution of anticipatory strategy. Their great dependency on feedback for the motor control increased their execution duration. However, in the present study, no significant difference was found in the ‘reach time’ between the control group and DCD group. That suggested that in the present task children with DCD were able to use anticipatory strategy similar to their healthy counterparts for the reaching motion. Since the sliding pathway of the toy car was fixed on the plate, the position of the toy car only varied along this path according to the speed, the anticipatory strategy for the reaching out motion was straightforward. As a result their reliance on vision information to guide their on-going reaching movement towards the toy car might not be significantly greater than that of the healthy children.

In the second phase of the movement, proprioceptive information about the weight of the toy car was necessary to generate the required force for grasping the toy car. Proprioceptive information about the position of the fingers involved in the grasp was also required to refine the shape of the hand grasp. A successful grasp required well functioning visual sensory system in the first phase and accurate proprioceptive sensory system in the second phase and effective integration between the sensory and motor systems. The performance of the second phase was reflected by the 'grasp time'. There was a trend of difference in the 'grasp time' between the control group and DCD group. The trend of between-group difference in the 'grasp time' ($p = 0.089$) was similar to that of MT ($p = 0.091$). Therefore, we postulated that the difference in MT was mainly contributed by the difference in 'grasp time'.

Proprioceptive information about the weight of the toy car was required to produce adequate force in the second phase. The trend of using a longer 'grasp time' hence longer MT in DCD group could be related to their poor proprioceptive sense (Laszlo et al., 1988; Smyth, 1994; Johnston et al., 1987). They required longer time to collect information on the weight of the toy car. Their accuracy of motor control became worse when the allowed time decreased (Henderson et al, 1992). At the second phase, the demand for accuracy was much greater than that in the first phase as accurate force was required and appropriate shape of the grasping hand had to be formed. As a result children with DCD required longer 'grasp time', but not longer 'reach time', to meet the increased demand on accuracy.

Lundy-Ekman et al. (1991) found that a successful movement required effective regulation of the sequence of agonist and antagonist muscles so that appropriate force could be produced and accurate movement could be performed. In the present setup, children were required to regulate the sequence of agonist and antagonist muscles in their hand so that appropriate force was built up and accurate shape of the grasping hand was formed. Ineffective regulation of muscle work might be one of the reasons for the prolonged 'grasp time', hence prolonged MT in the present study.

Regarding the magnitude of prolonged MT, Huh et al. (1998) found that DCD group moved significantly slower than control group when aiming at target of short distance (198 ms vs. 163 ms) and long distance (240 ms vs. 204 ms). They did not break down various phases of the movement in the study but their degree of difference in total MT between the two groups was similar to that of the present study. Henderson et al. (1992) reported that children with DCD took a MT (641 ms) almost double as that of the control group (338 ms) when reaching their hand to a small moving target. These investigators suggested that children with DCD moved much slower and more inconsistently with increased demand on accuracy of movement responses. In the present study, MT of DCD group was longer than that of control group by a lesser degree of 3% to 35%. The size of the trunk of the toy car to be grasped in the present study was much greater than the small key to be pressed in the study by Henderson et al. (1992). As size of target increased, the demand on accuracy of movement responses decreased. Therefore the difference in MT in the present study was less than that of Henderson et al. (1992).

Within each group, children in both DCD group and control group significantly adjusted their MTs in response to the change in slope, hence speed. Healthy children decreased their MT by 108 ms from the condition of gentle slope W_0S_8 to steeper slope W_0S_{15}. Similarly, children with DCD decreased their MT by 132 ms in response to the same change in slope. Although DCD children took a prolonged MT to complete this reach-and-grasp task, they preserved the ability to adjust their MT according to a change in speed in the successful trials. No previous study has reported on the ability of children with DCD in adjusting MT in response to change in speed.

In previous studies, MT was not found to be affected by additional load for a normal person. Subjects could merely programme a greater muscle force to move a heavier object at the same speed as that of a lighter object (Decety, Jeannerod & Prablanc, 1989; Jeannerod, 1997). That agreed with the results of the present study that no significant change in the MT was detected with regard to a change in weight of the toy car. There was also no significant correlation between MT and PF used in either group.

5.3.6 Peak force (PF)

PF was the maximal force used to secure the grasp of the toy car. Its value should be proportional to the weight of the object to be picked up. The adjustment in PF reflected how effective a child used the proprioceptive sense to monitor the motion performed.

5.3.6.1 Grasp of a static toy car

Clinically, it was observed that children with DCD exhibited a lot of difficulties in modulating force output. They easily crushed or broke objects that should be handled gently with light force. They were also observed to close containers or slam a door with too much force. They might greet people with an excessive force that people feel painful from the contact. Similarly, in the present study, children with DCD demonstrated a trend of using greater force than healthy children even when grasping a static toy car. The difference was greater with a lighter toy car that provided children with smaller proprioceptive sensory information. This agreed with the suggestions by Laszlo & Bairstow (1983) and Lundy-Ekman et al. (1991) that children with DCD had great difficulties to modulate force due to limitation in sensitivity to kinesthesis, as a result greater force was used to compensate for their relatively poorer kinesthetic perception. In addition to their kinesthetic deficiency, Lundy-Ekman et al. (1991) also proposed that the greater force output in children with DCD was due to a deficit in timing control where onset of antagonist muscle activity was delayed and agonist muscle activity was prolonged. By measuring the electromyographic activities in motion, William et al. (1998) found children with DCD had significantly longer onset latency of antagonist, hence an increased duration of agonist activity. That could be one of the reasons for the greater force output in the present study. Further study employing electromyography could confirm that suggestion.

Pereira et al. (2001) found that children with DCD used greater force than control group in a gripping task of various frictional properties. These investigators proposed that an excessive grip force was a compensatory mechanism for an impaired sensory-motor integration as even healthy humans were found dramatically increasing their grip force when the fingers were anesthetized (Johansson & Westling, 1984). The greater grip force compensated for a lack of stability of the basic coordination profile and allowed children to establish a more stable grip in particular when holding slippery objects. In the present study, the side of the trunk where the toy car was to be grasped was smooth and slippery. Children with DCD who had impaired sensory-motor integration could have used greater force than control group to ensure the grasp was secured. Hill & Wing (1998) also found that children with DCD used greater force in a gripping task especially at the end of the movement due to their ineffective motor control. Findings from the fore-mentioned previous studies suggested that the greater force used by the DCD group in the present study could be due to: a) inaccurate judgment of the weight of the toy car; b) exaggerated proprioceptive feedback from a greater force was required to make sure the grasp was secured especially at end of the grasping motion; c) inefficient control of agonists and antagonists muscle activity. The difference was less obvious when the weight of the grasping target was heavier. That reflected that the heavier the target, the more proprioceptive sensory information they received, the more accurate proprioceptive sense would be, and the applied force became more appropriate to the weight of the toy car.

5.3.6.2 Grasp of a moving toy car

In the static conditions, the between-group difference for the PF did not reach a significant level. However, in dynamic conditions, i.e., when time allowed was constrained, children with DCD used significantly greater force than healthy children to grasp the toy car in all 4 conditions ($p<0.01$, Table 4.9). Earlier studies had found that children with DCD used greater force than control group in picking up static object but the force control in performing a dynamic task was not examined (Hill & Wing, 1998; William et al., 1998; Lundy-Ekman et al., 1991 and Laszlo & Bairstow, 1983). Results of the present study indicated that when children with DCD were asked to perform a task within a time limit, their impairment in kinaesthetic perception and sensory-motor integration became more obvious. Therefore, the force they produced became significantly greater than optimal for the weight of the toy car.

In all successful trials, within each group, both healthy children and children with DCD adjusted their PF significantly according to change in slope, hence speed. Children with DCD used greater force to secure the grasp when the toy car moved faster even though its weight remained the same. Their motor control system appeared to use greater force to make up for the time constraint. However, this strategy appeared to be more effectively employed in the control group. With no weight added, when the slope increased from 8° to 15°, healthy children increased their PF by 34 % whereas DCD group increased their PF only by 22 %. With weight added, when the slope increased from 8° to 15°, healthy children increased their PF by 21 % whereas DCD group increased their PF only minimally by 5.3 %. Healthy children could produce greater force in faster condition than in slower condition, to make up for limitation in time. Hence they managed to successfully secure the grasp in all 240 trials. Although children with DCD used greater force in general, they could not adjust their force as effectively as the healthy children did with respect to the change in speed demand. Therefore, children with DCD failed exceptionally more trials in the fastest condition, W_AS_{15}.

5.3.7 Rate of force production

The present study was the first one known to examine rate of force production in a hand grasping movement in children with DCD. In successful trials, the difference between control group and DCD group for the rate of force production was not statistically significant. Both groups of children had to produce PF at a similar rate in order to meet the constraints of both ‘time’ and ‘weight’. However, it was noted that the rate of force production by DCD group in the fastest condition W_AS_{15} was exceptionally high and varied (227.07 ± 436.30 N/s). It was also noted that children with DCD had the highest failure rate in that condition. As discussed in Chapter 5.3.6.2 (p.122), children with DCD already had to use significantly greater force to grasp the toy car in all 4 conditions, i.e. to trade off accuracy of force output for the speed, but they also had to perform with the shortest movement time (also shortest reach time and shortest grasp time) in that fastest condition. Such a high rate of force production would possibly be too demanding for them, as a result they failed to produce force with such a high rate and failed many trials in this condition. Even in successful trials, the performance among children in DCD group was very heterogeneous which could be reflected by the excessively large standard deviation in 3 out of 4 conditions.

Within each group, both groups did not change their rate of force production significantly in response to change in weight. However, there was a trend that both groups increased their rate of force production in response to an increase in slope, hence speed. In W_0 conditions, control group increased their force output rate by 46.6 % and DCD group increased by 28.4 % in response to a steeper slope. In W_A condition, the percentage of change was even more obvious especially in DCD group. Control group increased their force output rate by 58.9 % and DCD group increased by 138.1 % in response to a steeper slope. A moderate to good inverse correlation between MT and rate of force production was found in control group. A shorter MT was associated with a quicker rate of force production. This inverse correlation applied similarly for DCD group with the exception for the fastest conditions W_AS_{15}, in which the time allowed would be close to or even beyond their force production capacity. However the capacity of the rate of force production of children with DCD was not investigated in any previous study. That would be an area worthy for future study. The present study found that children with DCD tended to use excessive force and therefore a faster force production rate was required to successfully complete the task. Those children with DCD who could not cope with this high rate of force production would fail to complete the trial. The shorter the time allowed, the more obvious their difficulty would be. That could be reflected by the high failure rate of 38 out of 85 trials in the fastest condition W_AS_{15}. As a contrast, all the healthy children who had more efficient adjustment of rate of force production could complete all trials.

5.3.8 Limitation of the design and suggestions for future study

Since the setup was developed with economical parts without extensive technical enhancement, there had been events of malfunction in the course of transportation due to poor contact of parts. In order to eliminate the errors in the measurement of force and time, and to ensure the stability of the setup, number of premises for data collection was minimized. Also, only children diagnosed with DCD at two child assessment centres were recruited and children in control group were recruited in nearby communities. With better technical support and a more robust setup, the setup could be taken to a wider range of location. And more subjects from different socioeconomic background could be recruited for the study. Twelve healthy children and seventeen children with DCD were recruited to perform the main study. The greatly varied performance among children with DCD, reflected by their large SDs in MT and grasp time, had made the results of between-group comparison statistically insignificant although inspection of raw data did show a large difference. A larger sample size might improve the generalizability of the outcome of this study.

In the present study, a toy car of rectangular shape was used as the grasp target for better sensitivity and reliability of measurements. If the toy car could be replaced by a round shaped object in the future study, that would better reflect their performance in a ball game and the appropriateness of their hand grip could also be analyzed. Results of the present study found that both healthy group and DCD group did not adjust their RT, MT, PF and rate of force production much in response to change in weight of the toy car. By using targets with larger difference in weight, the importance of motor control in response to change in weight could be elucidated. Further study on the rate of force production in different phases of a dynamic motion is also needed to reveal their difficulty in force control. In order to enhance understanding of underlying causes for their longer RT, investigation of the movement of the eye ball may help to distinguish whether it was due to an ineffective eye tracking or an inaccurate or inefficient planning process. Measurement of electromyographic activities can reflect the control of onset latency of agonist and antagonist muscle groups. This may further explain the longer grasp time, longer MT and greater PF in DCD group. In this study, poor proprioceptive sense was suspected to be one of the major contributors for the ineffective and inefficient performance of DCD group. It is worthy to have this measured before the test trials, the correlation between the accuracy of their proprioceptive sense and their performance could then be analyzed. Moreover by observing the arm motion in the course of the task, e.g. the degree of freedom or the moving path, other coordination problem might be disclosed. It is hope that a better understanding of the underlying deficits can lead to a more focused, hence more effective training program.

Chapter 6 Conclusion

The present study was the first one known to examine the performance of a functional dynamic reach-and-grasp task in children with DCD. The testing setup was designed to simulate a "play" or "catch a ball" situation. Moreover, it was also the first study to examine the rate of force production, the movement time with it split into the crude reaching phase and the fine-tuned grasping phase, as well as changes of RT, MT, PF and rate of force production with respect to changes in "speed" and "weight" of object. The testing procedure was developed with reliability established since the Intraclass Correlation Coefficients of test-retest reliability were above 0.83 for RT, MT and PF. Healthy children completed the reach-and-grasp task with 100% successful rate, but children with DCD succeeded only 65.3% of the trials. Results of the present study confirmed that children with DCD were less effective in performing a dynamic reach-and-grasp task that required adjustment of both force and response time. The most common reasons for failed trials were 'Child picked the toy car up at the wrong spot', 'Toy car ran off the board without being picked up' and 'Child pressed down the toy car to stop it but did not pick it up as instructed'. They might have planned an inaccurate action in the first place due to inaccurate prediction of toy car's motion resulted from their deficient visual perception.

Therefore, they grasped the toy car at a wrong site. The inaccurate performance could be related to speed-accuracy trade off. In order to perform the task within a limited time, they could have traded off the accuracy of their grasp, resulting in grasps at the wrong sites. Children with DCD also needed longer MT to execute the motion. Therefore when the toy car slid down speedily in the fastest condition, they were not able to reach the toy car before it ran off the board.

Their high failure rate could also be due to limitation in sensitivity to kinaesthesis. Children with DCD might not be able to estimate accurately the weight of the toy car. As a result they tended to produce force more than optimal in each condition to compensate for their impaired kinaesthetic perception and sensory-motor integration. And since they needed significantly longer RT to plan, time left to perform movement became shorter. However, they also needed longer MT to execute the motion and greater force to secure the task. Therefore, they had the highest failure rate in the fastest condition where the time allowed to produce their excessive force output was just too short for them.

In successful trials, DCD group performed with similar within-subject variability as that of the control group for RT in all 4 conditions. However, children with DCD had much more varied MT in all 4 conditions and that was possibly due to their weak anticipatory control and ineffective feedback control during on-going movement. Therefore they moved more inconsistently and less accurately in performing the task.

In successful trials, children with DCD took significantly longer RT than control group to plan for a reaction in all 4 conditions. The prolonged RT could be related to their visual perceptual problems; slowness in processing temporal and spatial information; and slowness in translating these information into planning a movement. Both groups did not adjust their RT significantly in response to change in weight or slope. That might be because the dynamic reach-and-grasp task in the present study was simple, and movement pattern to be planned in all four conditions were very similar even with a change in slope or weight.

DCD group tended to use longer MT than control group, although the difference did not reach a significant level. That was possibly due to their weak anticipatory control and ineffective feedback control. They needed longer time to monitor the execution process. They used longer MT to gain the accuracy of performance as suggested by Fitts' Law of speed-accuracy tradeoff. Although children with DCD were slower in performing the task, they preserved the ability to shorten the MT when the slope was increased.

Children with DCD used greater PF than control group even when grasping a static toy car, although the difference did not reach a significant level. When grasping a moving toy car, they used significantly greater PF than healthy children. That could be related to their inaccurate kinaesthetic perception, and ineffective integration of visual and proprioceptive information to estimate accurately weight of the toy car especially in a short period of time. As a result, they produced an above-optimal force to secure their grasp. Both groups increased their PF significantly when the slope was increased. That reflected the motor control system of both groups used greater force to make up for the time constraint.

Regarding the rate of force production, there was no between-group difference. Both groups showed a trend to increase the rate of force production when the slope was increased. Worthnotingly, DCD group produced an exceptionally high rate of force production in the fastest condition W_AS_{15}. That high rate of force production could be too demanding for them and therefore this could have led to the high failure rate in this condition.

To conclude, children with DCD had 34.7% of failure when performing the dynamic reach-and-grasp-task. Within the successful trials, those children took a significantly longer RT and had a tendency of prolonged MT as compare with healthy children. In addition, they applied a significantly larger PF to pick up the toy car. However, those children preserved their ability to adjust MT, reach time and PF according to a change in speed of the car.

Since the present study was the first study examining rate of force production, MT with it split into the crude reaching phase and the fine-tuned grasping phase, as well as changes of RT, MT, PF and rate of force production with respect to changes in "speed" and "weight" of object in a dynamic reach-and-grasp task, it provided unprecedented findings that children with DCD could actually adjust their movement time, particularly in the crude reaching phase, and their peak force and rate of force production in response to the change in speed of the target. However, their adjustment was obviously not as effective as that of the healthy children, therefore their reach-and-grasp performances were comparatively poorer. Moreover, their performance is also jeopardised by their prolonged RT, prolonged MT (in particular the fine-tuned grasping phase), and their significantly greater PF required. So in order to improve their performance in ball games in which a lot of accurate reach-and-grasps were demanded, their RT and MT have to be reduced, and their PF has to be optimised according to the change in the external demand. Clinically, table games or computer games that involve arm movement in response to visual stimulus with quantified feedback can be used to train up their response time (the sum of reaction time and movement time). Games to elicit different targeted hand gripping force with timely and quantified feedback can also help them to adjust their force output accordingly. Since nowadays children in Hong Kong are facing pressing academic demand and are having less time for outdoor activities, these activities are convenient as they can easily be practised indoors in short rest between homework. With more efficient and accurate control of force and speed, their motor skills in outdoor ball games would be enhanced.

REFERENCES

American Psychiatric Association (1987) *Diagnostic and statistical manual of mental disorders* (3rd Ed.). Washington, DC: American Psychiatric Association.

American Psychiatric Association (1994) *Diagnostic and statistical manual of mental disorders* (4th Ed.). Washington, DC: American Psychiatric Association.

American Psychiatric Association (2000) *Diagnostic and statistical manual of mental disorder*s (4th Ed.). Washington, DC: American Psychiatric Association.

Anson, J.G. (1992) Neuromotor control and Down syndrome. In J.J. Summers (ed.) *Approaches to the study of motor control and learning* (pp. 387-412). Amsterdam: Elsevier Science.

Ayres, A.J. (1960) Occupational therapy for motor disorders resulting from impairment of the central nervous system. *Rehabilitation Literature*, 21, 302-310.

Ayres, A.J. (1965) Patterns of perceptual-motor dysfunction in children: A factor analytic study. *Perceptual and Motor Skills*, 20, 335-358.

Ayres, A.J. (1980) *Sensory integration and learning disorders*. Los Angeles: Western Psychological Corporation

Ayres, A.J. (1989) *The Sensory integration and praxis tests*. Los Angeles: Western Psychological Services.

Ayyash, H.F. & Preece, P.M. (2003) Evidenced-based treatment of motor co-ordination disorder. *Current Paediatrics*, 13, 360-364.

Barnett, A.L., Kooistra, L. & Henderson, S.E. (1998) ‘Clumsiness’ as syndrome and symptom. *Human Movement Science*, 17, 435-447.

Barnhart, R.C., Devenport, M.L., Epps, S.B. & Nordquist, V.M. (2003) Developmental Coordination Disorder. *Physical Therapy*, 83(8), 722-731.

Brenner, M.W., Gillman, S., Zanwill, O.L., & Farell, M. (1967) Visuo-motor disability in school children. *British Medical Journal*, 4, 259-262.

Bruininks, R.H. (1978) *Bruininks-Oseretsky Test of Motor Proficiency: Examiner's Manual*. American Guidance Service.

Case-Smith, J. & Weintraub, N. (2002) Hand function and Developmental Coordination Disorder. In Cermak, S. & Larkin, D. (Ed.) *Developmental Coordination Disorder*. (pp. 157-171). Delmar, Thomson Learning.

Cantell, M., Smyth, M., & Ahonen, T. (1994) Clumsiness in adolescence: Educational, motor, and social outcomes of motor delay detected at 5 years. *Adapted Physical Activity Quarterly*, 11, 115-129.

Cantell, M. (1998) *Developmental coordination disorder in adolescence: perceptual motor, academic and social outcomes of early motor delay*. Finland: Research Centre for Sport and Health Science.

Cermak, S. (1985) Developmental dyspraxia. In Roy, E.A. *Neuropsychological studies of apraxia and related disorders* (pp. 225-248). Amsterdam: North-Holland.

Cermak, S. (1991) Somatodyspraxia. In Fisher A.G., Murray, E. A & Bundy A.C. *Sensory integration: Theory and practice* (pp. 137-165). Philadelphia: F.A. Davis.

Cermak, S. & Larkin, D. (2002) Visual perception in children with Developmental Coordination Disorder. In Cermak, S. & Larkin, D. (Ed.) *Developmental Coordination Disorder*. (pp. 113-116). Delmar, Thomson Learning.

Cermak, S., Trimble, H., Coryell, J. & Drake, C. (1991) The persistence of motor deficits in older students with learning disabilities. *Japanese Journal of Sensory Integration,* 2(1), 17-31.

Chan, S.H.S. (2006) Developmental Coordination Disorder. In *A Primer in common developmental disabilities: experience at Child Assessment Service, Hong Kong*. Child assessment service, Department of Health, Hong Kong Special Administrative Region Government, p.183-233.

Chan, S.H.S., Ng, A.M.Y., Lin, L.S.Y., Leung, E.Y.W., Poon, C.Y.C., Ng, R.H.K. & Tsang, L.H.L. (2004) Brief report on a retrospective study of children with Developmental Coordination Disorder. *Brainchild*, The Hong Kong Society of Child Neurology and Developmental Paediatrics.

Chen, H.F., Tickle-Degnen, L. & Cemak, S. (2003) Treatment effectiveness of top-down approaches for children with developmental coordination disorder: a meta-analysis. *Journal of Occupational therapy Association*, 21, 16-28.

Clements, S.D. (1966) *Minimal brain dysfunction in children: Terminology and identification*. NINBD Monograph 3. Washington, DC: U.S. Government.

Crawford, S.G., Wilson, B.N. & Dewey, D. (2001) Identifying Developmental Coordination Disorder: Consistency between Tests. *Physical and Occupational therapy in Pediatrics*, 20 (2/3): 29-50.

Decety, J., Jeannerod, M. & Prablanc, C. (1989) The timing of mentally represented actions. *Behavioural Brain Research*, 34, 35-42.

Denckla, M.B. (1984) Developmental dyspraxia: The clumsy child. In M.D. Levine & P. Satz, *Middle childhood: Development and dysfunction,* (pp. 245-260). Baltimore: University Park.

Denckla, M.B. & Roeltgen, D.P. (1992) Disorders of motor function and control. In Rapin, I. & Segalowitz, S.J. *Handbook of neuropsychology. Vol.6. Child* *neuropsychology* (pp.455-476). Amsterdam: Elsevier Science.

Dewey, D. (1995) What is developmental dyspraxia? *Brain & Cognition*, 29, 254-274.

Dewey, D. & Wilson, B.N. (2001) Developmental coordination disorder: what is it? *Physical and Occupational therapy in Pediatrics*, 20 (2/3), 5-27.

Forsstrom, A. & von Hofsten, C. (1982) Visually directed reaching of children with motor impairments. *Developmental Medicine and Child Neurology*. 24, 653-661

Forssberg, H. (1998) The neurophysiology of manual skill development. In: K. J. Connolly (Ed.), *The psychobiology of the hand* (pp. 97-122). Cambridge: Mac Keith Press.

Ford, D.R. (1996) *Diseases of the nervous system in infancy, childhood and adolescence*. (5th Ed.) Springfield, IL: Thoma.

Fox, A.M. & Lent, B. (1996) Clumsy children primer on developmental coordination disorder. *Canadian Family Physician*. 42, 1965-1971.

Frostig, M. (1968) *Sensory-motor development*. Special Education, 57(2), 18-20

Geuze R. & Borger H. (1998) Children who are clumsy: Five years later. *Adapted Physical Activity Quarterly*, 10, 10-21.

Gillberg, I.C., & Gillberg, C. (1989) Children with preschool minor neurodevelopmental disorders IV. Behaviour and school achievement at age 13. *Developmental Medicine and Child Neurology*, 31, 3-13.

Gubbay, S.S. (1975) *The clumsy child: A study in developmental apraxic and agnostic ataxia*. London: W.B. Saunders.

Gubbay, S.S. (1978) The management of developmental apraxia. *Developmental Medicine and Child Neurology*, 20, 643-646.

Harter, S. (1987) The determinants and mediational role of global self-worth in children. In N. Eisenberg, *Contemporary issues in developmental psychology* (pp. 219-242). New York: Wiley.

Henderson, S.E. & Hall, D. (1982) Concomitants of clumsiness in young school children. *Developmental Medicine & Child Neurology*, 24, 448-460.

Henderson, S., May, M. & Umney, D.S. (1989) An exploratory study of goal-setting behaviour, self-concept and locus of control in children with movement difficulties. *European Journal of Special Needs Education*, 4(1), 1-15.

Henderson, L., Rose, P. & Henderson, S. (1992) Reaction time and movement time in children with a developmental coordination disorder. *Journal of Child Psychology and Psychiatry*, 33, 895-905.

Henderson, S.E. & Sugden, D.A. (1992) *Movement Assessment Battery for Children*. New York: Psychological Corporation/Harcourt Brace-Jovanovich.

Hill, E. L. & Wing, A. M. (1998) Developmental disorders and the use of grip force to compensate for inertial forces during voluntary movement. In K.J. Connolly (Ed.), *Psychobiology of the hand* (pp. 199-212). London: Mac Keith Press.

Hoare, D. (1991) Classification of movement dysfunctions in children: descriptive and statistical approaches. Unpublished doctoral dissertation, University of Western Australia, Nedlands, Australia.

Hoare, D. (1994) Subtypes of developmental coordination disorder. *Adapted Physical Activity Quarterly*, 11, 158-169.

Holsti, L., Grunau, R.V. & Whitfield, M.F. (2002) Developmental coordination disorder in extremely low birth weight children at nine years. *Developmental Behavior of Pediatrics*, 23, 9-15.

Huh, J., Williams, H. & Burke, J. (1998) Develppment of bilateral motor control in children with developmental coordination disorder. *Developmental Medicine and Child Neurology*, 40, 474-484.

Jeannerod, M. (1997) *The cognitive neuroscience of action*. London: Blackwell.

Johansson, R. S. & Westling, G. (1984) Roles of glabrous skin receptors and sensorimotor memory in automatic control of precision grip when lifting rougher or more slippery objects. *Experimental Brain Research*, 56, 550-564.

Johnston, L.M.; Burns, Y.R.; Brauer, S.G. & Richardson, C.A. (2002) Differences in postural control and movement performance during goal directed reaching in children with developmental coordination disorder. *Human Movement Science*, 21, 583-601.

Johnston, O., Short, H., & Crawford, J. (1987) Poorly coordinated children: A survey of 95 cases. *Child: Care, Health and Development*, 13, 361-376.

Kadesjo, B. & Gillberg, C. (1999) Developmental coordination disorder in Swedish 7 year-old children. *Journal of the American Academy of Child and Adolescent Psychiatry*, 38, 820-828.

Kaplan, B.J., Wilson, B., Dewey, D. & Crawford, S. (1994) The genetic basis of clumsiness, and its overlay with other disorders. Paper presented at the conference Children and Clumsiness Public Forum, London, Canada.

Karrer, R. (1986) Input, central and motor segments of response time in mentally retarded and normal children. In M.G. Wade (Ed.) *Motor skill acquisition of the mentally handicapped: Issues in research and training* (pp. 167-187). Amsterdam: Elsevier Science.

Keogh, J.F. (1968) Incidence and severity of awkwardness among regular school boys and educationally subnormal boys. *Research Quarterly*, 39, 806-808

Keogh, J.F., Sugden, D., Reynard, C.L., & Calkins, J. (1979) Identification of clumsy children: Comparisons and comments. *Journal of Human Movement Studies*, 5, 32-41.

Kephart, N.C. (1960) *The slow learner in the classroom*. Columbus, OH: Merrill Books.

Knuckey, N.W., Apsimon, T.T. & Gubbay, S.S. (1983) Computerized axial tomography in clumsy children with developmental apraxia and agnosia. *Brain and Development*, 5(1), 14-20.

Kong, E. (1963) Minimal cerebral palsy: The importance of its recognition. In Bax, M. & Keith, R.M., *Minimal cerebral dysfunction*. *Little Club Clinics in developmental Medicine no. 10 (p. 29-31).* London: Heinemann Medical.

Larkin, D. & Parker, H. E. (1997) Physical self-perceptions of adolescents with a history of developmental coordination disorder. Poster presentation at NASPSPA, Denver, U.S.A.

Laszlo, J. & Bairstow, P. (1983) Kinaesthesis: Its measurement, training and relationship to motor control. *Quarterly Journal of Experimental Psychology*, 35, 411-421.

Laszlo, J. I., Bairstow, P. J., Bartrip, J., & Rolfe, U. T. (1988). Clumsiness or perceptual-motor dysfunction? In A. M. Colley & J. R. Beech (Eds.), *Cognition and action in skilled behaviour*, 293-310. Amsterdam: North Holland.

Lefebvre, C. & Reid, G. (1998) Prediction in ball catching by children with and without developmental coordination disorder. *Adapted Physical Activity Quarterly*, *15*, 299-315.

Lord, R., & Hulme, C. (1987).Perceptual judgments of normal and clumsy children. *Developmental Medicine and Child Neurology*, 29, 250-257.

Lord, R., & Hulme, C. (1988) Visual perception and drawing ability in clumsy and normal children. *British Journal of Developmental Psychology*, 6, 1-9.

Losse, A., Henderson, S.A., Elliman, D., Hall, D., Knight, E. & Jongmans, M. (1991) Clumsiness in Children: Do they grow out of it? A 10-year follow-up study. *Developmental Medicine Child Neurology*, 33: 55-68.

Lundy-Ekman, L., Ivry, R., Keele, S., & Woollacott, M. (1991) Timing and force control deficit in clumsy children. *Journal of Cognitive Neuroscience*, 3, 367-377.

Mandich, A., Polatajko, H.J. & Rodger, S. (2003) Rites of passage: understanding participation of children with developmental coordination disorder. *Human Movement Science*, 22, 583-595.

Mandich, A., Polatajko, H.J., Macnab, J.J. & Miller, L.T. (2001) Treatment of children with developmental coordination disorder: what is the evidence? *Physical and Occupational Therapy in Pediatrics*, 20(2/3), 51-68.

Marlow, N., Roberts, B.L. & Cooke, R.W.I. (1993) Outcome at 8 years for children of birthweights of 1250g or less. *Archives of Disease in Childhood*, 68, 286-290.

Mervis, C.B., Robinson, B.F. & Pani, J.R. (1999) Visuospatial construction. *American Journal of Human Genetics*, 65, 1222-1229.

Missiuna, C. (1994) Motor skill acquisition in children with developmental coordination disorder. *Adapted Physical Activity Quarterly*, 11, 214-235.

Missiuna, C., & Polatajko, H. (1995) Developmental dyspraxia by any other name: Are they all just clumsy children? *American Journal of Occupational Therapy*, 49, 619-628.

Miyahara, M. & Mobs, I. (1995) Developmental; dyspraxia and developmental coordination disorder. *Neuropsychology Review,* 5, 245-268.

Mon-Williams, M.A., Wann, J.P. & Pascal, E. (1999) Visual-proprioceptive mapping in children with developmental coordination disorder. *Developmental Medicine and Child Neurology*, 41, 247-254.

Nichols, P.L. & Chen, T. (1981) *Minimal brain dysfunction*. Hillsdale, NJ: Erbaum.

Orton, S.T. (1937). *Reading, writing and speech problems in children*. New York: Norton.

Pehoski, C. (1995) Object manipulation in infants and children. In A. Henderson & C. Pehoski (Eds.), *Hand function in the child: Foundations for remediation* (pp. 136-153). St. Louis, MO: Mosby.

Pereira, H.S., Landgren, M., Gillberg, C. & Forssberg, H. (2001) Parametric control of fingertip forces during precision grip lifts in children with DCD (developmental coordination disorder) and DAMP (deficits in attention motor control an perception). *Neuropsychologia*, 39, 478-488.

Peters, J.M., Barnett, A.L. & Henderson, S.E. (2000) Clumsiness, dyspraxia and developmental coordination disorder: how do health and educational professionals in the UK define the terms? *Child: Care, Health and Development* 27(5), 399-412.

Pitcher, T.M., Piek, J.P. & Barrett, N.C. (2002) Timing and force control in boys with attention deficit hyperactivity disorder: Subtype differences and the effect of comorbid developmental coordination disorder. *Human Movement Science,* 21, 919-945.

Polatajko, H.J., Fox, A.M. & Missiuna, C. (1995) An international consensus on children with developmental coordination disorder. *Canadian Journal of Occupational Therapy*, 62, 3-6.

Polatajko, H.J., Macnab, J.J. & Anstett, B. (1995) A clinical trial of the process-orientated treatment approach for children with developmental co-ordination disorder. *Developmental Medicine of Child Neurlogy*, 37, 310-319.

Portney (2000) *Foundations of clinical research*. (2nd Ed.) Prentice Hall.

Raynor, A.J. (1998) Fractionated reflex and reaction times in children with Developmental Coordination Disorder. *Motor Control*, 2, 114–124.

Revie, G. & Larkin, D. (1993) Looking at movement: Problems with teacher identification of poorly coordinated children. *ACHPER National Journal*, 40(4), 4-9.

Rizzolatti, G., Luppino, G. & Matelli, M. (1998) The organization of the cortical motor system: New concepts. *Electroencephalography and Clinical Neurophysiology*, 106, 283-296.

Rösblad, B. & von Hofsten, C. (1994) Repetitive goal-directed arm movements in children with developmental coordination disorder: Role of visual information. *Adapted Physical Activity Quarterly*, 11, 190-202.

Rowe, J.B. & Frackowiak, R.S.J. (1999) The impact of brain imaging technology on our understanding of motor function and dysfunction. *Current Opinion in Neurobiology*, 9, 728-734.

Schellekens, J., Scholten, C. & Kalverboer, A. (1983) Visually guided hand movements in children with minor neurological dysfunction. Response time and movement organization. *Journal of Child Psychology and Psychiatry*, 24, 89-102

Schoemaker, M.M. & Kalverboer, A.F. (1994) Social and affective problems of children who are clumsy: How early do they begin? *Adapted Physical Activity Quarterly*, 11, 130-140.

Skinner, R.A. & Piek, J.P. (2001) Psychosocial implications of poor motor coordination in children and adolescents. *Human Movement Science*, 20, 73-94.

Smyth, T.R. (1991) Abnormal clumsiness in children: A defect of motor programming? *Child: Care, Health and Development*, 17, 283-294

Smyth, T.R. (1996) Clumsiness: kinaesthetic perception and translation. *Child care, health and development*, 22 (1), 1-9.

Smyth, T.R. & Glencross, D.J. (1986) Information processing deficits in clumsy children. *Australian Journal of Psychology*, 38, 13-22.

Sovik,N. & Maeland, A.F. (1986) Children with motor problems (clumsy children). *Scandinavian Journal of Educational Research*, 30, 39-53.

Stordy, B.J. (2000) Dark adaptation, motor skills, docosahexaenoic acid, and dyslexia. *American Journal of Clinical Nutrition*, 71 (1 Suppl S), 323S-326S

Sugden, D. & Keogh, J. (1990) *Problems in movement skill development*. Columbia, SC: University of South Carolina Press.

Szklut, S., Cermak, S., & Henderson, A. (1995) Learning disabilities. In D. Umphred (Ed.), *Neurological rehabilitation* (3rd Ed., p. 312-359). St. Louis: Mosby.

Taylor, M.J. (1990) Marker variable for early identification of physically awkward children. In G. Doll-Tepper, C. Dahms, B. Doll, & H. von Selzam (Eds.), *Adapted physical activity* pp. 379-386. Berlin; Springer-Verlag.

Theios, J. (1975) The components of response latency in simple human information processing tasks. In P.M.A. Rabbitt & S. Dornic (Eds.) *Attention and performance* (pp. 418-440). London: Acedemic Press.

Touwen, B.C.L. (1990) Variability and stereotypy of spontaneous motility as a predictor of neurological development of preterm infants. *Developmental Medicine and Child Neurology*, 32, 501-508.

Van Dellan, T. & Geuze, K.H. (1988) Motor response programming in clumsy children. *Journal of Child Psychology and Psychiatry*, 29, 489-500.

Van der Meulen, J., Denier van der Gon., Gielen, C., Gooskens, R., & Willemse, J. (1991) Visuomotor performance of normal and children with developmental coordination disorder: Fast goal-directed arm movements with and without visual feedback. *Developmental Medicine and Child Neurology*, 33, 40-54.

Wall, A.E., Reid, G. & Paton, J. (1990) The syndrome of physical awkwardness. In G. Reid, *Problems in movement control (*p. 283-316). Amsterdam: Elsevier Science.

Walton, J.N., Ellix, E. & Court, S.D.M. (1962) Clumsy children: Developmental apraxia and agnosis. *Brain*, 85, 603-612.

Wang, J. & Stelmach, G.E. (2001) Spatial and temporal control of trunk assisted prehensile actions. *Experimental Brain Research*, 136, 231-240.

Wann, J., Mon-Williams, M. & Rushton, K. (1998) Postural control and coordination disorders: The swinging room revisited. *Human Movement Science*, 17, 491-513.

Ward, A. & Rodger, S. (2004) The application of cognitive orientation to daily occupational performance (CO-OP) with children 5-7 years with developmental coordination disorder. *British Journal of Occupational Therapy*, 67(6), 256-264.

Weiss, A.D. (1965) The locus of reaction time change with set, motivation, and age. *Journal of Gerontology*, 20, 60-64.

Wigglesworth, R. (1963) The importance of recognizing minimal cerebral dysfunction in paediatric practice. In M. Bax & R. Mac Keith, *Minimal cerebral dysfunction*. *Little Club Clinics in developmental Medicine no. 10* (pp. 34-38). London: Heinemann Medical.

Williams, H. G. (2002) Motor control in children with developmental coordination disorder. In Cermak, S. & Larkin, D. (Ed.) *Developmental Coordination Disorder*. (pp. 117-137) Delmar, Thomson Learning.

Williams, H., Fisher, J. & Tritschler, K. (1983) Descriptive analysis of static postural control in 4, 6 and 8 year old normal and motorically awkward children. *American Journal of Physical Medicine*, 62(1), 12-26.

Williams, H., Huh, J. & Burke, J. (1998) Planning of unimanual and bimanual responses in children with developmental coordination disorder: A reaction time analysis. Unpublished data, Motor Development and Control Laboratory, University of South Carolina, Columbia.

Williams, H., Woollacott, M. & Ivry, R. (1992) Timing and motor control in clumsy children. *Journal of Motor behavior,* 24, 165-172.

Willingham, D.B. (1998) A neuropsycholological theory of motor skill learning. *Psychological Bulletin,* 105, 558-584.

Wilson, B.N., Kaplan, B.J., Crawford, S.G., Campbell, A. & Dewey, D. (2000) Reliabilty and validity of a parent questionnaire on childrenhood motor skills. *American Journal of Occupational Therapy*, 54(5), 484-493.

Wilson, P. H., Maruff, P., Ives, S. & Currie, J. (2001) Abnormalities of motor and praxis imagery in children with DCD. *Human Movement Sciences*, 20, 135-159.

Wilson, P. H. & Mckenzie, B. E. (1998) Information processing deficits associated with developmental coordination disorder: A meta-analysis of research findings. *Journal of Child Psychology and Psychiatry*, 39, 829-840.

Wing, A. & Kristofferson, A. (1973) Response delays and the timing of discrete motor responses. *Perception and Psychophysics*, 14, 5-12

World Health Organization (1996) *Multiaxial classification of child and adolescent psychiatric disorders*. Cambridge: Cambridge University Press.

Wright, H. & Sugden, D. (1996) A two step procedure for the identification of children with developmental co-ordination disorder in Singapore. *Developmental Medicine and Child Neurology*, 38, 1099-1105.

Appendix III CAS-DCD Functional Checklist

衛生署

兒童體能智力測驗服務

兒童日常生活表現及體能協調調查問卷

姓名: ( )
性別: 男 / 女 編號:
出生日期/年齡: /

填表日期:

填表人: 父親/母親/其他(註明)

為能更詳細了解貴子女在日常生活和體能協調的表現，請填寫以下問卷。
('✓ '適當答案，' ? '不清楚項目)

學習表現：

✓ 最適合的答案

1. 整體學業成績 ---------------------------------- [好] [尚可] [差] [不合格]
2. 中、英書法科 ---------------------------------- [好] [尚可] [差] [不合格]
3. 體育科 -- [好] [尚可] [差] [不合格]
4. 美勞科 -- [好] [尚可] [差] [不合格]

心理/情緒表現：

✓ 最適合的答案

1. 介意別人批評自己的弱點 ------------------ [經常] [間中] [很少] [無]
2. 知道自己能力差，用方法掩飾(如說'不想做'，'不喜歡做') ------------------------------- [經常] [間中] [很少] [無]
3. 做不到時，會喊或發脾氣 ------------------- [經常] [間中] [很少] [無]
4. 做不到時，會埋怨他人 ----------------------- [經常] [間中] [很少] [無]
5. 畏縮，缺乏信心參與活動 -------------------- [經常] [間中] [很少] [無]
6. 接受自己能力差，會努力嘗試 -------------- [經常] [間中] [很少] [無]

抄寫能力：

✓ 最適合的答案

1. 速度慢，用很長時間做功課 ----------------- [經常] [間中] [很少] [無]
2. 手易倦 -- [經常] [間中] [很少] [無]
3. 執筆欠佳，姿勢差，控制不靈活 ------------ [經常] [間中] [很少] [無]
4. 雖用心寫字，但不公整 ----------------------- [經常] [間中] [很少] [無]
5. 寫出格 -- [經常] [間中] [很少] [無]
6. 筆畫次序亂 ------------------------------------ [經常] [間中] [很少] [無]
7. 不能將字寫貼在線上，有高有低 ----------- [經常] [間中] [很少] [無]

日常生活技巧：

✓ 最適合的答案

1. 「論論盡盡」，例如常倒瀉水，容易碰跌
物件，或手中物件易跌 ---------------------- [經常] [間中] [很少] [無]
2. 手不靈活，常用身「就」碗或簿 ------------- [經常] [間中] [很少] [無]
3. 飲食 － 用筷子不靈活，會跌 ----------- [經常] [間中] [很少] [無]
－ 食飯不整潔，會瀉飯 ----------- [經常] [間中] [很少] [無]
－ 倒水入杯時，會瀉 ------------- [經常] [間中] [很少] [無]
4. 穿衣 － 扣鈕、拉鍊有困難，速度慢 ----- [經常] [間中] [很少] [無]
－ 縛鞋帶困難，易鬆 ------------- [經常] [間中] [很少] [無]
－ 衣衫不整齊 ---------------------- [經常] [間中] [很少] [無]
5. 清洗 － 用牙刷不靈活 -------------------- [經常] [間中] [很少] [無]
－ 扭不乾毛巾 ---------------------- [經常] [間中] [很少] [無]
－ 洗頭、梳頭、沖涼「論盡」---- [經常] [間中] [很少] [無]
6. 用文具 － 揼不實間尺，間線會斜 ------ [經常] [間中] [很少] [無]
－ 塗色出界 ------------------------ [經常] [間中] [很少] [無]
－ 手工差，剪不好圖形 --------- [經常] [間中] [很少] [無]
7. 玩遊戲/玩具 － 裝配玩具零件不靈活 -- [經常] [間中] [很少] [無]
－ 砌拼圖能力差 ----------- [經常] [間中] [很少] [無]
－ 畫圖畫差，空間位置感
不好 ----------------------- [經常] [間中] [很少] [無]
－ 不懂玩韆鞦，搖不動 --- [經常] [間中] [很少] [無]
8. 整理書包 – 凌亂，不整齊 ---------------- [經常] [間中] [很少] [無]

體能活動：

✓ 最適合的答案

1. 走路時無端跌倒 ------------------------------ [經常] [間中] [很少] [無]
2. 自己腳踢到自己腳或踏到別人的腳上 --- [經常] [間中] [很少] [無]
3. 行路或跑步的姿勢怪怪地 ----------------- [經常] [間中] [很少] [無]
4. 對距離的判斷不準確，會撞到周圍的人或
物件，如窗櫥、燈柱、枱角 ------------------- [經常] [間中] [很少] [無]
5. 跌或踫到周身瘀 ------------------------------ [經常] [間中] [很少] [無]
6. 對學習新的體能活動時，感到困難，做得
很「論盡」(如玩千秋、跳繩、踏單車、
游泳、球類活動) -------------------------------- [經常] [間中] [很少] [無]
7. 不能跟同齡小孩玩體能遊戲如踢球、攀爬
或追逐遊戲 ------------------------------------ [經常] [間中] [很少] [無]
8. 寧願與年紀較小的孩子玩體能遊戲 ------ [經常] [間中] [很少] [無]

9. 體育課時，易被老師/同學批評爲做得不
好或沒有盡力做 ------------------------------ [經常] [間中] [很少] [無]
10. 體能活動或體育課時，朋輩或同學不願選
擇他爲隊友或拍擋 --------------------------- [經常] [間中] [很少] [無]
11. 不喜歡體能活動或上體育課 -------------- [經常] [間中] [很少] [無]
12. 在玩球類活動如羽毛球、乒乓球時，不能
開波或拍到波 -------------------------------- [經常] [間中] [很少] [無]
13. 易感到攰，喜歡「攤」在床、地或椅上 ------ [經常] [間中] [很少] [無]
14. 坐姿不好，喜歡依傍着枱、椅或別人 ------ [經常] [間中] [很少] [無]
15. 做功課時，喜歡伏在桌上 ------------------- [經常] [間中] [很少] [無]
16. 特別留心或緊張時，會流口水或張開口--- [經常] [間中] [很少] [無]
17. 嬰孩時期有爬行 ------------------------------ [經常] [間中] [很少] [無]
18. 大肌肉發展(如行、跑、跳、上落樓梯) 比同齡小孩子慢 --------- [有] [無]
19. 小肌肉發展(如用手指拾小物件、扣鈕、執筆) 比同齡小孩子慢 --- [有] [無]
20. 不能玩公園中的____________________
21. 曾經/現在參與的課外活動
(a) 體能活動，曾經參與，如:____________________
現在參與，如:____________________
(b) 興趣班，曾經參與，如:____________________
現在參與，如:____________________
表現如何？ 跟得上嗎？____________________

Appendix IV Parent Consent form

香港理工大學康復治療科學系科研同意書

科研題目：正常發育及患有「發展性協調障礙」的孩子，在學習一種新的抓握動作時，如何調教他們的力度控制及動作反應時間。

科研人員：物理治療師梁玉華

導師：麥潔儀博士; Dr Kevin Kwong

科研內容：在測試過程中，小孩會坐在一張有靠背，適合他高度的椅子上，椅子貼近一矮桌，桌上放一斜板，其間斜板的斜度會被分別調教為 8° 或 15°。研究員會從斜板上將一架玩具車溜下，玩具車的重量會被分別調教為 180 克 或 340 克。當孩子看到車溜下時，他便要將玩具車抓起，使其離開斜板。如是者，孩子共重覆以上的動作 20 次，測試全程約需 25 分鐘，這些動作將會用作日後的電腦分析。

對項目參與人仕和社會的益處：是項測驗結果可使我們對一般小孩及患有「發展性協調障礙」的孩子的力度控制及動作反應有更深的認識，從而使治療師將來可以更有效地治療患有「發展性協調障礙」的小孩子。

潛在危險性：測試的動作不會引起孩子的不舒服或傷害他們的健康。

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、無任何原因放棄參與此次研究, 而此舉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給與此研究無關的人員，我的名字或相片不會出現在任何出版物上。

本人可以用電話 2727____ 來聯繫此次研究課題負責人:物理治療師梁玉華。若本人對此研究人員有任何投訴，可以聯繫梁女士（部門科研委員會秘書），電話：27665397。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：__________________