LOW(ER) MOTOR COMPETENCE IN OBESE CHILDREN: TOWARDS A BETTER UNDERSTANDING OF THE CONTRIBUTING FACTORS

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In 1962, Neel published his widely cited article entitled *Diabetes mellitus: a “thrifty genotype” rendered detrimental by “progress”* in which he proposed that efficient and rapid fat storage in times of plenty would have been advantageous to survive at periods of famine in ancient history (i.e., two million years ago). Evidence supports the hypothesis that a combination of famine and food scarcity naturally selected those individuals with efficient fat storage (Richards & Patterson, 2006). Historically, a heavy or fat child meant a healthy child, one who was more likely to survive in times of malnutrition and food shortage compared to a leaner child (de Onis et al., 2010; Ebbeling et al., 2002). However, in modern society, where there is abundance of unhealthy and energy dense food such genes are likely to be disadvantageous because they promote fat storage in preparation for famine that probably never comes (Lob-Corzilius, 2007). Adding this together with a significant decrease in physical activity levels of people living in modern society (i.e., characterized by social development, economical welfare, and technological progress) compared with people living two million years ago, this results in widespread obesity (Lobstein et al., 2004).

The growing prevalence of childhood obesity contributed to the importance of research on motor competence in obese children, especially since well-developed skills can be seen as precursors of successful and continuing engagement in physical activity as well as the foundations for sport-specific skills (Barnett et al., 2009; Bonvin et al., 2012; Lopes et al., 2011; Poulsen et al., 2011; Stodden et al., 2008). A previous dissertation entitled “Motor competence in overweight and obese children” already highlighted that the level of motor competence is inversely related to weight status in childhood (D’Hondt, 2011a). Yet, differences in motor skill performance between obese children and their healthy-weight peers are mainly observed during the execution of gross motor tasks which can be explained by the mechanical constraints associated with moving excess mass.

However, fine motor competence is equally important and needs further investigation in the obese population since recent studies tentatively argued that childhood obesity is also associated with poorer fine motor skill performance (Bernard et al., 2003; D’Hondt et al., 2008, 2009; Petrolini et al., 1995). It seems that obese children have difficulties with the integration of sensory information as well as transmitting proper muscle commands in the planning and control of movement which points to a poorer perceptual-motor function. Numerous studies already established a possible link between a decreased perceptual-motor function, and children’s academic achievement (Cameron et al., 2012; Grissmer et al., 2010; Son & Meisels, 2006). Furthermore, perceptual-motor problems are likely to hinder the
continuous engagement in various forms of physical activity as well as the successful execution of simple daily life tasks (Henderson & Sugden, 1992). Further research is thus paramount to clearly identify the underlying mechanism(s) of a non-optimal perceptual-motor function in obese children. By obtaining a better insight in the mechanisms explaining possible motor difficulties in the obese pediatric population, we hope to contribute to the development of tailored intervention programs aimed at enhancing (fine) motor competence in these children and help movement therapists, teachers, parents, etc. in giving valuable movement tips and tricks, instruction and guidelines.

Therefore, the present doctoral thesis will specifically focus on the association between childhood obesity and (fine) motor competence in primary school children (6- to 12-year-old). Understanding the interrelationship between both factors is important as it can help to determine which interventions are needed to have a positive impact on both (factors). This doctoral research must be seen as a first step towards a better understanding of the factors contributing to obese children’s (in)competence in both gross and fine motor skills. Before addressing the original research in separate chapters, the general introduction will start with a brief review of the literature focusing on alarming facts and figures associated with the childhood obesity epidemic. In the next section, a more detailed understanding of children’s motor competence and development through childhood will be given with a focus on possible differences according to weight status. Finally, in the third section, the research questions and the outline of this thesis will be presented.
REFERENCES


PART 1:
GENERAL INTRODUCTION
& OUTLINE OF THE THESIS
1. **THE CHILDHOOD OBESITY EPIDEMIC: (ALARMING) FACTS & FIGURES**

1.1. **Definition(s) of overweight and obesity**

The disparate use of the concepts ‘overweight’ and ‘obesity’ entails some confusion. Since these two important health conditions are often not clearly defined, this dissertation starts with a clear definition of both concepts. **Overweight** can be defined as a condition of excess body weight relative to body height, regardless of a person’s body composition (including percentage body fat) (Freedman et al., 2005). This term is frequently used to refer to a moderate form of obesity or to identify people at risk for the development of obesity. **Obesity**, on the other hand, explicitly refers to a condition of excess body fat(ness) and is associated with an increased risk of numerous health problems (Flegal et al., 2010; Krebs et al., 2007).

1.2. **Prevalence and trends in childhood obesity**

Using the widely accepted International Obesity Task Force (IOTF) criteria (Cole et al., 2000), it has been shown that in the past decades both prevalence and severity of overweight and obesity in children has increased dramatically worldwide (Berghöfer et al., 2008; Brug et al., 2012; Flegal & Troiano, 2000; Lobstein et al., 2004; Ogden et al., 2012; Olds et al., 2010). This means that there is not only an increase in the number of children facing one of these conditions, but also that the degree of overweight and obesity in itself is increasing. Based on global IOTF data, nowadays 200 million primary school children are estimated to be overweight including 40 to 50 million suffering from obesity (http://www.iotf.org). Worldwide, childhood overweight and obesity is reported to be the highest in the United States (U.S.). Most recent data indicate that 31% of the American school-aged youth suffers from overweight, including 16.9% with obesity (Ogden et al., 2012), followed by Europe where approximately 20-25% suffers from overweight, including 5-10% with obesity (Brug et al., 2012). But also in other developed and developing countries prevalence levels are rising (Olds & Maher, 2010). For example in Brazil, prevalence levels of underweight are dropping and levels of overweight are rising in children due to the rapid economic changes and the increase in food supplies (Wang et al., 2002).

In **Europe**, overall prevalence levels of overweight (including obesity) are high among children and adolescents. Based on the IOTF standard (Cole et al., 2000), recent data indicate that overweight levels range between 21.8% (including 4.1% with obesity) and 25.8% (including 5.2% with obesity) among European school-aged girls and boys,
respectively (Brug et al., 2012) (see Figure 1). Prevalence rates vary greatly across European countries, with the highest prevalence levels being observed in southern European countries also referred to as a north-south trend (Brug et al., 2012; Lobstein et al., 2004; Lobstein & Frelut, 2003; Pigeot et al., 2009). For example in Greece, 44.4% of the Greek boys are overweight, with 11.2% being obese, and 37.7% of Greek girls are overweight, including 9.7% obese (Brug et al., 2012). Conversely, school-aged children in northern European countries show lower prevalence rates in the range of 10-20% (Lobstein & Frelut, 2003). In Norway, for example 15.1% of the boys are overweight (including 0.4% with obesity) and 13.8% of the girls (including 2.4% with obesity) (Brug et al., 2012). The nature of these differences between the northern and southern part of Europe is not completely clear. According to Lobstein et al. (2004), the problem could be found in a difference in socio-economic status (SES) between the northern and southern regions of Europe. People in the south of Europe would be at greater risk to develop overweight or obesity because of a lower SES compared to the north of Europe.

Based on the same European data set, Brug et al. (2012) reported an overweight prevalence of 16.9% in Belgian boys and 13.5% in Belgian girls aged 10-12 years, with obesity alone accounting for 3.7% and 2.3%, respectively. From these recent Belgian data, it can be concluded that prevalence levels in Belgium are comparable with the prevalence rates in northern regions of Europe.

Over the last three decades, childhood obesity prevalence levels have been increasing with an average of 0.5% per year (Olds & Maher, 2010). However, recent data of the last 5 to 10 years indicate a clear tendency towards a stabilization in the prevalence rates of overweight and obesity in children and adolescents from Australia (O’Dea & Dibley, 2009; Olds et al., 2010), Europe (Lioret et al., 2009; Lissner et al., 2010; Mitchell et al., 2007; Salanave et al., 2009), Japan (Yoshinaga et al., 2009) and the USA (Benson et al., 2009; Ogden et al., 2010), while increases were still observed in Chinese and Vietnamese children (Dieu et al., 2009; Ji et al., 2009). The idea that prevalence levels of overweight and obesity in children continue to rise could be questioned and a certain leveling off of the obesity epidemic could be tentatively suggested (Olds & Maher, 2010; Rokholm et al., 2010).

This does not indicate that the epidemic is losing his strength and is gradually being solved. Because the global assessment of trends in the obesity epidemic is a time-consuming and major challenge, it must be clear that the available evidence for a possible leveling off is far from comprehensive. Furthermore, it must be kept in mind that the number of overweight and obese children remains dramatically high and has never been larger than today (Brug et al., 2012; Rokholm et al., 2010). These high numbers are alarming because of the negative impact of overweight and obesity on physical health and psychosocial wel-
being, even at a young age. Research into the consequences, causes, prevention and treatment of obesity is therefore paramount and should be a priority.

**Figure 1.** Geographical prevalence (%) of overweight (OW) and obesity (OB) among boys (M) and girls (F) aged 10-12 years from seven European countries using the cut-off points recommended by the International Obesity Task Force (adapted from Brug et al., 2012 & Verloigne, 2012).
1.3. Assessment of childhood overweight and obesity

Accurate assessment of body composition is important and offers the possibility to (correctly) identify children as overweight or obese. During the last decades, extensive research into the methods to assess weight status in children and adolescents has been performed. Ideally, obesity assessment should be done with a measure which allows to estimate total body fat mass or percentage body fat including magnetic resonance imaging (MRI), densitometry (e.g., under water weighing and air displacement plethysmography or BODPOD), computerized axial tomography (CT or CAT), dual-energy X-ray absorptiometry (DeXA), and isotope dilution (Deurenberg & Yap, 1999; Fields & Goran, 2000; Lobstein et al., 2004). In spite of the high degree of accuracy (i.e., small measurement error) associated with these laboratory techniques, most of them entail high costs and require a high level of expertise to use the assessment equipment properly. Furthermore, many of the abovementioned methods use radiation and other techniques that are not suitable for use in children (Goran et al., 1996). A last disadvantage can be found in the fact that each of these techniques is too time-consuming to be used on a large scale (Deurenberg & Yap, 1999; Edelman et al., 1993; Lobstein et al., 2004). To deal with the disadvantages of the abovementioned laboratory techniques, indirect measures or measures of relative fatness were developed which are easier to apply in field conditions.

One possible alternative technique is bioelectrical impedance analysis (BIA), which measures the impedance of the body to the flow of a low-level electric current being transmitted through the body. BIA assumes that fat mass contains no water and fat-free mass is hydrous. The latter contains large amounts of water and electrolytes and is a good electrical conductor whereas fat mass is a poor conductor. Therefore, conductivity will reflect the amount of fat-free mass in the body (Houtkooper et al., 1989; Lobstein et al., 2004; Lukaski et al., 1985; Roche et al., 1993; Schaefer et al., 1994). Fat-free mass can be estimated from the measured impedance by entering the resistance data into regression equations (and by subtraction, the fat mass can also be calculated) (Lobstein et al., 2004). BIA is perhaps the most accessible, widely used, time saving, inexpensive, and portable measurement method, and is considered an ideal tool for body composition analysis and estimation of percentage body fat in children (Dehghan & Merchant, 2008; Kettaneh et al., 2005; Pecoraro et al., 2003). Nevertheless, there are a number of factors that influence the measurement, including body shape, body and skin temperature, skin humidity, nutritional status, physical activity level, and posture during measurement. Prediction equations for BIA also need to be chosen very carefully according to age, gender, level of physical activity,
level of overweight and ethnicity of the population under study (Deghan & Merchant, 2008; Deurenberg & Yap, 1999).

A number of other anthropometric-based measurements are available such as measuring and computing skinfold thickness, waist-to-hip ratio, waist circumference and body mass index (BMI). These indirect measures are widely used estimates of fatness and have been used extensively in large epidemiological studies because they can be applied more easily in children than laboratory techniques (Deghan & Merchant, 2008; Lobstein et al., 2004). Despite the fact that these indirect measures are less accurate in estimating body fat than laboratory measures, numerous studies showed a strong relationship between anthropometric-based measurements and laboratory techniques such as densitometry or DEXA ($r^2 = 0.71-0.87$) (Goran, 1996; Goran et al., 1998; Van Loan & Mayclin, 1992). It must be kept in mind that the criterion validity of these indirect methods is lower compared with the accurate laboratory methods described above (Deurenberg & Yap, 1999).

In practice, however, laboratory measurements of body fatness have proven to be difficult in children. Consequently, an anthropometric-based measurement of body weight rather than a direct measurement of body fatness is frequently used to estimate body fat in children. Nowadays, the most common measurement tool in children is the BMI also referred to as the Quetelet index, which was originally developed by the Belgian statistician Adolphe Quetelet (1796-1874) and has to be calculated as body weight in kilograms divided by the squared height in meters ($kg/m^2$) (Eknoyan, 2007). It is an indirect measure of obesity based on the assumption that a different weight for individuals of the same length is mainly due to a difference in fat mass, although the latter is not effectively measured. Using BMI to estimate body composition in children has several advantages. This measure is highly correlated with laboratory measures of body composition including DEXA ($r^2 = 0.85-0.89$) (Must & Anderson, 2006; Pietrobelli et al., 1998). Furthermore, BMI in children also correlates well with health-related measures and with various adverse complications of childhood obesity, such as hypercholesterolemia, hypertension, and long-term development of cardiovascular disease (Pietrobelli et al., 1998; Straus, 2002). It must be mentioned that these results only relate to Western populations since the relationship between BMI and body fat greatly varies across populations (Lobstein et al., 2004). BMI is often used as a screening tool for overweight and obesity based on which individuals can be referred to specific anthropometric assessment of body fat (Must & Anderson, 2006). Despite the likelihood of misclassification of a small percentage of “false positives” (i.e., high BMI but low body fat), the great majority of individuals with high BMI actually have excess body fat. Using BMI to estimate body fat is not without limitations. First of all, BMI cannot distinguish fat mass and fat free mass and no information about body fat distribution can be given (Semiz et al., 2006; Wells & Fextrell,
2006). However, knowledge about abdominal fat as an indicator of central fatness is of particular concern because it is correlated with a higher prevalence of metabolic and cardiovascular diseases (Gary & Tang, 2007). Furthermore, BMI might not be a sensitive estimate of body fatness in people with exceptional body height (i.e., very short or tall), an unusual fat distribution, or strong muscle development (e.g., increased lean muscle mass in athletes or body builders). Finally, the relationship between BMI and body fat percentage varies widely among individuals and according to race (Lobstein et al., 2004; Straus, 2002). Nevertheless, BMI is widely recognized as the most universally applicable method to estimate body fatness and can be used to categorize people as healthy-weight, overweight or obese throughout the life span.

In adults, the World Health Organization (WHO) BMI cut-off points of 25 and 30 kg/m² are used to classify overweight and obesity, respectively (WHO, 2000). Given that children’s and adolescents’ BMI greatly varies with physical growth and maturation, age- and gender-specific reference values must be used to define childhood and adolescent overweight and obesity (Cole et al., 2000; Lobstein et al., 2004). Numerous classification methods based on specific BMI cut-off points in specific reference populations have been developed to define overweight and obesity in both children and adolescents. However, results can vary considerably when different cut-offs are used (Janssen et al., 2005; Wang et al., 2004).

In many countries, BMI reference data originate from monitoring children’s growth and development. One reference set of BMI values that has been widely used in the U.S. is based on age- and gender-specific 85th and 95th percentiles of national reference data that are employed as cut-off points to identify childhood overweight and obesity, respectively (Cole et al., 2000; Must et al., 1991; Olds & Maher, 2010). These BMI-for-age charts were initially developed by Must et al. (1991) and were updated and revised in 2000 by the U.S. Centers for Disease Control and Prevention (CDC; Kuczmaszki et al., 2000) based on data from five large representative American surveys. For wider international use, it is questioned why other countries would apply cut-off points that are exclusively based on data from an American reference population (Cole et al., 2000). Regardless of the reference population, the rationale for using the 85th or 95th percentiles can also be criticized as arbitrary (Olds & Maher, 2010). More specifically, the use of 85th and 95th percentile cut-off points includes the assumption that the prevalence of overweight and obesity is the same for boys and girls and for each age group (i.e., 15% will always be overweight and 5% obese) (Jebb & Prentice, 2001).
In 2000, the IOTF (Cole et al., 2000) developed BMI criteria that could be used for international comparisons without depending on U.S. reference data solely and without using specific percentiles of a specific population. Based on six pooled international data sets (i.e., Brazil, Great Britain, Hong Kong, the Netherlands, Singapore, and the U.S.), age- and gender-specific BMI cut-off points were developed for children 2 to 18 years of age. This IOTF standard was derived from percentile curves that passed through the adult cut-off point of 25 kg/m² for overweight and 30 kg/m² for obesity at the age of 18 years (Cole et al., 2000; Lob-Corzilius, 2007). Based on these IOTF criteria, it can be determined which BMI-value corresponds with overweight or obesity at any given age varying between 2 and 18 years with an interval of six months (see Table 1). A major limitation of the IOTF cut-offs could be found in the fact that the reference data sets not adequately represent non-Western populations and therefore must be used with caution outside the reference population. Nevertheless, being simple to use and linked to the WHO adult cut-offs for overweight and obesity, the IOTF classification system is especially recommended to facilitate international comparisons and closely monitor the global obesity epidemic (Wang et al., 2004).

In conclusion, national (local) and international references can be used to identify children as overweight and obese. For use within a single country, a national reference often will be more suitable, allowing to compare children with a reference group of children from the same country. For international comparisons of prevalence, a consistent definition should be used across countries or research groups. It must be acknowledged that both methods have their advantages and limitations (Wang et al., 2004). The continued use of BMI-based definitions has many practical advantages, including relative ease of obtaining weight and height measurements. However, some of the limitations of these definitions should also be recognized, including the statistical rather than clinical definition of cut-off values and the approximate nature of BMI as a measure of body fatness. Despite their limitations, BMI-based definitions of overweight and obesity provide practical definitions that are valuable for general public health services (Olds & Maher, 2010).
**Table 1.** International BMI cut-off points for overweight and obesity by gender between 2 and 18 years, defined to pass through body mass index of 25 and 30 kg/m² at age 18, obtained by averaging data from Brazil, Great Britain, Hong Kong, Netherlands, Singapore, and United States (adopted from Cole et al., 2000). The age range of the children participating in the studies mentioned in the original research of this doctoral thesis is marked in grey.

| Age (years) | Body mass index 25 kg/m² | | Body mass index 30 kg/m² | |
|-------------|--------------------------|--------------------------|--------------------------|
|             | Males | Females | Males | Females |
| 2           | 18.41 | 18.02   | 20.09 | 19.81   |
| 2.5         | 18.13 | 17.76   | 19.80 | 19.55   |
| 3           | 17.89 | 17.56   | 19.57 | 19.36   |
| 3.5         | 17.69 | 17.40   | 19.39 | 19.23   |
| 4           | 17.55 | 17.28   | 19.29 | 19.15   |
| 4.5         | 17.47 | 17.19   | 19.26 | 19.12   |
| 5           | 17.42 | 17.15   | 19.30 | 19.17   |
| 5.5         | 17.45 | 17.20   | 19.47 | 19.34   |
| 6           | 17.55 | 17.34   | 19.78 | 19.65   |
| 6.5         | 17.71 | 17.53   | 20.23 | 20.08   |
| 7           | 17.92 | 17.75   | 20.63 | 20.51   |
| 7.5         | 18.16 | 18.03   | 21.09 | 21.01   |
| 8           | 18.44 | 18.35   | 21.60 | 21.57   |
| 8.5         | 18.76 | 18.69   | 22.17 | 22.18   |
| 9           | 19.10 | 19.07   | 22.77 | 22.81   |
| 9.5         | 19.46 | 19.45   | 23.39 | 23.46   |
| 10          | 19.84 | 19.86   | 24.00 | 24.11   |
| 10.5        | 20.20 | 20.29   | 24.57 | 24.77   |
| 11          | 20.55 | 20.74   | 25.10 | 25.42   |
| 11.5        | 20.89 | 21.20   | 25.58 | 26.05   |
| 12          | 21.22 | 21.68   | 26.02 | 26.67   |
| 12.5        | 21.56 | 22.14   | 26.43 | 27.24   |
| 13          | 21.91 | 22.58   | 26.84 | 27.76   |
| 13.5        | 22.27 | 22.98   | 27.25 | 28.20   |
| 14          | 22.62 | 23.34   | 27.63 | 28.57   |
| 14.5        | 22.96 | 23.66   | 27.98 | 28.87   |
| 15          | 23.29 | 23.94   | 28.30 | 29.11   |
| 15.5        | 23.60 | 24.17   | 28.60 | 29.29   |
| 16          | 23.90 | 24.37   | 28.88 | 29.43   |
| 16.5        | 24.19 | 24.54   | 29.14 | 29.56   |
| 17          | 24.46 | 24.70   | 29.41 | 29.69   |
| 17.5        | 24.73 | 24.85   | 29.70 | 29.84   |
| 18          | 25    | 25      | 30    | 30      |
1.4. Causes

Individual’s body weight is controlled by numerous **physiological mechanisms** that maintain balance between energy intake (i.e., dietary behavior) and energy expenditure. Total daily energy expenditure consists of three main components which are resting metabolic rate (i.e., 60-75%), exercise or daily physical activity (i.e., 15-35%) and thermogenesis or the thermogenic effect of food (i.e., 5-10%) (Perkins, 2010) (see Figure 2). Weight gain is the normal physiologic response that occurs when energy intake exceeds energy expenditure (i.e., a positive energy balance) and will result in overweight and eventually in obesity when this energy imbalance persists.

**Figure 2.** The energy balance equation. Energy intake is symbolized by the food triangle and total energy expenditure by its three principal components: resting metabolic rate, exercise or daily physical activity, and thermogenesis (adapted from Perkins, 2010).

It is important to understand which factors have the possibility to upset the balance between energy intake and energy expenditure. Understanding these **causes** is a first step to counterbalance the childhood overweight and obesity epidemic. Because of the rapidly increased prevalence levels of overweight and obesity in genetically stable populations in recent decades, genetics alone cannot be the only explanation. If the cause would be purely genetic, the change in prevalence levels would be much slower (Anderson & Butcher, 2006; Eaton & Eaton, 2003; Ebbeling et al., 2002; Rosin, 2008). The epidemic of obesity is
probably caused by environmental factors affecting food intake and/or physical activity levels. Genetic factors, however, can have a great effect on an individual’s predisposition to develop overweight or obesity (Anderson & Butcher, 2006; Ebbeling et al., 2002; Rosin et al., 2008). It is clear that genetic factors may play an important role in the development of overweight or as Bray (1996) proposed “genes load the gun, and a permissive or toxic environment pulls the trigger”. Recent studies, therefore, emphasize the crucial interaction between intrinsic and extrinsic factors in the development of overweight and obesity (Barsh et al., 2000; Cole, 2007; Kiess et al., 2001; Rosin, 2008). It is during childhood that genetic and clearly environmental factors are of the greatest importance. Manipulation of the environment will have the greatest impact and the greatest potential to combat overweight and obesity in children.

1.4.1. INTRINSIC FACTORS

Twin studies show that 50–90% of the variance in BMI could be explained by genetic factors (Kiess et al., 2001; Lob-Corzilius, 2007; Maes et al., 1997). It was also found that the strongest risk factor for the development of childhood obesity is an obese weight status of (at least) one of the parents. This can be caused by a common genetic factor or environmental factors which are highly shared in the same household (i.e., family impact on energy expenditure and intake) (Cole, 2007). Whitaker et al. (1997) postulated that parental obesity more than doubles the risk of (adult) obesity among both obese and non-obese children under 10 years of age. At the moment, more than 20 genes have been discovered that may play a role in the development of body fat (Wyatt et al., 2006). These genes can be seen responsible for the development of obesity within families. Despite the fact that our understanding of the exact mechanism by which these genes have a negative effect on the energy balance (i.e., the genetic, biological, and biochemical factors underlying obesity) is currently incomplete, the use of novel approaches is rapidly unraveling this complex metabolic disease (Mutch & Clément, 2006; Wyatt et al., 2006). In recent years, significant progress has been made through genome-wide association studies. Based on this technique at least 19 genetic loci incontrovertibly associated with obesity were discovered in less than three years (Loos, 2009; Vimaleswaran & Loos, 2010). It can be expected that these newly identified genetic loci will offer new insights in the complex physiology regulating the energy balance.

Furthermore, gene mutations can also cause a deficit in the energy balance entailing a higher susceptibility to develop obesity. There are about 30 inherited disorders in which childhood obesity is a clinical feature, including Prader-Willi syndrome, Duchenne muscular
dystrophy, Bardet-Biedl syndrome, etc. (Bell et al., 2005). Yet, these disorders only explain a small percentage of childhood obesity, approximately 1–2 % (Lobstein et al., 2004).

1.4.2. EXTRINSIC FACTORS

Energy expenditure is one side of the energy balance equation and mainly determined by being physically active. Physical activity is defined by Caspersen et al. (1985) as any bodily movement produced by skeletal muscles that results in energy expenditure. Contrasting our ancestor’s lifestyle of hunting and fishing to survive, nowadays people do not have the necessity to be physically active to satisfy their basic needs in modern environments (Wyatt et al., 2006). Overall, trends in the built environment have resulted in more car trips and fewer foot or bicycle transportation and less physically active or more sedentary jobs due to modern technology (Wyatt et al., 2006). Furthermore, cities have less free and open spaces for children to be physically active like parks, recreational areas, bike lanes, playground, etc. The combination with more crowded traffic implying danger makes parents keep their children safe inside the house (Lob-Corzilius, 2007; Wieting, 2008). Accordingly, more and more children are not meeting the health recommendation of 60 minutes of moderate to vigorous physical activity per day (Sallis et al., 2000). Physical activity levels have declined dramatically in the past decades and the abovementioned factors all contribute significantly to an “obesogenic” environment resulting in reduced energy expenditure (Eaton & Eaton, 2003; Lob-Corzilius, 2007).

Beside physical activity levels that are declining, recent evidence underlines the importance of sedentary behavior which is another important energy balance-related behavior. Sedentary behavior refers to any waking behavior characterized by an energy expenditure ≤1.5 METs while in a sitting or reclining posture (Sedentary Behaviour Research Network, 2012). Nowadays, most children prefer sedentary pastimes such as watching television and using digital media (Biddle et al., 2004), and there seems to be a link between these sedentary activities (especially television viewing) and the prevalence of childhood overweight and obesity. Television viewing may affect children’s energy balance in several ways; it may increase children’s desire for energy dense snacks by the commercials and may reduce the time spent in more energy-expensive activities. Having a sedentary lifestyle was long time considered as the opposite of being sufficiently physically active, but research has demonstrated that sedentary behavior and physical activity are two unique behavioral constructs, independently related to various health outcomes such as overweight and obesity (Salmon et al., 2008). It is possible for an individual to accumulate large amounts of both moderate-to-vigorous physical activity (MVPA) and sedentary behavior in the course of a day.
because too much sitting is different from too little exercise (Healy et al., 2008; Owen et al., 2010; Tremblay et al., 2010). Sedentary behavior has been identified as a potentially risk factor for the development of chronic disease (Healy et al., 2007; Owen et al., 2009). Even if people meet the health recommendations for MVPA, there may be significant adverse metabolic and health effects from prolonged sitting (Healy et al., 2007). A systematic review by Tremblay et al. (2011) concluded that increased sedentary time was associated with unfavorable body composition in 5- to 17-year-old boys and girls. Thus, the health risk of sedentary behavior also applies to primary school children who have prolonged sitting time during school hours. Reducing sitting time may be as important as encouraging physical activity to prevent or treat (childhood) obesity. Recently developed guidelines on sedentary behavior recommend children to spend no more than 2 hours per day on screen time and to limit sedentary transport, prolonged sitting time and time spent indoors (Hamilton et al., 2008; Tremblay et al., 2011).

As seen in Figure 2, energy intake is at the other side of the energy balance equation opposing energy expenditure. A lot of dietary factors contributing to the total energy intake (i.e., sugar-sweetened beverages, portion size, family meals, meal frequency, fast food consumption, snacking, fruit juice consumption, and fruit and vegetables consumption, etc.) are potentially associated with the development of obesity (Ledoux et al., 2011; Moreno et al., 2010). In general, total energy intake has increased significantly in all age groups over the last 20 years (Nestle & Jacobson, 2000) and is associated with a high(er) caloric intake of energy-dense foods (Lob-Corzilius, 2007). A high consumption of sugar-sweetened beverages (Clabaugh & Neuberger, 2011; Woodward-Lopez et al., 2011) and a low meal frequency, especially breakfast frequency (Koletzko & Toschke, 2010; Rampersaud et al., 2005; Szajewska & Ruszczynski 2010), were identified as the most important energy (intake) balance-related behaviors associated with the development of overweight and obesity in 10- to 12-year-old children.

From the abovementioned factors, it is clear that not one critical cause for the increase in childhood obesity can be put forward. Rather, many complementary factors and environmental changes seem to have upset the energy balance by affecting children’s energy intake (i.e., an increase) and/or their energy expenditure (i.e., a decrease) (Anderson & Butcher, 2006).
1.5. Consequences

In the past decades, both prevalence and severity of childhood overweight and obesity has increased dramatically worldwide and childhood obesity has developed into a considerable worldwide public health problem with **significant economic and social consequences**. Most complications associated with childhood overweight and obesity only appear later in life. However, some consequences can already be seen at a young age (Daniels, 2006; Must & Strauss, 1999). Obese children who are already suffer from serious negative health effects at a young age will probably experience significant negative personal and health consequences for many years. This is not only detrimental for the obese child’s well-being but also for the society because of the high economic burden associated with the treatment of (childhood) obesity.

The most widespread consequences of childhood obesity are **psychosocial** in nature. At a young age, obese children are often the victim of systematical discrimination (Dietz, 1998) and stereotyped as (emotionally) unhealthy, academically unsuccessful or less intelligent, socially inept, unhygienic, and lazy (Hill & Silver, 1995; O’Brien et al., 2007; Puhl & Heuer, 2009). Children with overweight and obesity have less friends, do less well at school and are more bullied compared with their healthy-weight peers (Neumark-Sztainer et al., 2002). These negative social experiences with others hamper obese children in the development of their social skills and relationships. Obese children also have to deal more with emotional problems such as low self-esteem, increased anxiety and depressive thoughts (Warschburger, 2005). Preference tests also demonstrated that 10- to 11-year-old children rather prefer to be friends with children suffering a variety of disabilities, while overweight children are ranked lowest in the preference list (Dietz, 1998; Must & Straus, 1999).

Besides the stigma and negative social experiences associated with childhood obesity, several **medical complications** already appear at a young age having the potential to significantly impact on obese children’s physical well-being and quality of life. The impact of childhood overweight and obesity on the pulmonary system is not fully known (Kohler & van den Heuvel, 2008; Verhulst et al., 2008). Obesity appears to be an important risk factor in the development of sleep-disordered breathing and asthma in children (Kohler & van den Heuvel, 2008; Must & Straus, 1999). Of particular concern, is the fact that obese children with obstructive sleep apnea demonstrate clinically significant reductions in learning and memory function compared with obese children without obstructive sleep apnea (Rhodes et al., 1995).
Cardiovascular disease (CVD) is the leading cause of death worldwide (Hardy et al., 2004). The causes of CVD are diverse but atherosclerosis and hypertension are the most common. The pathology of CVD begins early in life, making prevention starting from childhood indispensable. The most important process for developing CVD is atherosclerosis or when an artery wall thickens or hardens as a result of the accumulation of fatty materials (i.e., cholesterol and triglycerides). This process starts with a fatty streak and evolves into a fibrous plaque that could ultimately cause a heart attack or a stroke caused by plaque ruptures that will block blood flow to the heart or to the brain, respectively. The well-known risk factors for this progression in adults include cigarette smoking, high blood pressure, elevated cholesterol, and diabetes (Daniels, 2006).

Childhood overweight is also related to some factors that are strongly associated with CVD, such as hypertension and dyslipidemia. Obesity seems to be associated with elevated blood pressure in children and the development of hypertension later in life (Daniels, 2006; Lauer et al., 1991), although the mechanism of this relationship is not fully understood. Dyslipidemia or abnormal changes in cholesterol and triglycerides in the blood may occur in children and adolescents as a result of obesity. The most common change associated with obesity is a decrease in HDL cholesterol and an increase in triglycerides which has the potential to accelerate the atherosclerosis process (Daniels, 2006).

Recently, higher inflammatory markers are being seen in children as a consequence of obesity which could have significant influence on factors like dental disease and gastrointestinal issues (Singer et al., 2014; Visser et al., 2001).

Type 2 diabetes, also known as adult-onset diabetes, is one of the most frequent pathological consequences of childhood obesity. However, until recently, the most common form of diabetes in children was Type 1. Increased weight gain represents the strongest factor contributing to the high incidence level of Type 2 diabetes in children (Dietz, 1998; Hardy et al., 2004). Other conditions associated with diabetes include a higher occurrence of metabolic syndrome in young people which is characterized by a compilation of cardiovascular disease risk factors (i.e., central fatness, glucose intolerance, dyslipidemia, high blood pressure).

The most common orthopedic problems in children include tibia vara (i.e., Blount’s Disease) and slipped capital femoral epiphysis. In children suffering these orthopedic complications, the capacity of bone and cartilage did not develop to an adequate level to carry their excess weight and complications appear to result from the impact of increased weight on a developing skeletal system. The excess body mass in obese children could lead to a bowing of the tibia and femur which could lead to tibia vara characterized by overgrowth
of the medial aspect of the proximal tibial metaphysis or slipped capital femoral epiphysis which is characterized by an external rotation of the femur from the growth plate (Daniels, 2009; Dietz, 1998; Must & Strauss, 1999). The pain and musculoskeletal discomfort associated with these complications could be associated with an impairment in obese children’s mobility or functionality which could increase the likelihood that overweight and obese children will withdraw from physical activity (Hardy et al., 2004; Taylor et al., 2006; Wearing et al., 2006). Withdrawing from physical activity opportunities could not only negatively impact on children’s (already) obese weight status but also on their level of motor competence (Stodden et al., 2008). Children not receiving enough opportunities to practice motor skills through physical activity will probably suffer from motor competence and coordination difficulties, which is the subject of our next section.
2. MOTOR COMPETENCE AND MOTOR DEVELOPMENT IN CHILDHOOD:
COMPARING HEALTHY-WEIGHT AND OBESE CHILDREN

The dramatic increase in the prevalence and severity of childhood obesity together with the increased likelihood that overweight and obese children would withdraw from physical activity and not receive enough movement opportunities (Hardy et al., 2004; Taylor et al., 2006; Wearing et al., 2006), stimulated the research into the relationship of childhood obesity with motor competence. There is a growing awareness that children’s motor competence level plays a crucial role in physical and psychological health during childhood and even throughout the lifespan. Therefore, a greater insight in the impact of overweight and obesity on children’s motor competence and development would be of great value in both prevention and treatment of the condition (Tsiros et al., 2011; Wearing et al., 2006). In this section, a more detailed description of children’s motor competence and development through childhood will be presented with a specific focus on possible differences according to weight status.

2.1. Motor competence: Definitions and concepts

In the literature, most of the motor development related terms are used inconsistently which often causes confusion. Agreement on the meaning of each of these terms has to be universal and consistency is needed. Before a detailed description of children motor’s development can be given, a conceptualization of the most frequently used terms in the motor domain will be given.

A motor or movement skill can be defined as a learned, goal-oriented, voluntary movement task or action of one or more parts of the body (Burton & Miller, 1998). Motor skills are most frequently categorized in two ways. By function (i.e., locomotor vs. object control skills) or according to muscle groups involved (i.e., gross vs. fine motor skills) (Burton & Rodgerson, 2001). Locomotor skills are movements that transport an individual through space from one place to another (e.g., running, hopping and skipping), whereas object-control skills include fine motor manual movements and gross motor skills that involve the control of objects primarily with the hands and feet (e.g., kicking, catching and throwing). Gross motor activities refer to movements of the entire body or major segments of the body (e.g., walking, maintaining balance and coordination). Fine motor activities refer to movements requiring precision and dexterity as in manipulative tasks (e.g., building blocks, rings and large puzzles or scribbling and drawing with crayons and pencils) (Gabbard, 2008). Many motor tasks incorporate both fine and gross motor elements (Malina et al., 2004).
Motor competence refers to the degree of skilled performance in a wide range of motor tasks as well as the movement quality, coordination and control underlying a particular motor outcome (Burton & Miller, 1998; Gabbard, 2008). Numerous studies confirm the relevance of an adequate level of motor competence in childhood by its relationship with social benefits, psychological well-being, physical activity, physical fitness and a healthy body composition, indicating that the level of motor competence in childhood is an important contributor to the health and well-being of children and later in life (Barnett et al., 2008; Bouffard et al., 1996; D’Hondt et al., 2011b; Fisher et al., 2005; Graf et al., 2004; Haga, 2008; Hands, 2008; Piek et al., 2006; Wrotniak et al., 2006).

Motor development reflects changes in motor behavior over the lifespan and the processes which underlie these changes and the factors that affect them (Clark & Whitall, 1989) which can be studied both as a process and a product. As a process, motor development involves the study of underlying individual, environmental, and task demands that influence change in motor behavior from infancy through older adulthood (Newell, 1986). As a product, motor development may be regarded as descriptive or normative change over time and is typically viewed as age-related changes in motor behavior and motor performance (Gallahue et al., 2012).

The essence of motor behavior and motor performance is based on a subject’s ability to receive and interpret sensory information leading to a modified response pattern. During life, there are numerous moments when the ability to recognize a stimulus and process information is critical to produce an effective motor response (e.g., catching a ball). To generate this successful motor response, a dynamic interplay between the perceptual and motor systems exists (Fjortoft, 2004). This is also referred to as perceptual-motor skills allowing sensory information to be successfully obtained and understood with appropriate reaction. The information-processing model include(s) four different phases and involve(s) the processes that are required to detect, process and convert a received internal or external stimulus into a motor response as displayed in Figure 3 (Gabbard, 2008).

![Figure 3. The general information processing (perceptual-motor) model (adapted from Gabbard, 2008, p. 171).](image-url)
First of all, afferent or sensory information (e.g., a light or a sound stimulus) stimulates sensory receptors (e.g., the retina or Golgi) by triggers received from the internal and external environment, also referred to as sensation. In the next phase, these nerve impulses are transmitted to the brain in forms of neural energy via afferent neural pathways (Gallahue et al., 2012; Gabbard, 2008). At this point perception occurs which can be seen as the monitoring and interpretation of sensory information in the cortex of the brain. Internal motor decisions are made based on the combinations of sensory and long-form information. Once the information is processed, it will be sent to the muscles and create a motor response in the motor action phase. Another complex function of the brain in this process is the integration of information coming from different sensory modalities. This sensory information provides the basis for the formulation of the actual motor response. Adequate motor response will only be produced if information from sensory modalities is continuously being integrated and adapted while formulating the motor response. All these phases together are called motor control processes.

2.2. The assessment of motor competence in childhood

Assessment tools for motor competence provide the opportunity to observe, document, and interpret change in motor behavior across the life span, as well as to determine the motor developmental position of an individual at a particular moment in time with respect to peers (Gabbard, 2008). These assessment tools are used for many reasons in multiple settings. Independent of the setting (e.g., hospitals, physical education classes, universities or home environment), objective, reliable and valid tools are required to make a complete and comprehensive evaluation of a child’s current level of motor competence (Gabbard, 2008; Cools et al., 2009; Van Waerlaerde et al., 2007; Williams & Monsma, 2007).

Techniques used for assessing motor competence ideally incorporate measures of both process and product aspects of movement performance. Product-oriented measures primarily focus on the performance outcome of motor behavior such as time, distance or successful attempts, and are quantitative in nature (Burton & Miller, 1998). Process-oriented measures, on the other hand, evaluate the presence or absence of different movement components for a given motor action and are most often qualitative in nature (for an example see Figure 4). This measurement technique is concerned with how the skill is performed rather than the outcome or product of the movement execution (Gabbard et al., 2008; Williams & Monsma, 2007). Results suggest that the relationship between process and product-oriented measures is strong but becomes even stronger as children become more proficient and more consistent in performance (Miller et al., 2007; Roberton & Konszak,
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2001). While both assessment methods are valuable in judging the motor competence of children, process-oriented assessment tools have the advantage of allowing accurate identification of those skill components with the lowest degree of mastery which may be targeted for improvement (Ulrich, 2000) (see Figure 4).

### Object control subtest

<table>
<thead>
<tr>
<th>Skill</th>
<th>Materials</th>
<th>Directions</th>
<th>Performance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Striking a stationary ball</td>
<td>A 4-inch lightweight ball, a plastic bat, and a batting tee</td>
<td>Place the ball on the batting tee at the child’s belt level. Tell the child to hit the ball hard. Repeat a second trial.</td>
<td>Dominant hand grips bat above nondominant hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nonpreferred side of the body faces the imaginary tosser with feet parallel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hip and shoulder rotation during swing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Transfers body weight to front foot</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bat contacts ball</td>
</tr>
</tbody>
</table>

### Locomotor subtest

<table>
<thead>
<tr>
<th>Skill</th>
<th>Materials</th>
<th>Directions</th>
<th>Performance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
<td>60 feet of clear space and two cones</td>
<td>Place two cones 50 feet apart. Make sure there is at least 8 to 10 feet of space beyond the second cone for a safe stopping distance. Tell the child to run as fast as possible as he or she can from one cone to the other when you say “Go”. Repeat a second trial</td>
<td>Arms move in opposition to legs, elbows bent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Broad period where both feet are off the ground</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Narrow foot placement landing on heel or toe (i.e., not flat footed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-support leg bent approximately 90 degrees (i.e., close to buttocks)</td>
</tr>
</tbody>
</table>

### Skill illustration

**Figure 4.** Illustration of an object control and a locomotor subtest of the TGMD-2, including a checklist of the different performance criteria for each skill (adopted from Ulrich, 2000).
A great repertoire of assessment tools have been developed to evaluate children’s motor competence (Cools et al., 2009), for example the Motoriktest für Vier- bis Sechsjährige Kinder (MOT4-6; Zimmer & Volkamer, 1987), the Movement Assessment Battery for Children (second edition) (MABC; Henderson & Sugden, 1992; MABC-2; Henderson et al., 2007), the Bruininks Oseretsky Test of Motor Proficiency – second edition (BOT-2; Bruininks & Bruininks, 2005), the Test of Gross Motor Development – second edition (TGMD-2; Ulrich, 2000), and the KörperkoordinationsTest Für Kinder (KTK; Kiphard & Schilling, 1974, 2007). Most of these assessment tools evaluate both gross and fine motor competence. The choice of which test battery to use depends on the purpose of the assessment tool and the age (group) of the children (Burton & Miller, 1998; Cools et al., 2009). In the studies presented in the original research of this doctoral thesis, the BOT-2 Short Form (Bruininks & Bruininks, 2005) and the KTK (Kiphard & Schilling, 1974, 2007) were used to assess children’s motor competence.

The BOT-2 is a clinical measure that is one of the most widely used tools by occupational therapists for evaluating motor deficits in children and adolescents and can be considered a reliable measure of both gross and fine motor skills in individuals, 4 through 21 years of age (Bruininks & Bruininks, 2005). The BOT-2 contains 53 different items from eight subtests: fine motor precision (seven items), fine motor integration (seven items), manual dexterity (five items), bilateral coordination (eight items), balance (nine items), running speed and agility (five items), upper limb coordination (seven items) and strength (five items). The BOT-2 Short Form derived from the BOT-2 is shorter and easier to administer and features a total of 14 items representing the same subtests (see Table 1 in Chapter 1, p. 70). Raw performance scores on the different BOT-2-items must be converted into point scores, which allow a participant’s item performances to be evaluated on a graded scale. Adding these individual point scores together, a subtest total point score is obtained. The total point score for the BOT-2 Short Form must be converted into a standard score according to age- and gender-specific normative tables based on reference values of 1520 children from 239 settings living in all states of the U.S. in 2004-2005. Most motor assessment tools have normative data that are only representative for the U.S. population. The absence of European normative data must be kept in mind when the BOT-2 is used for cross-cultural use because clearly identified differences between movement skill development of American and European children exist (Cools et al., 2009). All together, the items provide a comprehensive index of motor proficiency as well as separate measures of both fine and gross motor skills. For the BOT-2 Short Form (including knee push-ups), a very high inter-rater reliability coefficient of 0.98 and a test-retest reliability coefficient of 0.80 over a time interval of 7 to 42 days were found. Content validity was also shown by a high correlation (r =
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0.80) between the BOT-2 Short Form and the BOT-2 Complete Form (Bruininks & Bruininks, 2005).

The KTK is one of the few tests that mainly focuses on the gross motor coordination of children aged 5-15 years of age. It is a standardized product-oriented test, developed and recently revised by Kiphard and Schilling (Kiphard & Schilling, 1974, 2007). The popularity of this test battery for assessing the motor coordination of children has grown in different countries, amongst which Belgium and Portugal, and in different settings (i.e., medical, psychiatric, social and health-related settings). This original German test battery is a frequently used, highly reliable and valid instrument not only distinguishing between normal and motor-impaired children but also between normal and talented children. The test battery consists of four subtests all loading on one factor (i.e., gross motor coordination): (1) walking backwards along balance beams of decreasing width (6.0 cm, 4.5 cm, 3.0 cm), (2) moving sideways on wooden boards during 20 s, (3) one-legged hopping over foam obstacles with increasing height in consecutive steps of 5 cm, and (4) two-legged jumping from side to side during 15 s. The raw scores of each subtest are converted into a standardized score (i.e., motor quotient) adjusted for age (for all four subtests) and gender (for the one-legged hopping and two-legged jumping). The norms for these different motor quotients are based on the performance of a reference group consisting of 1228 normally developing German children in 1974. Adding together the four motor quotients results in an overall motor quotient (MQ), which is a general measure of the motor coordination of the children and allows for comparisons between different ages and gender. The MQ of children is normally distributed with a mean score of 100 ± 15 and can also be converted into a percentile score. The latter allows the classification of children in five different levels of gross motor coordination ranging from severe motor impairment (MQ <70; < 3rd percentile), moderate motor impairment (MQ = 71-85; 3rd–15th percentile), normal motor coordination (MQ = 86-115; 16th–84th percentile), good motor coordination (MQ = 116-130; 85th–98th percentile) to high motor coordination (MQ = 131-145; ≥ 99th percentile). Accordingly, in a normal population, a child with an overall KTK performance equal or below the 15th percentile (i.e., an MQ score below 86) faces gross motor coordination problems and is actually in need of special attention (Kiphard & Schilling; 1974, 2007). The psychometric characteristics of the KTK have been documented by Kiphard & Schilling (1974; 2007). For the raw score on the total test battery, a test–retest reliability coefficient of 0.97 was reported. For the raw scores on the four subtests, sufficiently reliable coefficients were reported ranging from 0.80 ≥ r ≤ 0.96. Furthermore, the KTK showed good internal consistency by showing strong significant relationships (0.60≥ r ≤ 0.81) between test items for the reference group of 1228 children. Good construct validity was proved through differentiation from disabled children. With the
KTK, 91% of children with brain damage could be differentiated from normally developing children. Content and internal structure validity were respectively demonstrated by a high explained variance on total KTK scores by the KTK subtests and by a factor analysis where all test items load on the same factor.

The previously mentioned assessment tools (i.e., BOT-2 Short Form and KTK) were used to investigate motor competence in this doctoral thesis because they are both frequently used, highly reliable and valid test instruments. Only recently, a study of Fransen et al. (2014) assessed the convergent and discriminant validity between these two test batteries (in 2485 children, aged 6-12 years), which is particularly interesting since both test batteries have been used frequently in research on motor competence in children (Barnett, 2008; Vandorpe et al., 2011). The moderately strong associations between the total scores for the BOT-2 Short Form and KTK show that both tests mainly measure the same construct, being general motor competence. Nevertheless, it seems that there is little standardized information on simple and easy-to-use evaluation of fine motor skills alone in children. At the moment, no motor assessment tool is considered the golden standard for assessing fine motor skills. Different research methods to evaluate fine motor skills are being used varying from questionnaires to standardized motor tests containing some fine motor items (Bruininks & Bruininks, 2005; Henderson & Sugden, 1992; Henderson et al., 2007; Zimmer & Volkamer, 1987). It is necessary to develop standardized guidelines to measure developmental change of fine motor skills in childhood. This dissertation will try to give the first step to evaluate fine motor skills from a different perspective.

2.3. Motor development in children

2.3.1. OUR THEORETICAL VIEW ON MOTOR DEVELOPMENT

To assist the reader in a consistent interpretation of our findings, this section will focus on the theoretical underpinnings of motor control and development on which this dissertation is based.

First of all, it needs to be mentioned that the original research included in this dissertation (cfr. chapters in PART 2) was not conducted from a theory-driven approach but from a descriptive point of view. In other words, the central aim of this dissertation was not to test assumptions of models related to a specific theory on motor development but to map the movement difficulties in obese children and to investigate the underlying factors or mechanisms leading to differences in motor competence compared to healthy-weight peers.
Accordingly, our studies mainly focus on the behavioral level and must be considered practically oriented instead of fundamentally based. Ultimately, a better understanding of the different factors affecting motor competence and development in children should lead to more specific guidelines to improve the complex issue of childhood obesity prevention and intervention. Nevertheless, the reader of this dissertation will benefit from a concise and comprehensive explanation of the theoretical viewpoint than can be used to frame our results.

A first theory is typically associated with a maturational view of motor development and considers our mind to be a computer that processes all kinds of information to control muscles and joints. This information processing model assumes that movement is prescriptive resulting from motor programs that are developed “a priori” and ran in the central nervous and musculoskeletal system. However, this model has been criticized given that external factors are not taken into account leading to the implicit assumption that motor development is predetermined from conception and birth onwards. According to a second theory or, Newell’s model of constraints (1986), motor behavior and the evolution thereof develops from the complex interaction of three distinct categories of constraints: organismic, environmental and task constraints (see Figure 5). In this model, organismic or individual constraints refer to a person’s unique set of physical (e.g., morphological, neurological) and mental characteristics (e.g., attention, motivation). Both other categories of constraints are external to the organism. Accordingly, Newell’s model emphasizes the need to consider the characteristics of the individual performer, the environment in which the action occurs and the specific requirements of the executed task in order to understand human movement. (Haywood & Getchell, 2009; Newell, 1986).

Figure 5: Schematic diagram of the three categories of constraints specifying motor behavior and the evolution in motor behavior (adapted from Newell, 1986).
Both theories contain a number of shortcomings that cannot easily be explained. As already mentioned, the information processing model does not take external factors affecting motor development into account. The second theory excludes the idea that the some kind of internal representation (motor program, schema, etc.) in the central nervous system is needed in controlling and adapting motor behavior. Furthermore, there is no general consensus on which theory is superior to the other and both theories can be used to understand motor control and development (Lenoir et al., 1999; Van der Kamp, 1999).

Basically, the dynamic systems approach or Newell’s constraints model (1986) can be seen as the foundation for our work. In line with this dynamic systems theory and contrasting the maturational view of motor development, we assume that motor development cannot be seen as the development of only one system (i.e., central nervous system) but rather as the development of multiple systems. In our model, weight status (i.e., morphological constraint) and the quality of the information processing system (i.e., neurological constraint) can in essence be considered organismic constraints. With respect to this neurological constraint, we do believe that a motor program or schema-based approach can be used to explain (fine) motor control. In our framework, the central nervous system and its neurophysiological processes are needed to produce effective motor behavior. However, our viewpoint does not exclude other external factors influencing this developmental process and motor behavior as for example the task constraints (i.e., gross vs. fine motor skills) or the environment (i.e., residential setting vs. home environment) in which motor behavior is being performed and the extent to which it is expressed in adequate motor competence. Because we believe in a combination of both theories as a framework for motor development, different terms and terminology originating from these different systems are used together throughout this work.

2.3.2. DETERMINANTS OF MOTOR DEVELOPMENT AND GENERAL FACTS

In this section, motor development will be discussed from a developmental systems perspective. This perspective holds the idea that human (motor) development is ‘the product of changing relations between the developing person and his or her changing multilevel environmental contexts’ such as the home environment, school, culture, etc. (Gabbard, 2008). This interrelated nature of human (motor) development is illustrated in Figure 6. This figure symbolizes how biological characteristics (i.e., heredity, maturation, and self-organizing properties) interact with environmental contexts (i.e., ecological systems and affordances) to determine motor development and behavior at any given point in time.
First of all, it needs to be mentioned that each child is unique and develops in its own unique way. Consequently, a wide range of individual differences in human (motor) development exist also known as variation in human motor behavior (Gabbard, 2008). Motor development is often described as distinct stages in the life span referring to age-related phases and changes in movement. These phases in motor development must be seen as general guidelines. It is assumed that specific milestones or motor behaviors may be accomplished at varying age levels and the ages at which certain milestones are acquired are therefore purely indicative because no specific age norms for the acquisition of motor skills in children exist (Cools et al., 2009; Malina et al., 2004). A child can sometimes be in different stages for the different fundamental movement skills. In addition, some children will have the ability to learn new skills faster than others. If a child is not able to perform the skills required to achieve a certain motor milestone at a given age, this does not mean that this child is motor delayed. At a given age, a child will perform motor skills above and below those indicated for their age which is perfectly logical and in line with the idea of the developmental systems perspective. Delays in motor development happen for a variety of reasons and not all delays occur because of a specific disorder. Some children just seem to have more trouble meeting milestones than others.
2.3.3. GROSS MOTOR DEVELOPMENT

Different developmental models depict the relationship between motor behavior and specific age-related stages and phases from infancy through childhood to adolescence (Clark & Metcalfe, 2002; Gabbard, 2008; Gallahue et al., 2012; Stodden et al., 2008). This doctoral thesis will focus on the developmental continuum of lifelong motor development by Gabbard (2008) which is illustrated in Figure 7.

![The development Continuum](image)

**Figure 7.** The continuum depicts the phases and stages of lifelong motor development (adopted from Gabbard, 2008, p. 13).
All developmental models are quite unequivocal. The first phase or reflexive phase, starts at about the third fetal month and continues into the first year of life as can be seen in the development continuum of Gabbard (2008) (see Figure 7). In this phase, children’s motor behavior is characterized by reflexes (i.e., primitive, postural and locomotor) and spontaneous movements which gradually disappear while voluntary control increases and children continue into the rudimentary phase. In this phase, voluntary movements in their first form are generally emerging in a cephalo-caudal / proximo-distal order such as creeping, walking, crawling and voluntary grasping.

In early childhood (from 2 to 6 years), fundamental movement skills (FMS) are gradually being developed in the fundamental movement phase (Clark & Metcalfe, 2002; Gabbard, 2008; Gallahue et al., 2012). FMS are mostly classified into locomotor (e.g., running, jumping and hopping), and object-control skills (e.g., catching, throwing and kicking) (Lubans et al., 2010). The FMS phase is a major milestone for the development of life-span motor development. Skills developed and acquired during this phase can be seen as the building blocks for efficient and more complex motor skills in later phases of the development (Clark & Metcalfe, 2002; Seefeldt, 1980). These building blocks are prerequisites for specialized movements and adequate participation in many organized and non-organized physical activities for children (Lubans et al., 2010; Malina et al., 2004). If children do not acquire basic motor competence during the early years, the ability to successfully perform in more complex motor skills, sports or games will be compromised. Accordingly, FMS are crucial to participate successfully and in an enjoyable way in physical activity, and can therefore be seen as the foundation for a physically active lifestyle (Logan et al., 2011a; Lubans et al., 2010; Malina et al., 2004).

The environment also plays an important role in the degree to which FMS develop. FMS do not naturally emerge in children but have to be taught, practiced and reinforced by both parents and teachers (Gabbard, 2008; Goodway & Branta, 2003; Malina et al., 2004; Robinson & Goodway, 2009). Early childhood is commonly recognized as the window of opportunity in which to develop FMS competence. During this window of opportunity, neural networking is optimal for gross motor skill development. That is, early childhood represents a critical period in neuronal development in which experience may be most effective in forging connections (Gabbard, 2008). This indicates that physical activity and early movement opportunities and experiences are of major importance in the early development of adequate motor competence in childhood. This also points to the fact that optimal development is activity-dependent which has significant implications for early movement experiences and motor development programs.
Children develop a variety of FMS during the preschool years (e.g., jumping, running, kicking, throwing, catching, etc.) and a vast majority of FMS are mastered by 6 or 7 years of age. The environment plays an important role in the degree to which these FMS develop since these FMS do not naturally emerge. Around the beginning of later childhood (from 6 years of age), these FMS are refined through practice and instruction in the **sport or specialized movement phase**. During this phase, the basic fundamental movement patterns are adapted and integrated into more complex movement activities, which are fundamental to many games and sports.

### 2.3.4. FINE MOTOR DEVELOPMENT

The previous section discussed the development of gross motor skills but **fine motor skills** are equally important and as essential for normal motor development through childhood (Henderson & Sugden, 1992).

The development of the brain and nerve pathways already starts during the growth of the fetus in the womb. From birth, the various motor and sensory areas of the brain develop step by step in a hierarchical order (Gabbard, 2008). Although several recent studies demonstrated that much of the brain development occurs during the first years of life (Dubois et al., 2008; Faria et al., 2010; Hermoye et al., 2006; Provenzale et al., 2007), this complex process of brain maturation continues well beyond infancy (Lebel et al., 2008; Lebel & Beaulieu, 2011). The cerebellum, better known as the small brains, registers the impulses from internal and external stimuli and sends impulses through efferent nerves to the effectors resulting in coordinated movements. At the age of four, most connections between the brains and the cerebellum are myelinated which makes it possible to send information with a higher speed to the effectors. However, this increased speed of information transmission is not required for the development of gross motor skills. Therefore basically every child can start learning these skills at the age of two. On the other hand, fine-motor skills do require a faster impulse conduction that can only be obtained when the myelin sheath is formed (around three to four years of age). Therefore, these skills can only be taught **starting from the age of four**.

Fine motor skills typically develop in a reasonably **consistent and predictable pattern** in the early years of childhood. The process begins in infancy when a two- to three-month-old baby first flickers at a toy. By age one, babies should be able to drop and pick up a toy and grasp an object, and put it into their mouth (i.e., releasing and transferring objects). Subsequently, they progress to use their fingers to manipulate and explore things and by the age of two a child should be able to throw a ball and scrabble with a pen. By age three,
children can usually copy a circle and build a tower with small blocks. A four-year-old should be able to copy a cross and print some letters. By the age of five, children start to use “school tools” such as scissors, markers, crayons, pencils and glue. Because children develop in their own unique way, they will possess varying skill levels in the first year of primary school, ranging from having highly developed fine motor skills to having very low fine motor skills.

An adequate level of fine motor skills (such as writing and drawing) is important because together with gross motor skills these skills can be seen as the foundation for basic skills needed in everyday life. Fine motor skills require a high level of fine motor coordination to be regulated with precision and they also rely on perceptual and cognitive functions. The automation of such fine motor skills consumes a lot of time and effort even for normally developing children (Ohtoshi et al., 2008). The possibility of a child to write legibly with appropriate speed is also a key requirement for taking notes during class and conducting exams associated with academic performance. About five percent of the primary school children fails to develop sufficient movement skills to achieve a typical progression at school level (Smits-Engelsman et al., 1998).

2.4. The role of motor competence for physical activity in childhood

There is a general consensus that the level of motor competence is not only important for the successful execution of everyday activities, but it is also an underlying factor paramount to learning other movements and skills essential to the context of physical activity in general and sports in particular (Henderson & Sugden, 1992; Burton & Miller, 1998; Clark & Metcalfe, 2002; Malina et al., 2004; Gabbard, 2008). The level of motor competence is believed to be the foundation for a physically active lifestyle (Barnett et al., 2009; Castelli & Valley, 2007; Clark & Metcalfe, 2002; Fisher et al., 2005; Lopes et al., 2011; Stodden et al., 2008; Wrotniak et al., 2006). If children do not acquire basic motor competence, the ability to successfully perform in more complex motor skills, physical activities, sports or games will be compromised (Malina et al., 2004).

This reciprocal and dynamic relationship between motor competence and physical activity is at the heart of a conceptual model proposed by Stodden et al. (2008) (see Figure 8). The authors propose different relationships between motor competence and physical activity according to children’s developmental age and believe that the relationship between motor competence and physical activity will strengthen over developmental time. It is suggested that young children’s physical activity drives their development of motor competence in early childhood (i.e., EC in the model). Increased physical activity at a young
Part 1

age provides more opportunities to promote neuromotor development and develop FMS. However, in early childhood, physical activity and motor competence are rather weakly related. As children transition to middle and later childhood (i.e., MC and LC in the model, respectively), Stodden et al. (2008) hypothesized that the relationship between physical activity and motor competence will strengthen. At this point in time, motor competence level drives physical activity levels as higher levels of motor competence offer a greater movement repertoire and more possibilities to engage in various physical activities regularly. In the model, different factors are taught to mediate and interact with the dynamic relationship between motor competence and physical activity. The mediating role of perceived motor competence and health-related fitness will be briefly discussed as these variables were no subject of our research in PART 2 of this dissertation.

First of all, it must be mentioned that perceived motor competence is a concept that changes across developmental time (Harter, 1999). In EC, perceived motor competence will not be strongly correlated to actual levels of motor skill competence nor physical activity as young children demonstrate limited accuracy in perceiving their motor competence and generally show overestimated levels of perceived motor competence relative to their actual motor competence (Goodway & Rudisill, 1997). By MC, children’s perceived motor competence will approximate their actual motor competence because a more sophisticated cognitive capacity allows them to more accurately compare themselves with their peers. Health-related fitness might also play a mediating role in the emergent relationship between physical activity and motor competence. In EC, the acquisition of FMS (i.e., motor competence) promotes physical fitness, again, with a weak relationship at this point in developmental time. In MC, however, children with higher actual and perceived motor competence will be more physically active and probably demonstrate higher health-related fitness.

As can be seen in Figure 8, there is a dynamic and reciprocal relationship between obesity and physical activity, motor competence, perceived motor competence and health-related fitness. Over time, higher perceived and actual levels of motor skill competence will motivate children to be even more physically active and will result in higher levels of health-related fitness, promoting a healthy weight status. These interactions can be referred to as a positive spiral of engagement, whereas in children with lower actual and perceived motor competence, a negative spiral of disengagement is seen. Children with low levels of actual motor competence demonstrate low(er) levels of perceived motor skill competence and low(er) levels of health-related fitness and are, by consequence, less (motivated to be) physically active. These children may also prefer more sedentary pastimes in order to avoid movement difficulties and will drop out of physical activity (Bouffard et al., 1996; Cairney et al., 2005; Wrotniak et al., 2006). Because adequate motor competence and physical activity
may assist in maintaining a physically active lifestyle, a lack thereof puts less skilled children at risk for developing overweight or obesity which will result in a negative spiral of disengagement (Cairney et al., 2005; Stodden et al., 2008). These outcomes will negatively feed back into the model, further lowering opportunities to develop their motor competence level.

Based on the conceptual model, motor competence plays an important role in adhering to a physically active lifestyle and children with lower movement skills could be at risk for developing overweight or obesity (Barnett et al., 2009; Castelli & Valley, 2007; Clark & Metcalfe, 2002; Fisher et al., 2005; Lopes et al., 2011; Stodden et al., 2008; Wrotniak et al., 2006). Therefore, **greater insight in obese children’s level of motor competence** would be valuable in further investigating the relationship between motor competence and physical activity and in the practical application of the conceptual model proposed by Stodden et al. (2008).

![Figure 8. Stodden’s conceptual model indicating the developmental mechanisms influencing physical activity patterns of children (adopted from Stodden et al., 2008)](image-url)
2.5. Relationship between level of motor competence and weight status in children

About 10 years ago, little attention was given to the relationship of childhood obesity with motor competence. Previously published studies mainly focused on the relationship between childhood obesity and the overall level of physical fitness and its different components (i.e., flexibility, speed, strength, endurance, etc.). For example, numerous studies have shown a strong inverse relationship between excess body mass and children’s performance on several physical fitness tests (Casajús et al., 2007; Deforche et al., 2003; Tokmakidis et al., 2006). Children with obesity appeared to have reduced physical fitness on all tests requiring propulsion or lifting the body mass (e.g., standing-broad jump, sit-ups, speed shuttle run, etc.). In tests requiring flexibility, excess body mass is not likely to hinder performance (Casajús et al., 2007; Deforche et al., 2003; Tokmakidis et al., 2006).

In contrast, motor competence within the obese childhood population was not yet thoroughly investigated. Only recently, studies focused specifically on gross motor competence in relation to children’s weight status and demonstrated that children’s motor competence (and coordination) indeed acts as an important predictor for their continuous engagement in physical activity (Barnett et al., 2009; Castelli & Valley, 2007; Lopes et al., 2011). Taking into account the fact that physical activity serves as a central component in both the prevention and treatment of obesity, greater insight into the actual motor competence of children facing this condition is required.

2.5.1. POSTURAL CONTROL & BALANCE

Obesity has been strongly linked to differences in postural control outcomes for both the adult and pediatric population (Bernard et al., 2003; Colné et al., 2008; Deforche et al., 2009; D’Hondt et al., 2008; D’Hondt et al., 2009; Goulding et al., 2003; Hue et al., 2007; McGraw et al., 2000). Within the adult population, excess mass appears to affect body geometry and segment mass, potentially influencing the ability to maintain balance (de Souza et al., 2005). Although research into the effects of altered body geometry has not been completed in the pediatric population, it is likely that increased body weight imposes a significant constraint on static and dynamic balance control during activities of daily living (Bernard et al., 2003; Hue et al., 2007; Savelsbergh et al., 2005).

Laboratory-based studies concerning postural control have reported contradicting findings on the relationship between weight status and balance impairment in children and
adolescents during quiet stance (Bernard et al., 2003; Colné et al., 2008; McGraw et al., 2000; D’Hondt et al., 2011c). Some studies suggest that static postural control is independent of weight status (Bernard et al., 2003; D’Hondt et al., 2011c). Conversely, Colné et al. (2008) found that instability during static conditions is limited to an increased sway area over the centre of pressure in obese compared to normal-weight adolescents when standing upright. Additionally, McGraw et al. (2000) demonstrated that obese boys had increased sway areas and variability in the medial-lateral direction than normal-weight prepubertal boys during quiet stance. Because excess mass has a large influence on the ability to shift weight laterally, obese children could display diminished medial-lateral stability. Therefore, they probably experience more difficulties in performing basic motor tasks that challenge medial-lateral stability. As challenges to the visual system accentuated between-group differences, McGraw et al. (2000) also suggested a higher visual dependency of obese boys during static postural control. Although this dependency has not been established in other postural control research (Bernard et al., 2003; D’Hondt et al., 2011c), it could be indicative for potential impairment in sensory organization among obese children.

Standardized field tests have shown a more consistent discrepancy between obese and normal-weight children’s performance on static balance tasks. For instance, obese boys showed lower performances during unilateral stance on a balance beam compared to normal-weight peers (Deforche et al., 2009). Similarly, Goulding et al. (2003) reported a negative relationship between fatness and static balance based on subtests of the Bruininks–Oseretsky Test of Motor Proficiency (Bruininks, 1978). Overweight and obese children also had lower performances than normal-weight counterparts on the static balance subtest of the Movement Assessment Battery for Children (D’Hondt et al., 2009; Henderson & Sugden, 1992) and the European physical fitness test battery (Adam et al., 1988; Deforche et al., 2003). When using the Movement Assessment Battery for Children, 20% of the variance in the balance score could be explained by BMI (D’Hondt et al., 2009). Overall, these clinical stability tests suggest that overweight and obesity impose constraints on children’s static balance. Since a stable static posture is crucial for adequate movement performance (Westcott et al., 1997), the obese children’s decreased static balance could therefore affect their ability and willingness to participate in activities of daily living and even more complex movement situations.

Dynamic balance is also an essential prerequisite to successfully engage in several activities of daily living. Graf et al. (2004) found that dynamic balance was poorer in obese compared to healthy-weight children when walking backwards along balance beams. Goulding et al. (2003) also reported diminished balance control when comparing overweight and normal-weight adolescents on five dynamic balance skills of the Bruininks–Oseretsky
Test of Motor Proficiency. In agreement with standardized field tests, laboratory-based studies have also found dynamic balance impairments in obese pre-pubertal boys, when compared to their normal-weight counterparts (Colné et al., 2008; Deforche et al., 2009; McGraw et al., 2000). However, the tasks used both in field and laboratory settings have focused on single plane motion. Accordingly, multi-planar motions such as found in physical activities could have an even stronger negative relationship to pediatric obesity. Although static and dynamic components are both important to overall motor function, the more consistent impairment in obese children occurred during dynamic balance tests (Colné et al., 2008; Deforche et al., 2009; Goulding et al., 2003; Graf et al., 2004; McGraw et al., 2000). Given that obese children consistently show poorer dynamic balance during basic motor tasks, more complex tasks could prove too difficult and prohibit further participation in physical activity.

2.5.2. LOCOMOTION

Even though locomotion is one of the most common and natural modes of physical activity, it is based on a complex biomechanical process (Saibene & Minetti, 2003). The postural control system is challenged to a much greater degree during locomotion activities compared to static and dynamic balance tasks. Forward progression includes unstable phases when the center of mass moves outside the base of support; during this time balance must still be preserved (Winter, 1995).

Previous studies showed an impaired dynamic balance performance in obese children (Deforche et al., 2009; Goulding et al., 2003; Graf et al., 2004). Given that dynamic balance is particularly important in terms of its contribution to gait, it could be assumed that their locomotion will be affected too. However, evidence concerning the gait characteristics of obese children is limited. The available literature suggests that excess mass negatively impacts on locomotion tasks such as walking, specifically affecting spatiotemporal parameters (Colné et al., 2008; Deforche et al., 2009; D’Hondt et al., 2011d; McGraw et al., 2000; Hills & Parker, 1991a, 1991b, 1991c, 1992; Morrison et al., 2008; Nantel et al., 2006).

Obese children walk with a larger step width and a greater base of support compared to normal-weight children (Deforche et al., 2009; Hills & Parker, 1991a, 1991b, 1991c). These adaptations in gait could be a consequence of the increased medial-lateral instability observed in obese children (Donelan et al., 2004; McGraw et al., 2000). It is hypothesized that obese children adjust their foot placement in order to enlarge the narrowed base of support associated with walking and thereby diminish medial-lateral instability. However, increased step width can also be attributed to increased thigh circumference, requiring that
the obese child maintains a wider base of support (Browning & Kram, 2007). Increased step width can have negative implications on joint kinetics; higher frontal plane joint moments can increase joint pain and reduce motivation to exercise (Gushue et al., 2005; Shultz et al., 2009).

The decreased dynamic stability in obese children also has an effect on the temporal parameters of gait. Obese children spend more time in double support stance phase and subsequently less time in swing phase than normal-weight children (Colné et al., 2008; Hills & Parker, 1991a, 1992; McGraw et al., 2000; Morrison et al., 2008; Nantel et al., 2006). The reduction in swing time produces a decreased step length (McGraw et al., 2000; Hills & Parker, 1991a, 1991c). These altered gait parameters allow the obese child to spend extra time in a more stable position and maintain dynamic balance. However, the tentative walking pattern associated with these changes can hamper optimal gait development in obese children. They could perceive these tasks as being more difficult and this could decrease their motivation to exercise.

2.5.3. GROSS MOTOR SKILL COMPETENCE

Gross motor skills rely on static and dynamic balance; therefore, the established balance impairments could also affect an obese child’s ability to perform gross motor skills. Differences in motor competence between obese and healthy-weight children seem to emerge already at a very young age given that obesity was already associated with impairment in gross motor competence in preschool children (Castetbon et al., 2012; Cawley & Spiess, 2008; Deforche et al., 2009; D’Hondt et al., 2009; Logan et al., 2011b; Lubans et al., 2010; Morano et al., 2011; Nervik et al., 2011; Slining et al., 2010; Tsiros et al., 2011). For example, Cawley & Spiess (2008) demonstrated an 11.1% lower probability of a perfect score on motor skills in 2- to 3-year-old obese boys compared to normal-weight boys. Prevalence of impairment in gross motor skills has been shown to be higher among 4- to 8-year-old obese males than in healthy-weight counterparts (Mond et al., 2007). These findings were also confirmed in 5- to 10-year-old overweight and obese children who displayed poor gross motor skills on the MABC (D’Hondt et al., 2009). Outcomes of the KTK showed decreased gross motor coordination in overweight and obese primary school children (D’Hondt et al., 2011b; Graf et al., 2004, 2007). In the study by Graf et al. (2004), overweight children were categorized as having a normal gross motor coordination, whereas children in the obese group were labelled as facing a moderate motor disorder. In the study by D’Hondt et al. (2011b), 43.3% of the overweight children, and more than 70% of the obese children were classified as being motor impaired in contrast to only 18.9% of the healthy-weight children. These findings confirm the assumption that children’s and adolescents’ ability to
perform gross motor skills is significantly related to their body composition (Okely et al., 2004). Multiple recent studies added significantly important evidence to this emergent area of research and confirmed the inverse relationship between childhood obesity and various measures of motor competence in primary school children (Cliff et al., 2011, 2012; Graf et al., 2004; Jones et al., 2010; Lopes et al., 2012; Lubans et al., 2010; Okely et al., 2004; Southall et al., 2004; Tsiros et al., 2011).

The negative association between weight status and gross motor skills even seems to deteriorate with increasing age in childhood (D’Hondt et al., 2011b). The detrimental effect of overweight and obesity is probably due to the fact that a greater proportion of excess mass has to be supported or moved against gravity while performing gross motor tasks (D’Hondt et al., 2009, 2011c; Deforche et al., 2003; Graf et al., 2007). This supports the assumption that excess mass could prevent overweight and obese children from an optimal execution of movement in preschool and primary school children.

2.5.4. FINE MOTOR SKILL COMPETENCE

Very few studies investigated the relationship between weight status and fine motor skills; and the resulting findings are not always conclusive. Some studies mention no differences in the prevalence of impairment in fine motor skills between obese and healthy-weight children (Bonvin et al., 2012; Castetbon et al., 2012; Mond et al., 2007). Similarly, obese and healthy-weight children tend to show no differences in speed of limb movement on a plate tapping task in which only the distal limb itself is moved (Deforche et al., 2003; Malina et al., 2004). The basic task of plate-tapping limited the amount of non-contributory mass involved, allowing obese children to perform similarly to healthy-weight children. When the fine motor skill required more complex dexterity, significant differences in fine motor skills between obese and healthy-weight children were found. For example, D’Hondt et al. (2008) investigated fine motor competency on a peg placing task. The increase in manual dexterity necessary to grip a peg and accurately position it on a board proved more difficult for obese children. This decreased fine motor competence was also confirmed by a tendency towards lower scores among obese children on the manual dexterity cluster of the Movement Assessment Battery for Children (D’Hondt et al., 2009). Because fine motor skill is seemingly affected when non-contributory mass is limited but the task is complex, excess mass cannot solely explain these differences. This finding is in line with a previous study, suggesting poor fine motor performance in obese children when sensory information was needed to plan and control movement (Petrolini et al., 1995). Therefore, an impairment in the obese children’s
perceptual-motor function can be suggested (Bernard et al., 2003; D’Hondt et al., 2008, 2009; Petrolini et al., 1995; Wearing et al., 2006).

2.5.5. CONCLUSION

Evidence suggests that excess mass negatively impacts on obese children’s execution of gross motor tasks (Deforche et al., 2003; D’Hondt et al., 2009; 2011a, 2011b; Graf et al., 2004; Hills et al., 2002; Hue et al., 2007; McGraw et al., 2000; Tsiros et al., 2011). It was hypothesized that obese children’s reduced gross motor competence could be explained from a pure **mechanical point of view** which implies that obese children move differently compared to their healthy-weight peers due to the detrimental effect of supporting and moving a greater proportion of excess noncontributory mass against gravity and due to their different mass distribution. However, recent findings illustrate that not only gross motor competence but also fine motor competence is impaired in obese children, although the mechanical load to the system is greatly diminished in these tasks (Bernard et al., 2003; D’Hondt et al., 2008, 2009; Petrolini et al., 1995). In fine motor tasks, performance is predominantly determined by the quality of processing and integrating sensory information as well as transmitting proper muscle commands. Accordingly, it can be tentatively argued that obese children encounter difficulties when sensory information is needed to plan and control movement. **Perceptual-motor difficulties** may therefore play a role in explaining poorer (fine) motor skill outcomes in obese compared to healthy-weight children.

Greater insight into the exact nature of lower gross and fine motor competence among obese children is therefore essential. Research is required to obtain a more detailed understanding of the specific (fine) motor skills and possibly related perceptual-motor functions that are affected in obese children.
3. RESEARCH QUESTIONS AND OUTLINE OF THE THESIS

In the general introduction, the relevant literature related to the childhood obesity epidemic and the relationship between childhood obesity and motor competence was reviewed. As outlined in this introduction, essential knowledge regarding possible differences in fine motor skill competence according to children’s weight status (obese vs. healthy-weight) is currently lacking. Therefore, the general purpose of this doctoral thesis was to gain greater insight in obese children’s motor (in)competence and to obtain a better understanding of the two mechanisms (i.e., mechanical vs. perceptual-motor hypothesis, see conclusion p. 45) that are frequently used to explain lower motor competence in obese compared to healthy-weight children. Part two of this doctoral thesis contains original research that has been conducted to further explore these two mechanisms in five different studies with their own specific research questions. The original research consists of a collection of scientific articles that are published, accepted or under-review in international peer-reviewed journals. The purpose and the design of each individual study will be described in more detail in the section below.

All studies in this thesis were conducted to serve one overall objective which is to obtain a better understanding of the factors contributing to lower motor competence in obese children as compared to healthy-weight peers.

- The first aim was to extend the existing knowledge concerning the relationship between childhood obesity and both gross and fine motor skill competence in children (i.e., chapter 1) using a standardized motor assessment battery.
- The second aim was to gain greater insight in those aspects of perceptual-motor function that are affected in obese compared to healthy-weight children. To reach this objective, different fine motor tasks in which few body segments were involved and which rely on well-known principles of perceptual-motor function were used (i.e., chapter 2 and 3).
- The third aim was to examine the effect of a multidisciplinary obesity treatment program (and concomitant weight loss) on both gross and fine motor skill competence in 6- to 12-year-old children (i.e., chapter 4 and 5).

In chapter 1 of the original research, a closer look will be given to the relationship between weight status and both gross and fine motor skills using the BOT-2 (Bruininks & Bruininks, 2005). This is a product-oriented motor assessment instrument and is a technically acceptable measure of gross and fine motor competence in children. The BOT-2 items yield a comprehensive index of motor proficiency and separate composite scores for fine and
gross motor competence. This was a pure cross-sectional study trying to confirm possible weight-related differences in gross as well as fine motor performance.

In the second part of the original research, a greater range of fine motor tasks was assessed to obtain a more thorough understanding of the underlying perceptual-motor processes involved in fine motor functioning. Results of these two studies should allow us to confirm whether or not childhood obesity is associated with impaired perceptual-motor function. In chapter 2, differences in speed of information processing, decision-making and movement execution in response to visual stimuli were examined in obese children as compared to their healthy-weight peers. To achieve this objective, reaction time, movement time and response time were assessed by means of a simple reaction time and a choice reaction time task. The study presented in chapter 3 compares the use of online visual feedback between obese and healthy-weight children while performing a manual tracking task based on different calculated variables (i.e., number of lifts (#), pen up time (s), estimated mean overall velocity (cm/s), deviation from the target (cm), mean drawing axial pen pressure (N), crossing over (#), and root mean square deviation (cm)).

The final part of our original research reports the effects of a multidisciplinary obesity treatment program on both gross and fine motor skill competence. The recruited obese children followed an inpatient residential treatment program at a local medical care center (Zeepreventorium VZW, De Haan, Belgium) with a duration ranging from 4 to 10 months. By reducing obese children’s weight, it can be investigated if differences in motor performance can solely be attributed to the presence of excess mass or if a possible perceptual-motor deficit may also play a role in explaining obese children’s diminished gross and/or fine motor competence. Chapter 4 evaluates the short-term effectiveness of an obesity treatment program by describing changes in body weight, related anthropometric measures, and gross motor coordination. Secondarily, it was examined to what extent the amount of relative weight loss achieved by overweight and obese participants explained the projected improvement in gross motor coordination. The study presented in chapter 5 attempts to address a shortcoming in the literature and evaluates the effectiveness of a 10-month multidisciplinary treatment program for obese children in terms of changing weight-related measures as well as fine motor performance in a simple and a choice reaction time task as well as a manual tracking task.

Finally, in Part 3 of this dissertation, the main findings of the reported studies will be presented and discussed in the light of the existing literature, followed by an overall discussion and conclusion. An overview of practical implications will also be given together with a discussion of the strengths and limitations of the research presented in this dissertation. Finally, several guidelines for future research will be mentioned.
REFERENCES


PART 2:

ORIGINAL RESEARCH
CHAPTER 1:

Fine and gross motor skill differ between obese and healthy-weight children
ABSTRACT

Within the obesity literature, focus is put on the link between weight status and gross motor skills. However, research on fine motor skills in the obese childhood population is limited. Therefore, the present study focused on possible weight related differences in gross as well as fine motor skill tasks. Thirty-four obese children (12 ♀ and 22 ♂, aged 7–13 years) were recruited prior to participating in a multidisciplinary treatment program at the Zeepreventorium (De Haan, Belgium). Additionally, a control group of 34 age and gender-matched healthy-weight children was included in the study. Anthropometric measures were recorded and gross and fine motor skills were assessed using the Bruininks–Oseretsky Test of Motor Proficiency second edition (BOT-2). Results were analyzed by independent samples t-tests, multivariate analysis of variance, and a chi-squared test. Being obese was detrimental for all subtests evaluating gross motor skill performance (i.e., upper-limb coordination, bilateral coordination, balance, running speed and agility, and strength). Furthermore, obese children performed worse in fine motor precision and a manual dexterity task, when compared to their healthy-weight peers. No group differences existed for the fine motor integration task. Our study provides evidence that lower motor competence in obese children is not limited to gross motor skills alone; obese children are also affected by fine motor skill problems. Further investigation is warranted to provide possible explanations for these differences. It is tentatively suggested that obese children experience difficulties with the integration and processing of sensory information. Future research is needed to explore whether this assumption is correct and what the underlying mechanism(s) could be.

KEYWORDS
Children; Obesity; Gross motor skills; Fine motor skills; Fine motor precision; Fine motor integration; Manual dexterity

INTRODUCTION

Most studies focus exclusively on gross motor skills when examining the link between motor competence and weight status in children (Deforce et al., 2009; D’Hondt et al., 2009; D’Hondt et al., 2011; Graf et al., 2004; Okely & Booth, 2004; Okely et al., 2004; Poulsen et al., 2011). However, fine motor skills are equally important and can be seen as prerequisites to successfully engage in activities of daily living (Henderson & Sugden, 1992). The current findings in this emerging area of research implicitly suggest that obese children move differently due to their additional mass, which has to be supported or moved in gross motor tasks (D’Hondt et al., 2009; D’Hondt et al., 2011). Conversely, excess mass does not directly contribute to fine motor tasks, where the final outcome is mainly determined by the quality of information processing and integration of sensory information. To date, differences in fine motor skills have already been detected in clinical populations (e.g., cerebral palsy, developmental coordination disorder and attention deficit hyperactivity disorder) compared to typically developing children (Flapper et al., 2006; Himmelmann et al., 2006). Likewise, cautious suggestions have been made that fine motor skill performance in obese children is also different even though non-contributory mass is limited (D’Hondt et al., 2008; D’Hondt et al., 2009; Petrolini et al., 1995). When fine motor skill competence was investigated with a peg placing task, obese children performed more poorly than healthy-weight children (D’Hondt et al., 2008). This decreased fine motor competence was also seen in a tendency toward lower scores among obese children on the manual dexterity cluster of the Movement Assessment Battery for Children (D’Hondt et al., 2009). These findings are in line with a previous study, suggesting poor fine motor performance in obese children when sensory information was needed to plan and control movement (Petrolini et al., 1995). Yet, research on fine motor skills in the obese childhood population is limited.

The present study focused on both gross and fine motor skill tasks since the literature does not provide consistent evidence regarding possible body mass index (BMI)-related differences in the latter category. Different aspects of fine motor competence were assessed by measuring fine motor precision, fine motor integration, and manual dexterity. Fine motor precision requires precise control of finger and hand movements and emphasis is placed on accuracy (Bruininks & Bruininks, 2005). Fine motor integration refers to the extent to which visual perception and finger and hand movements are well coordinated. It is an essential component for the development and refinement of practical skills and must be developed adequately, so that a child’s attention can be focused on the content (i.e., what do I have to do?) and not the execution of the task (i.e., how do I have to do it?) (Jenkinson et al., 2008). A previous study by Petrolini et al. (1995) demonstrated that obese children committed approximately 50% more errors than non-obese children when they had to complete tasks
within the fine motor integration subtest of the Bruininks–Oseretsky Test of Motor Proficiency second edition (BOT-2) (Bruininks & Bruininks, 2005) (i.e., copying a square and a star). This could indicate that visual-motor difficulties may be one of the underlying mechanisms driving a child’s weight trajectory towards the development of overweight or and obesity. in obese children. Manual dexterity can be described as the ability to perform complex and precise movements of the hands with fluency, accuracy and speed according to the children’s developmental age. The acquisition of adequate manual dexterity enables a child to learn new skills and to perform tasks efficiently without excess effort (Jenkinson et al., 2008). Previous studies have already made tentative suggestions that obese children have lower performances on manual dexterity items (D’Hondt et al., 2008, 2009). Obese children achieved lower scores on a peg placing task (D’Hondt et al., 2008) and the manual dexterity cluster of the Movement Assessment Battery for Children like placing pegs, threading laces, and drawing a line between two solid lines of a flower trail as accurately as possible without lifting the pen (D’Hondt et al., 2009). This poor fine motor competence could hamper obese children in the normal execution of daily activities like tying shoelaces, picking up little things, and drawing or writing in a school environment.

In this study, the BOT-2 (Bruininks & Bruininks, 2005) was used to explore potential differences in both gross and fine motor skills according to children’s weight status. It was hypothesized that obese boys and girls would score lower on those items relying on gross motor skills compared to healthy-weight boys and girls. Furthermore, group differences between healthy-weight and obese children were expected on the fine motor precision, fine motor integration and manual dexterity tasks. Beyond differences in weight status and gender, age differences will also be explored, as it has been shown that the impact of excess mass and fatness on children’s motor competence increases as children grow older (D’Hondt et al., 2011). Therefore, it was hypothesized that obese children in the 10–13-year-old group would show significantly poorer performance on the BOT-2 compared with the corresponding 7–9-year-old group.

MATERIALS AND METHODS

Participants

A total of 68 children (24 girls and 44 boys aged 7–13 years) took part in this study. Thirty-four obese children (12 girls and 22 boys) were recruited through a local rehabilitation center (Zeepreventorium VZW, De Haan, Belgium) offering a 10-month inpatient treatment program to obese children. Every child starting treatment in September 2008 and 2009
received an information letter to participate in this study, resulting in a sample of 34 children. The number of obese children participating in this study was rather limited since the intake of children in the program is restricted to a maximum of 20 children each year. The obese children had no underlying endocrine disease and were free from any serious comorbidities. A normal intelligence quotient (i.e., IQ > 70) was an additional criterion for entry in the program.

For each of these 34 obese children, a healthy-weight control child was recruited through a local primary school and selected from a larger data set based on age and gender, and additionally body height. These participants were classified as healthy-weight based on internationally accepted BMI cut-off points relative to age and gender (Cole et al., 2000), and represented the healthy-weight group which was not involved in any kind of treatment. The study sample was sub-stratified into a younger (aged 7–9 years, N = 26) and an older age group (aged 10–13 years, N = 42) with weight status (obese vs. healthy-weight) evenly distributed in both age groups.

**Procedures**

The obese children’s data were collected prior to the start of the multidisciplinary residential treatment program (August 2008 or August 2009) to avoid that outcome(s) could be influenced by the treatment program. The healthy-weight children were tested in the beginning of 2010. Both parents and school or rehabilitation staff of all participants gave written informed consent for the child to participate in this study. The protocol was approved by the Ethical Committee of the Ghent University Hospital. All procedures were conducted in agreement with the principles expressed in the Declaration of Helsinki.

The BOT-2 was administered and scored by trained examiners of the Department of Movement and Sports Sciences, consistent with a standardized protocol (Bruininks & Bruininks, 2005). All tests were performed in light sportswear and barefoot. Prior to each test item the children received an oral explanation about the specific test procedure. Children were verbally encouraged by their examiner to perform all test items to the best of their abilities.

**Anthropometric measures**

Standing height to the nearest 0.1 cm was measured with a portable stadiometer (Harpenden, Holtain, Ltd., Crymych, UK) while the children stood barefoot in the anatomical position. Body weight to the nearest 0.1 kg was determined using a digital balance scale (Tanita, BC-420SMA, Weda B.V., Naarden, Holland).
Motor skill assessment

In this study the short form of the BOT-2 was used, which can be considered a reliable (reliability coefficients 0.80’s, interrater reliability 0.90s) measure of both fine and gross motor skills in individuals, 4 through 21 years of age (Bruininks & Bruininks, 2005). The BOT-2 contains 14 different items from 8 subtests. Table 1 depicts the items per subtest along with the raw score range and the relationship between obtained score and performance level. Raw performance scores on the fourteen different BOT-2-items were converted into point scores, which allow a participant’s item performances to be evaluated on a graded scale. Adding these individual point scores together, a subtest total point score is obtained. Point scores of all fourteen items are added to obtain the total point score (total BOT-2). All together, the items provide a comprehensive index of motor proficiency as well as separate measures of both fine and gross motor skills. By using gender and age specific normative tables (Bruininks & Bruininks, 2005), standard scores (standard BOT-2) can be calculated along with the corresponding percentile rank. Finally, a descriptive category (well-below average, below average, average, above average, and well-above average) can be allocated to each performance, which represents the participant’s standard score in relation to the reference sample used.

Statistical analysis

Data were analyzed using SPSS software for Windows (version 19.0). The level of significance was set at \( p < 0.05 \) and significance levels varying between 0.10 and 0.05 were considered as a trend to significance. Descriptive statistics (mean ± standard deviation) were calculated for both anthropometric and motor skill variables, including item and subtest scores. An independent samples t-test was used to compare anthropometric characteristics between the two BMI groups. To explore interactions with age and gender, all fourteen items of the BOT-2 as well as the subtest, the total BOT-2 score, and the standard BOT-2 score were implemented in a 2 (BMI group) x 2 (gender) x 2 (age group) MANOVA. \( F \)-values, \( p \)-values and partial eta squared (\( \eta^2 \)) values were reported as MANOVA outcomes. Eta squared values range between 0 and 1 and the following guidelines must be kept in mind when interpreting these values: 0.01 = small, 0.06 = medium, 0.13 = large. To further investigate interaction effects, independent samples t-tests were used for each BMI group separately. Additionally, Pearson \( \chi^2 \) analyses were conducted to investigate the relationship between BMI group (healthy-weight vs. obese) and the level of motor performance. For this purpose, the five descriptive categories of the BOT-2 were combined into three categories namely “below average” (i.e., well-below average and below average), “average” (i.e., average) and “above average” (i.e., above average and well-above average).
Table 1. BOT-2 items overview according to subtest, raw score range and relationship between score and performance.

<table>
<thead>
<tr>
<th>Subtest and items</th>
<th>Raw score (range)</th>
<th>Relationship: score – performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fine motor precision</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawing lines</td>
<td>0 – 21</td>
<td>Low score = high performance</td>
</tr>
<tr>
<td>Folding paper</td>
<td>0 – 12</td>
<td>High score = high performance</td>
</tr>
<tr>
<td><strong>Fine motor integration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copying a square</td>
<td>0 – 5</td>
<td>High score = high performance</td>
</tr>
<tr>
<td>Copying a star</td>
<td>0 – 5</td>
<td>High score = high performance</td>
</tr>
<tr>
<td><strong>Manual dexterity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transferring pennies</td>
<td>0 – 20</td>
<td>High score = high performance</td>
</tr>
<tr>
<td><strong>Upper-limb coordination</strong></td>
<td></td>
<td></td>
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<tr>
<td>Dropping and catching a ball</td>
<td>0 – 5</td>
<td>High score = high performance</td>
</tr>
<tr>
<td>Dribbling a ball</td>
<td>0 – 10</td>
<td>High score = high performance</td>
</tr>
<tr>
<td><strong>Bilateral coordination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jumping in place</td>
<td>0 – 5</td>
<td>High score = high performance</td>
</tr>
<tr>
<td>Tapping feet and fingers</td>
<td>0 – 10</td>
<td>High score = high performance</td>
</tr>
<tr>
<td><strong>Balance</strong></td>
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<tr>
<td>Walking forward on a line</td>
<td>0 – 6</td>
<td>High score = high performance</td>
</tr>
<tr>
<td>Standing on balance beam</td>
<td>0 – 10</td>
<td>High score = high performance</td>
</tr>
<tr>
<td><strong>Running speed and agility</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One legged stationary hop</td>
<td>0 – 50</td>
<td>High score = high performance</td>
</tr>
<tr>
<td><strong>Strength</strong></td>
<td></td>
<td></td>
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<tr>
<td>Knee push-ups</td>
<td>0 to +36</td>
<td>High score = high performance</td>
</tr>
<tr>
<td>Sit-ups</td>
<td>0 to +36</td>
<td>High score = high performance</td>
</tr>
</tbody>
</table>

**RESULTS**

Table 2 provides detailed anthropometric characteristics according to BMI group. Significant differences were found for weight and BMI between the two groups (healthy-weight < obese). Descriptive statistics (mean ± standard deviation) of the raw performance scores on the fourteen different BOT-2 items and corresponding F-values are presented in Table 3. Table 4 provides descriptive statistics of the subtests, total BOT-2 and standard BOT-2 scores together with the F-values of main and interaction effects.
The 2 x 2 x 2 MANOVA analysis indicated that there was no significant three way interaction effect between gender, BMI and age group (F = 1.582, p = 0.120). Additionally, no significant interaction effects between gender and BMI group (F = 1.533, p = 0.054), and gender and age group (F = 0.905, p = 0.560) occurred, and no main group effect for gender was present (F = 1.218, p = 0.295). Therefore, gender is excluded from the analysis and Tables 3 and 4 represent the data of the 2 (BMI group) x 2 (age group) MANOVA analysis.

Table 2. Descriptive statistics according to BMI-group and summary of the independent samples t-test.

<table>
<thead>
<tr>
<th>Anthropometric characteristics</th>
<th>BMI group</th>
<th>Independent samples t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HW (N=34)</td>
<td>OB (N=34)</td>
</tr>
<tr>
<td></td>
<td>(mean ± SD)</td>
<td>(mean ± SD)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>10.5 ± 1.5</td>
<td>10.5 ± 1.5</td>
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<tr>
<td>Height (cm)</td>
<td>142.6 ± 9.8</td>
<td>149.0 ± 9.7</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>34.9 ± 6.8</td>
<td>66.0 ± 13.7</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.00 ± 1.73</td>
<td>29.50 ± 3.56</td>
</tr>
</tbody>
</table>

Note: HW: healthy-weight; OB: obese; SD: standard deviation.

* p < 0.01, ** p < 0.001.

Gross motor skill competence

As shown in Table 3, a main effect of BMI indicated that the healthy-weight group obtained significantly higher raw scores than the obese group for 6 out of 9 BOT-2 items relying on gross motor skill competence. For dribbling a ball (p = 0.073) and jumping in place (p = 0.050) a tendency toward significance was found indicating that the healthy-weight children outperformed the obese children. Conversely, there was no significant difference when walking forward on a line according to BMI group (p = 0.274). Similar to individual test item results, healthy-weight children performed higher for all gross motor subtests compared to their obese peers (Table 4). BMI-related differences further varied according to age group for the items knee push-up and dribbling a ball (Table 3). For knee push-ups the older healthy-weight participants obtained higher scores compared to their younger counterparts (p = 0.029). Within the obese group, no significant age-related progression in knee push-up performance was found (p = 0.264). For the dribbling ball item, differences according to age group did not reach a significant level in the healthy-weight group (p = 0.479); however, the
older obese children performed better than their younger peers ($p = 0.003$). Subsequently, the upper-limb coordination subtest obtained a similar significant interaction effect between BMI group and age as the dribbling ball item (Table 4).

**Fine motor skill competence**

A main effect of BMI was present for 1 out of 5 BOT-2 items relying on fine motor skills (Table 3). Healthy-weight children achieved a higher score compared to the obese children for transferring pennies ($p = 0.005$). Additionally, a similar trend was observed for the drawing lines ($p = 0.070$) and folding paper items ($p = 0.085$). There were no significant group differences when copying a square ($p = 0.230$) or a star ($p = 0.888$). A significant main effect of BMI group ($p = 0.030$) indicated that the obese children achieved significantly lower overall fine motor precision scores than the healthy-weight group. Additionally, a trend toward significantly poorer scores in obese children was seen for the manual dexterity subtest ($p = 0.065$), while no BMI-related differences occurred for fine motor integration ($p = 0.790$) (Table 4).

**Total motor competence and relationship between BMI group and level of motor competence**

The healthy-weight children outperformed their obese peers for the total BOT-2 ($p < 0.001$) and the standard BOT-2 score ($p < 0.001$). Furthermore, Pearson $\chi^2$ analyses indicated that there are significant differences in level of motor performance according to weight status. While no healthy-weight participants performed below average, the proportion of children showing below average performance was 38.2% in the obese group ($\chi^2 = 20.727; p < 0.001$). On the other hand, only 2.9% of the children belonging to the obese group displayed above average performance on the BOT-2, unlike 29.4% of the healthy-weight group. Furthermore, of all children showing above average performance, 90.9% belonged to the healthy-weight group.
Table 3. Raw BOT-2 item scores and summary of the MANOVA-analysis according to BMI-group stratified by age.

<table>
<thead>
<tr>
<th>BOT-2 ITEMS</th>
<th>Age</th>
<th>HW (mean ± SD)</th>
<th>OB (mean ± SD)</th>
<th>All (mean ± SD)</th>
<th>$F_{BMI}$</th>
<th>partial $\eta^2_{BMI}$</th>
<th>$F_{Age}$</th>
<th>partial $\eta^2_{Age}$</th>
<th>$F_{BMI \times Age}$</th>
<th>partial $\eta^2_{BMI \times Age}$</th>
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<tbody>
<tr>
<td>Fine motor items</td>
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<tr>
<td>Drawing lines</td>
<td>7-9y</td>
<td>0.38 ± 0.87</td>
<td>0.77 ± 1.01</td>
<td>0.58 ± 0.95</td>
<td>3.401‡</td>
<td>0.050</td>
<td>0.122</td>
<td>0.002</td>
<td>0.010</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>10-13y</td>
<td>0.29 ± 0.56</td>
<td>0.71 ± 1.06</td>
<td>0.50 ± 0.86</td>
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<td></td>
<td>All</td>
<td>0.32 ± 0.68</td>
<td>0.74 ± 1.02</td>
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<tr>
<td>Folding paper</td>
<td>7-9y</td>
<td>10.77 ± 1.42</td>
<td>10.15 ± 1.72</td>
<td>10.46 ± 1.58</td>
<td>3.065‡</td>
<td>0.046</td>
<td>3.422</td>
<td>0.051</td>
<td>0.057</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>10-13y</td>
<td>11.62 ± 0.80</td>
<td>10.81 ± 2.20</td>
<td>11.21 ± 1.69</td>
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<tr>
<td></td>
<td>All</td>
<td>11.29 ± 1.14</td>
<td>10.56 ± 2.03</td>
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<tr>
<td>Copying a square</td>
<td>7-9y</td>
<td>4.85 ± 0.38</td>
<td>4.69 ± 0.48</td>
<td>4.77 ± 0.43</td>
<td>1.470</td>
<td>0.022</td>
<td>0.154</td>
<td>0.002</td>
<td>0.081</td>
<td>0.001</td>
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<tr>
<td></td>
<td>10-13y</td>
<td>4.86 ± 0.36</td>
<td>4.76 ± 0.44</td>
<td>4.81 ± 0.40</td>
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<tr>
<td></td>
<td>All</td>
<td>4.85 ± 0.36</td>
<td>4.74 ± 0.45</td>
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<tr>
<td>Copying a star</td>
<td>7-9y</td>
<td>3.38 ± 1.61</td>
<td>3.85 ± 0.90</td>
<td>3.62 ± 1.30</td>
<td>0.020</td>
<td>0.000</td>
<td>1.039</td>
<td>0.016</td>
<td>2.201</td>
<td>0.033</td>
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<tr>
<td></td>
<td>10-13y</td>
<td>4.10 ± 1.14</td>
<td>3.71 ± 0.90</td>
<td>3.90 ± 1.03</td>
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<tr>
<td></td>
<td>All</td>
<td>3.82 ± 1.36</td>
<td>3.76 ± 0.89</td>
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<tr>
<td>Transfer pennies</td>
<td>7-9y</td>
<td>13.23 ± 1.96</td>
<td>11.77 ± 1.69</td>
<td>12.50 ± 1.94</td>
<td>8.276**</td>
<td>0.115</td>
<td>7.250**</td>
<td>0.102</td>
<td>0.034</td>
<td>0.001</td>
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<tr>
<td></td>
<td>10-13y</td>
<td>14.43 ± 1.83</td>
<td>13.14 ± 2.08</td>
<td>13.79 ± 2.04</td>
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<td></td>
<td>All</td>
<td>13.97 ± 1.95</td>
<td>12.62 ± 2.03</td>
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<tr>
<td>Gross motor items</td>
<td>7-9y</td>
<td>10-13y</td>
<td>All</td>
<td>7-9y</td>
<td>10-13y</td>
<td>All</td>
<td>7-9y</td>
<td>10-13y</td>
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<tr>
<td>Catching ball</td>
<td>5.00 ± 0.00</td>
<td>4.90 ± 0.44</td>
<td>4.94 ± 0.34</td>
<td>4.46 ± 0.97</td>
<td>4.62 ± 0.92</td>
<td>4.56 ± 0.93</td>
<td>4.73 ± 0.72</td>
<td>4.76 ± 0.73</td>
<td>4.56 ± 0.93</td>
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<td>0.008</td>
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<tr>
<td>Dribbling ball</td>
<td>8.69 ± 2.59</td>
<td>8.05 ± 2.52</td>
<td>8.29 ± 2.53</td>
<td>5.46 ± 3.36</td>
<td>8.95 ± 1.94</td>
<td>7.62 ± 3.06</td>
<td>7.08 ± 3.37</td>
<td>8.50 ± 2.27</td>
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<td>3.326‡</td>
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<td>4.981*</td>
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<td>10.515**</td>
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<td>0.141</td>
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<td>0.141</td>
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</tr>
<tr>
<td>Jumping in place</td>
<td>5.00 ± 0.00</td>
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<td>16.88 ± 7.52</td>
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Note: HW: healthy-weight; OB: obese; SD: standard deviation; ff: feet and fingers.

‡ 0.10 > p ≥ 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001.
Table 4. Subtests, total-2 and standard-2 scores, and summary of MANOVA-analysis according to BMI-group stratified by age.

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<tr>
<th>SUBTEST SCORES</th>
<th>Age group</th>
<th>HW (mean ± SD)</th>
<th>OB (mean ± SD)</th>
<th>All (mean ± SD)</th>
<th>F_{BMI}</th>
<th>partial $\eta^2_{BMI}$</th>
<th>F_{Age}</th>
<th>partial $\eta^2_{Age}$</th>
<th>F_{BMIxAge}</th>
<th>partial $\eta^2_{BMIxAge}$</th>
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<td>Fine motor precision</td>
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<td>12.95 ± 1.53</td>
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<td>13.15 ± 1.08</td>
<td>12.32 ± 1.79</td>
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<td>Fine motor integration</td>
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<td>Manual dexterity</td>
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<td>Upper-limb coordination</td>
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Note: HW: healthy-weight; OB: obese; SD: standard deviation.
‡ 0.10 > p ≥ 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001.
DISCUSSION

The present study investigated both gross and fine motor skill performance in healthy-weight and obese children using the BOT-2. In tasks relying on gross motor competence, BMI-related differences were expected to appear. However, we especially wanted to examine whether differences according to weight status would also emerge during fine motor tasks, when only a limited part of the body mass needs to be moved.

Gross motor skill competence

In line with previous research (Deforche et al., 2009; D’Hondt et al., 2009; D’Hondt et al., 2011; Graf et al., 2004; Okely & Booth, 2004; Okely et al., 2004; Poulsen et al., 2011), our results indicated that healthy-weight children outperformed obese children on all subtests requiring gross motor competence (i.e., upper-limb coordination, bilateral coordination, balance, running speed and agility, and strength). Accordingly, it can be suggested that obese children perform worse in weight-bearing tasks because a greater proportion of excess mass has to be supported or moved against gravity during these tasks (D’Hondt et al., 2008, 2009; D’Hondt et al., 2011; Shultz et al., 2010). Therefore, our data support the general assumption that excess mass prevents obese children from an optimal execution of movement.

When performing upper-limb coordination and more specifically dribbling a ball, obese children improved as they matured, whereas children in the healthy-weight group maintained a high performance level regardless of age. This indicates that although obese children still have a lower performance compared to the healthy-weight children, they do not experience more difficulties with increasing age. Unlike these findings, D’Hondt et al. (2011) recently suggested that older children encounter a higher negative impact of an increased weight status than younger children relative to age- and gender-specific standards. However, it should be mentioned that the previous study assessed gross motor coordination, while in our study this interaction-effect was only seen for the dribbling ball item. Accordingly, two different assessment tools were used having their own specific classification, reference-values, and reference population. Therefore, it is difficult to compare the two different classifications.

Fine motor skill competence

Compared to their healthy-weight peers, obese children achieved lower scores for the transferring pennies task, the only manual dexterity task included in the BOT-2. This task can be compared with the peg placing task used in the study of D’Hondt et al. (2008) with a
similar outcome. Additionally, obese children tended to have lower scores on the manual dexterity cluster of the Movement Assessment Battery for Children (D’Hondt et al., 2009). Findings from our study and the studies of D’Hondt et al. (2008, 2009) support the idea that childhood obesity is detrimental for manual dexterity. At the same time, a tendency toward BMI-related differences emerged in the fine motor precision test, suggesting obese children also perform more poorly than their healthy-weight counterparts when the fine motor task requires accuracy. However, when the integration of visual stimuli is combined with motor control, the healthy-weight and obese group obtained similar results. Obese children might create the opportunity to practice and improve their fine motor skills by playing video and computer games which can be advantageous in the development of their fine motor skills. Increased screen time has been associated with both adiposity and reduced physical activity (Tremblay et al., 2011); which could provide a positive feedback loop of decreased gross motor control; decreased physical activity; and increased time spent in screen activities. Because fine motor skills are not directly influenced by the amount of excess mass that participates in the movement, excess mass cannot solely explain the differences according to BMI group. Therefore, there could be a possible deficit in the integration and processing of sensory information in obese children. This is in line with other studies suggesting underlying perceptual-motor coordination difficulties in obese children (Bernard et al., 2003; D’Hondt et al., 2008; Petrolini et al., 1995). However, this relationship between perceptual-motor functioning and obesity in children needs further investigation.

Mechanisms and hypotheses

It has repeatedly been shown that obese children perform worse on gross motor tasks and the current state of research implicitly supports the assumption that obese children move differently compared to healthy-weight children due to their additional mass and different mass distribution (Deforche et al., 2003; D’Hondt et al., 2009; D’Hondt et al., 2011; Graf et al., 2004; Hills et al., 2002; Hue et al., 2007; McGraw et al., 2000; Tsiros et al., 2011). From this mechanical point of view, the motor planning and control processes are not supposed to be affected in obese children. However, recent evidence also suggests qualitatively worse performance on fine motor tasks, referred to as the perceptual-motor hypothesis (D’Hondt et al., 2008, 2009; Petrolini et al., 1995). This study confirms that obese children also suffer from impaired fine motor precision skills even though the non-contributory mass that participates in the movement is restricted and the outcome is mainly determined by the quality of information processing and the integration of sensory information. This suggests that obese children have difficulties when sensory information is needed to plan and control movement.
Future research

Functional magnetic resonance imaging could be a valuable tool to explore the neuromuscular functions and specific brain regions involved while executing certain fine motor skills and whether or not differences among obese and healthy-weight children exist in these brain functions.

Implications for public health

Given that both gross and fine motor skill competence can be seen as prerequisites to successfully engage in activities of daily living (Henderson & Sugden, 1992) as well as the foundations for sports-specific skills (Booth et al., 1997), a targeted approach to counter not only gross motor skills but also fine motor skills problems in obese children seems advisable. Further research is required to obtain a more detailed understanding of the specific (fine) motor skills and possibly related perceptual-motor and neuromuscular functions which obese children have the most difficulty mastering. This knowledge would be of great value to develop tailored intervention programs aimed at enhancing fine motor skill competence (and perceptual-motor function) in obese children.

Limitations

A first limitation can be found in the fact that we cannot rule out whether or not children’s physical activity level affects these results. In childhood, however, physical activity and movement experiences (in itself) are important because it offers children the opportunity to develop adequate motor skill competence and the ability to maintain a physically activity lifestyle (Fisher et al., 2005; Wrotniak et al., 2006). Motor skill proficiency seems to be an important correlate of consequent physical activity participation (Barnett et al., 2009; Lopes et al., 2011). However, recent literature demonstrates that obese children have poorer motor skills than their healthy-weight peers which seems to be an important barrier to physical activity participation. Withdrawing from physical activity only strengthens this relationship and consecutively impairs motor learning during childhood, which hampers the further development of motor skills (Lubans et al., 2010). Recently, D’Hondt et al. (2013) emphasized that obese children not engaging in regular sports activities in a sports club are at great risk. A targeted approach including motor skill instruction and improvement is warranted to increase the likelihood for a physically activity lifestyle in these inactive obese children.

A second limitation of the present study is the relatively small sample size which makes it difficult to generalize these findings to the entire childhood population. Further
investigation in a larger sample of obese children would be valuable. Furthermore, possible confounding factors affecting motor performance were possibly missed and because of the cross-sectional nature of this study no conclusions can be made regarding the causal nature of the relationship between obesity and motor skill proficiency among obese and healthy-weight children.

CONCLUSION

The present study reinforces the idea that obesity provides a constraint for gross motor performance in children. Additionally, obese children are also affected by fine motor precision problems and subtle differences in manual dexterity for which further investigation is warranted to provide possible explanations. It can be tentatively suggested that obese children experience difficulties with the integration and processing of sensory information. Future research will need to explore whether this assumption is correct and what the underlying mechanism(s) could be.

ACKNOWLEDGEMENTS

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REFERENCES


CHAPTER 2:

A comparative study of performance in simple and choice reaction time tasks between obese and healthy-weight children
ABSTRACT

This study investigated weight status related differences in executive functions and movement execution to determine whether or not childhood obesity is associated with impaired perceptual-motor function. Nineteen obese children (10 ♂ & 9 ♀, aged 6-12 years) and nineteen gender and age matched healthy-weight peers performed two computer-based reaction time tasks. For both the simple and four choice reaction time (SRT/CRT) task condition, absolute mean reaction time (RT) and movement time (MT) were determined and expressed as a percentage of total response time (RstT). During the SRT task, obese children were intrinsically slower than their healthy-weight peers as reflected by a significantly higher absolute RT, MT and RstT. In the CRT task, however, between-group differences were only present for RT and RstT, whereas absolute MT was comparable among obese and healthy-weight participants. As a result, the relative temporal structure of RstT significantly differed between BMI groups, with a higher RT percentage among the obese children. During the CRT condition, obese children probably await final decision-making with regard to the execution of their response movement, which then no longer needs to be adjusted. Our results therefore indicate the use of a more conservative strategy within the obese group, suggesting that childhood obesity is associated with impaired perceptual-motor function. Besides the widely accepted mechanical explanation, a better understanding of the mechanisms underlying obese children’s motor incompetence is needed to set up appropriate interventions to tackle this deficit and indirectly address associated health-related problems.

KEYWORDS
Children; Obesity; Perceptual-motor function; Response time; Reaction time

INTRODUCTION

The growing prevalence of childhood obesity (Lobstein et al., 2004; Monasta et al., 2010; Pigeot et al., 2009), has contributed to the importance of research on motor competence in obese children, especially since well-developed skills are considered a precursor of successful and continuing engagement in physical activity (Barnett et al., 2009; Bonvin et al., 2012; Lopes et al., 2011; Poulsen et al., 2011; Stodden et al., 2008). Many studies have consistently shown that the level of motor competence is inversely related to weight status in childhood. Yet, differences in skill performance between obese children and their healthy-weight peers are mainly observed during the execution of gross motor tasks (Castetbon & Andreyeva, 2012; Graf et al., 2004, 2007; Lopes et al., 2012; Morano et al., 2011; Okely et al., 2004). Therefore, obese children’s reduced motor function is generally believed to be the mechanical consequence of their excess noncontributory mass that needs to be stabilized or moved against gravity. A scarce number of studies, however, indicated that childhood obesity is also associated with poorer fine motor performances, although the mechanical load to the system is then greatly diminished. In these tasks, performance is predominantly determined by the quality of processing and integrating sensory information as well as transmitting proper muscle commands (D’Hondt et al., 2008; D’Hondt et al., 2009; Petrolini et al., 1995). Accordingly, perceptual-motor difficulties may play a role in explaining these poorer fine motor skill outcomes. Greater insight into the exact nature of lower motor competence among obese children is therefore required.

The measurement of reaction time (RT), movement time (MT) and response time (RsT) is considered a valuable tool to evaluate the time needed to initiate and execute a given action (Luce, 1986). Response time is the time frame between the onset of a stimulus and the completion of a corresponding motor response and can be further divided into RT and MT (Magill, 2011; Whelan, 2008). Reaction time is the time interval from the onset of the stimulus to the very beginning of the motor action, and reflects the integrity of the information processing system. Movement time, in turn, refers to the time interval from the initiation to the completion of the movement execution in response to the stimulus. It is also important to notice that RT and MT are considered to be relatively independent from each other (Magill, 2011).

Human’s information processing speed and quality can be evaluated either by using only one stimulus (i.e., simple reaction time [SRT] task) or two or more stimuli (i.e., choice reaction time [CRT] task). From an executive functions perspective, both tasks (SRT and CRT) are a measure of sustained attention. The tasks differ in the fact that the SRT task measures the ability to maintain focused continuously on one specific stimulus, while in the CRT task attention must be divided among different stimuli. Furthermore, the SRT task also
Reaction time task performance in obese children

measures pure processing speed since only one possible response can be given to a single stimulus. No response selection has to be made and the SRT motor response can already be planned in advance. However, the CRT task puts greater stress on the decision making process since each stimulus is linked to a different motor response, leading to prolonged RT (Magill, 2011). According to Kiselev et al. (2009), RT and age are inversely related in youth (i.e., RT will decrease with increasing age across developmental time), meaning that the full capacity of the information processing system is not reached before young adulthood (Hale, 1990; Kail, 1991). In addition, certain developmental disorders (e.g., Attention Deficit Hyperactivity Disorder, Developmental Coordination Disorder and dyslexia) affect RT task results. Children with one or more of these disorders exhibit difficulties in executive functioning, which inevitably leads to higher RT as compared to typically developing children (Alderson et al., 2007; Gooch et al., 2012; Mitchell et al., 1991). From the abovementioned perspective, it would be interesting to examine whether the affected perceptual-motor performance in children with developmental disorders also applies to children who are obese. To the best of our knowledge, no research on executive functions has been conducted within the obese childhood population. Nevertheless, if similar prolonged RT would systematically emerge among these children, it would support the hypothesis of an impaired perceptual-motor control function associated with obesity.

In this context, the purpose of our study was to investigate differences in executive functions and movement execution in obese children as compared to healthy-weight peers, when only a limited part of the body mass is involved in the motor action as response to a visual stimulus. To achieve this objective, RT, MT and RsT were assessed by means of an SRT and CRT task, both performed from a seated position. Results should allow us to determine whether or not childhood obesity is associated with impaired perceptual-motor function. We hypothesize that obese children will have more difficulties with the different constructs of executive functions (e.g., sustained attention and processing speed) which will be seen in longer RT in comparison with gender and age matched peers.

MATERIALS AND METHODS

Participants

A total of 38 children (aged 6–12 years, 18 girls and 20 boys) participated in this cross-sectional study. Half of the study sample (N = 19) was recruited through a local rehabilitation center (Zeepreventorium VZW, De Haan, Belgium), where they attended a multidisciplinary residential treatment program for obese children. The other participants (N = 19) included in this study had a healthy-weight and were recruited through a local primary school (EDUGO Slotendries, Oostakker, Belgium). They were selected from a larger pool of
230 children tested in order to accurately match the obese participants, based on gender and age.

**Procedure and materials**

At a single test moment, both anthropometric and response time measurements were successively conducted by two trained examiners. Children within the obese group were assessed within the first week of their residential stay, so that outcome(s) could not be influenced by the provided treatment program. During the tests, all participants wore light sportswear and were barefoot. Our study protocol was approved by the Ethics Committee of the Ghent University Hospital, and prior to data collection written informed consent was obtained from each child’s parent(s) and the school or rehabilitation center staff.

**Anthropometry**

Body height was measured to the nearest 0.1 cm using a portable stadiometer (Harpenden, Holtain Ltd., Crymych, UK). Body weight (0.1 kg) and an estimation of percentage body fat (0.1%) were determined using a digital scale with bioelectrical impedance analysis (Tanita, BC-420 SMA, Weda B.V., Naarden, Holland). From these data, BMI was calculated as body weight divided by squared height (kg/m²). Based on the internationally accepted BMI cut-off points for children (Cole et al., 2000), weight status (i.e., either obese or healthy-weight) was determined.

**Response time: reaction time and movement time**

Participants’ RsT was registered during two computer-based reaction time tasks performed from a comfortable seated position (i.e., both feet touching the ground and an elbow angle of about 100°), within the same experimental set-up using a custom-made device (see Figure 1). Children were seated in front of a laptop screen (diagonal size of 39.6 cm) on which visual stimuli were projected (i.e., highlighting green circles against a gray background). On the table leaf in between the participant and the laptop a wooden board (30 cm x 45 cm) with touch-sensitive metal plates was installed and connected to the laptop. All children were instructed to rest their left hand on the bigger plate (5 cm x 10 cm) on the bottom left of the board and to put their right hand on Plate 0 (5 cm x 5 cm) in order to start both tasks. Each time a visual stimulus appeared, they were asked to respond as quickly as possible by tapping the correct plate in corresponding to the alignment of circles on the screen (cfr. screen view on Figure 1). In the SRT task, which was performed first, participants always had to tap Plate 2 in response to a single stimulus. It involved three
practice trials, followed by ten test trials. In the CRT task, on the other hand, four possible stimuli corresponded to either Plates 1, 2, 3, or 4 (5 cm x 5 cm, each centered at a distance of 15 cm from the midpoint of Plate 0). This latter task consisted of four practice trials (i.e., one for each plate) followed by 16 test trials. In both tasks the inter-stimulus interval was randomly ranging between 2 and 4 s. For each response, the RT (time interval between stimulus presentation and the participant releasing Plate 0) as well as the MT (time interval between releasing Plate 0 and the target plate being tapped) were recorded. Which plate was tapped and whether the response was right or wrong was also stored during the CRT task.

Fig. 1. Schematic view of the experimental setup

**Statistical analysis**

Data from practice trials were excluded from all analyses. Absolute mean RT and MT (ms) were calculated based on the valid test trials for each participant (i.e., on average 92.8%) in both the SRT and CRT task. By summing these data, the average RsT (ms) in each task condition could be calculated. We also determined the percentage of RsT occupied by RT and MT (% of RsT), respectively. Finally, the error rate (%) of each child’s performance on the CRT task was computed.
Statistical analyses were performed using IBM SPSS Statistics 20.0 (SPSS Inc., Chicago, IL, USA), with the level of significance set at $p \leq 0.05$. Between-group differences in anthropometric characteristics were evaluated by means of an independent samples $t$-test. Absolute RT, MT and RsT (ms) were separately implemented in a 2 (BMI group: healthy-weight vs. obese) x 2 (condition: SRT vs. CRT task) repeated measures (RM) ANCOVA, with age included as a covariate. Given that the relative expressions of RT and MT (% of RsT) neutralize one another, the same analysis was repeated with only MT (% of RsT) as the dependent variable. Significant interaction effects were further examined by one-way ANCOVA’s per condition. Finally, between-group differences in the percentage of errors made during the execution of the CRT task were examined by means of an ANCOVA, also taking age variability into account.

<table>
<thead>
<tr>
<th>Anthropometric characteristics</th>
<th>BMI group</th>
<th>Independent samples $t$-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HW $(N = 19)$</td>
<td>OB $(N = 19)$</td>
</tr>
<tr>
<td>Gender</td>
<td>10 ♂ - 9 ♀</td>
<td>10 ♂ - 9 ♀</td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.9 ± 1.5</td>
<td>9.8 ± 1.5</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>143.1 ± 9.1</td>
<td>147.3 ± 9.6</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>34.2 ± 7.4</td>
<td>69.3 ± 13.4</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.48 ± 1.76</td>
<td>31.62 ± 3.51</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>17.8 ± 4.0</td>
<td>44.6 ± 5.7</td>
</tr>
</tbody>
</table>

BMI, body mass index; HW, healthy weight; OB, obese.

NS, not significant; ***, $p \leq 0.001$. 
RESULTS

Descriptive (means ± standard deviations) and comparative statistics (independent samples t-values) for the main anthropometric characteristics are presented in Table 1.

There were no significant differences between BMI groups in terms of age ($p = 0.864$) and body height ($p = 0.168$). With respect to body weight, BMI, and percentage body fat, between-group differences were found at the $p < 0.001$ significance level, with higher values for the obese participants as compared to their healthy-weight peers.

Table 2 provides an overview of all measurement outcomes (means ± standard deviations) both on the SRT and CRT task as a function of BMI group. The relative temporal structure in each task condition is presented in Figure 2, showing the respective contribution of RT and MT (% of RsT).

A recurring main effect of condition indicated that all participants in absolute terms needed more time when performing the CRT task compared to the SRT task. Regardless of BMI group, both RsT (ms) ($F_{condition(1,35)} = 19.605, p < 0.001$), RT (ms) ($F_{condition(1,35)} = 8.788, p = 0.005$) and MT (ms) ($F_{condition(1,35)} = 19.155, p < 0.001$) were found to be significantly higher in the CRT relative to the SRT condition. In addition, children in the obese group were intrinsically slower in comparison with their healthy-weight peers as demonstrated by a significantly higher RsT (ms) ($F_{BMI\ group(1,35)} = 9.413, p = 0.004$) as well as RT (ms) ($F_{BMI\ group(1,35)} = 16.374, p < 0.001$) across conditions. With respect to MT (ms), however, a significant interaction effect was shown ($F_{interaction(1,35)} = 13.694, p = 0.001$) revealing that group differences are dependent on the task condition. Post hoc one-way ANCOVA’s indicated that children in the healthy-weight group moved significantly faster than their obese peers ($F_{BMI\ group(1,35)} = 19.397, p < 0.001$), but this finding was not confirmed for the CRT task ($F_{BMI\ group(1,35)} = 0.258, p = 0.658$). In relative terms, MT (% of RsT) was also featured by a significant interaction effect ($F_{interaction(1,35)} = 16.254, p < 0.001$), meaning that the presence of a between-group difference in the proportion of MT (and RT) with respect to total RsT is also dependent on the task condition. Post hoc one-way ANCOVA’s indicated that the proportion of MT (% of RsT) was smaller for the obese as compared to the healthy-weight children on the CRT task ($F_{BMI\ group(1,35)} = 13.957, p = 0.001$), but not the SRT task ($F_{BMI\ group(1,35)} = 1.885, p = 0.179$). Finally, the error rate (%) during the CRT task was found to be higher among obese children relative to their healthy-weight peers ($F_{BMI\ group(1,35)} = 4.103, p = 0.050$), although in general relatively few errors were made (i.e., less than 6%).
**Table 2.** Measurement outcomes on the SRT and CRT task as a function of BMI group: means and standard deviations.

<table>
<thead>
<tr>
<th>Measurement outcomes</th>
<th>SRT task</th>
<th>CRT task</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>BMI group</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HW (N = 19)</td>
<td>OB (N = 19)</td>
</tr>
<tr>
<td>RsT (ms)</td>
<td>963.74 ± 125.25</td>
<td>1130.10 ± 129.60</td>
</tr>
<tr>
<td>RT (ms)</td>
<td>400.93 ± 51.60</td>
<td>460.69 ± 49.87</td>
</tr>
<tr>
<td>MT (ms)</td>
<td>562.81 ± 77.62</td>
<td>669.41 ± 86.06</td>
</tr>
<tr>
<td>RT (% of RsT)</td>
<td>41.65 ± 1.56</td>
<td>40.84 ± 1.95</td>
</tr>
<tr>
<td>MT (% of RsT)</td>
<td>58.35 ± 1.56</td>
<td>59.16 ± 1.95</td>
</tr>
<tr>
<td>Error rate (%)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

BMI, body mass index; HW, healthy weight; OB, obese; SRT, single reaction time; CRT, choice reaction time; RsT, response time; RT, reaction time; MT, movement time.

**Fig. 2.** Temporal structure of RsT in both SRT (top) and CRT task (bottom) conditions as a function of BMI group.
DISCUSSION

To our knowledge, this is the very first study to evaluate the perceptual-motor performance in obese children as compared to healthy-weight peers using SRT and CRT tasks. Differences in executive functions and movement execution were explored in both task conditions by analyzing the temporal structure of RsT.

The finding that participants needed more time when the information processing becomes more complex (i.e., during the CRT condition) is in line with the generic literature on this topic (Christina & Rose, 1985; Hick, 1952; Luce, 1986). Although this increase in RsT with increasing task demands applied to both healthy-weight and obese children, the latter BMI group displayed higher RsT (ms) in both task conditions. Therefore, it was useful to evaluate between-group differences in the time needed to initiate (i.e., RT) and execute the given action (i.e., MT) in more detail.

When performing the SRT task, involving only one possible response to a single visual stimulus and not requiring any response selection, obese participants displayed considerably higher absolute RT and MT, which might reflect greater difficulties with sustained attention and a lower speed of information processing and movement execution as compared to their healthy-weight peers. In particular, the finding that obese children need more time before they can start the execution of a simple motor response is novel and strongly suggests that differences in their motor behavior cannot solely be explained from the mechanical point of view. Obese participants’ prolonged MT, in turn, might be partly explained by the additional mass, different mass distribution and inertial properties associated with moving a heavier arm (Berrigan et al., 2006; D’Hondt et al., 2008). Yet, the proportion of RT and MT with respect to total RsT was similar for both BMI groups. Altogether, these findings seem to indicate that all children used the same strategy to accomplish the SRT task, with the obese group being intrinsically slower in reaction to a single stimulus as well as in response execution.

In the present study, the CRT task differed from the SRT condition in that four stimuli were presented each of them corresponding to a specific response, putting greater stress on the decision-making process and leading to prolonged RT in all participants. In contrast to the SRT task, no between-group differences in absolute MT were observed during the CRT condition. This observation detracts from the aforementioned mechanical assumption, which is inherently present in current literature to explain lower motor skill competence within the obese childhood population (Casajús et al., 2007; D’Hondt et al., 2009, 2012; Hills et al., 2002; Hue et al., 2007; McGraw et al., 2000; Tsiros et al., 2011; Wearing et al., 2006). In fact, the finding of a similar absolute MT for both healthy-weight and obese children is to be
attributed to a substantial change in the proportion of RT and MT with respect to total RsT from the SRT to the CRT task, especially among the healthy-weight participants. Consequently, a different relative temporal structure of RsT was established between BMI groups in the CRT condition, reflected by a smaller percentage of RT and thus a higher percentage of MT for the healthy-weight children as compared to their obese peers. Everything considered, our CRT findings may be explained by other strategies being used by obese versus healthy-weight children, when they are no longer moving their hand at maximum speed.

From the reported results, it should be clear that once more complex decision-making comes into play (i.e., during the CRT task) in order to initiate and execute the motor response a significant difference in the temporal structure of RsT between BMI groups occurs. With increased task demands, the ratio of relative RT to relative MT was no longer comparable for healthy-weight and obese children. Based on the visual representation of the CRT data at the bottom of Figure 2, it may be presumed that for all participants the moment of decision-making, in terms of which plate to tap depending on the presented stimulus (1, 2, 3 or 4), takes place at the same relative point in time (i.e., around 35% of total RsT). Accordingly, it may well be possible that children in the healthy-weight group release their hand from Plate 0 immediately after stimulus identification but before the actual response selection phase, resulting in a relative shorter RT as compared to the obese participants. The endpoint of their arm movement is then only finally determined during the ongoing action itself. So, healthy-weight children probably rely on their ability to either continue or redirect their movement in an accurate way. In this respect, the observation of a longer relative MT than the obese participants can be interpreted as the extra time needed to allow for online control and adjustments to the movement in progress. In the same line of thought, it can be tentatively suggested that the obese group uses a more conservative strategy. This means that the obese children probably wait to release Plate 0 until they have decided which target plate to tap in response to the visual stimulus. Obese participants might only initiate their movement after information processing is fully completed or nearer to completion, resulting in a relative longer RT than children in the healthy-weight group. As the execution of the arm movement is already planned in advance, no adaptations to the movement pattern will occur, even though the earlier made decision is potentially erroneous. It can be further suggested that the relative shorter MT in obese children serves as a compensation mechanism for a less well-developed perceptual-motor function. Whether or not both BMI groups effectively and/or consciously use a different strategy cannot directly be deduced from our study results, which also have to be confirmed per se.
Based on research in the past decade, it is now common knowledge that childhood obesity is associated with a poorer performance on gross motor tasks involving the stabilization or displacement of a great proportion of body mass (Casajús et al., 2007; Deforche et al., 2003; D'Hondt et al., 2009, 2012; Graf et al., 2004, 2007; Hills et al., 2002; Hue et al., 2007; McGraw et al., 2000; Tsiros et al., 2011; Wearing et al., 2006). Remarkably, our results demonstrated that being obese also imposes constraints on the execution of reaction time tasks, during which only the movement of the arm itself needs to be initiated and controlled. Since the contribution of excess mass to the final outcome in SRT and CRT task conditions was negligible, it can be tentatively argued that obese children encounter problems in executive functions. This is in line with earlier studies also suggesting perceptual-motor difficulties within the obese childhood population (Bernard et al., 2003; D'Hondt et al., 2008, 2009; Petrolini et al., 1995). Related to this novel point of view, our findings may hold several important implications. Numerous studies already established a possible link between a decreased perceptual-motor function, mainly based on significantly poor(er) fine motor performance, and children’s academic achievement (Cameron et al., 2012; Grissmer et al., 2010; Son & Meisels, 2006). Furthermore, perceptual-motor problems are likely to hinder a continuous engagement in various forms of physical activity as well as the successful execution of simple daily life tasks. Further research is paramount to clearly identify the underlying mechanism(s) of a non-optimal motor skill function in obese children in addition to the generally accepted mechanical assumption, for which experimental investigation is currently lacking too.

Although highlighting a new research topic within the obese literature, this study has some limitations that need to be considered when interpreting its results. No video recordings of participants’ test trials were available, which would have allowed greater insight in the extent to which children may or may not fine-tune their arm movement after releasing their hand from the start position. In addition, definitive conclusions on the association between childhood obesity and the use of a more conservative strategy as well as a potentially impaired perceptual-motor control must await additional information from future studies. Hence, more research is required to scrutinize obese children’s executive function in order to better understand the poorer perceptual-motor performance within this population.

In conclusion, obese children were found to be intrinsically slower as compared to healthy-weight peers in executive functions and decision-making in order to plan and control movement. Moreover, the present study results strongly suggest that childhood obesity is associated with an impaired perceptual-motor function when performing reaction time tasks, with only a limited part of the body mass involved in the corresponding motor action. However, gross motor skill competence may also be affected by such deficit. Accordingly,
our data stress the need to study obese children’s motor incompetence from a broader perspective, beyond the widely accepted mechanical explanation. Only by means of a comprehensive understanding of the underlying mechanisms, intervention programs aimed at enhancing neuromuscular function and motor skill performance can be developed and implemented within the obese childhood population, entailing indirect benefits in health-related behaviors and outcomes.

ACKNOWLEDGEMENTS

This study was funded by a Ph.D. fellowship of the Research Foundation–Flanders (FWO) awarded to Ilse Gentier. The authors are grateful to the managing board and staff of both the local rehabilitation center (Zeepreventorium VZW, De Haan, Belgium) and primary school (EDUGO Slotendries, Oostakker, Belgium) for supporting this study.
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CHAPTER 3:

Differences in the use of online visual feedback between obese and healthy-weight children during a tracking task
ABSTRACT

Being obese not only imposes significant constraints on children’s gross motor competence but also on the execution of fine motor skills. Because differences in motor competence between obese and healthy-weight children cannot solely be explained from a mechanical point of view, a more comprehensive understanding in the exact nature of obese children’s poorer fine motor competence is warranted. Therefore, the present study investigates the use of online visual feedback according to weight status. Thirty-four obese children (18 ♂ and 16 ♀, aged 6-12 years) and 34 age and gender matched healthy-weight peers performed a tracking task. The task consisted of manually tracking five different automatically generated curves displayed on a computer screen with a wireless stylus on a graphic tablet. A less accurate movement strategy was seen in obese children illustrated by a higher deviation from the target point ($p = 0.027$) and a higher mean deviation from the ideal curve ($p < 0.001$) compared to their healthy-weight peers. These accuracy problems could partially be explained by the obese children’s reduced online feedback capacities limiting their possibility to quickly detect and/or adapt movement errors. Our findings suggest that obese children might encounter difficulties with programming appropriate motor responses which might hinder their ability to adapt to demanding and changing environments, often found during physical activity.

KEYWORDS

Childhood; Obesity; Visual; Perceptual-motor function; Motor competence

INTRODUCTION

It is well-documented that obese children are not only less physically active (Deforche et al., 2009; Haerens et al., 2007; Page et al., 2005) but also display poorer motor skill performance in comparison with healthy-weight children. Obese children mainly show movement difficulties while participating in weight-bearing activities such as running, jumping or hopping (Deforche et al., 2003; D’Hondt et al., 2009, 2011; Gentier et al., 2013a). It is implicitly assumed that obese children’s lower gross motor competence can be explained from a pure mechanical point of view. This viewpoint implies that obese children move differently compared to their healthy-weight peers due to their additional mass that has to be stabilized or moved against gravity and their altered mass distribution (Deforche et al., 2003; D’Hondt et al., 2009, 2011; Gentier et al., 2013a, Graf et al., 2004; Hills et al., 2002; Hue et al., 2007; McGraw et al., 2000; Tsiros et al., 2011).

However, recent findings illustrate that childhood obesity also imposes significant constraints on obese children’s fine motor skill performance in different field-based tests [i.e., Movement Assessment Battery for Children (D’Hondt et al., 2009), Buininks-Oseretsky Test of Motor Proficiency – second edition (Gentier et al., 2013a), and a peg placing task (D’Hondt et al., 2008)] when compared to healthy-weight children. Furthermore, a recent study of Gentier et al. (2013b) examined weight status related differences in reaction and movement time by means of a simple and choice reaction time task. It was found that obese children were intrinsically slower as compared to healthy-weight peers in processing information and decision-making in order to plan and control movement. Because excess mass did not directly contribute to the final outcome in the fine motor tasks under study (D’Hondt et al., 2008, 2009; Gentier et al., 2013a, 2013b), it can be postulated that obese children encounter difficulties while picking-up, processing and integrating sensory information to plan and control the ongoing movement.

To obtain a more thorough understanding of the underlying perceptual-motor processes involved in fine motor performance in obese compared to healthy-weight children, a more in depth research in a greater range of fine motor tasks is warranted. Drawing or copying tasks can be seen as one of the most complex and demanding fine motor tasks which are the result of both cognitive and perceptual-motor processes requiring a high level of coordination and accuracy (Smits-Engelsman et al., 2001). Such tasks rely on somatosensory and visual perception, cognitive processes, and effective motor control. An effective drawing or copying performance will only be produced when motor responses are generated smoothly and when the movement pattern is controlled by an accurate motor control system in which feedback is used for immediate online control (Magill, 2011). Feedback can be seen as afferent information sent by various sensory receptors to the
central nervous system in order to update this motor control center about the correctness of the movement while the action is being performed. Using sensory feedback, movement errors can be detected and corrections to an ongoing movement can be programmed and initiated (Magill, 2011).

Because drawing or copying relies heavily on an individual’s feedback capacities, a tracking task was used to investigate possible weight related differences in tracking performance between obese and healthy-weight children. It was hypothesized that the obese children would have greater difficulties using online visual feedback while performing a tracking task in comparison with their age and gender matched healthy-weight peers.

MATERIALS AND METHODS

Participants

Sixty-eight children, including 36 males and 32 females aged 6-12 years, participated in this study. Thirty-four obese children were recruited through a local pediatric rehabilitation center (Zeepreventorium VZW, De Haan, Belgium) offering a 10 month multidisciplinary treatment program for childhood obesity. Thirty-four healthy-weight children were recruited through a local primary school (EDUGO, Slotendries, Oostakker, Belgium) with attention for age and gender to accurately match the obese children.

Procedures and materials

Anthropometric measurements and tracking task performance were assessed at a single test moment. The obese children’s data were collected at the start of the multidisciplinary treatment program (i.e., during the first month). Prior to participation, each child’s parent(s) and the school or rehabilitation center staff signed consent forms. The study was approved by the Ethics Committee of the Ghent University Hospital.

Anthropometry

Body height (0.1 cm) was measured with a portable stadiometer (Harpenden, Holtain Ltd., Crymych, UK) while the children stood barefoot in the anatomical position. Body weight (0.1 kg) and an estimation of percentage body fat (0.1%) were computed using a digital balance scale provided with bioelectrical impedance analysis technology (Tanita, BC-420SMA, Weda B.V., Naarden, Holland). Body mass index (BMI) (kg/m²) was calculated and used to classify the participants in different weight status groups (obese vs. healthy-weight) according to the internationally accepted BMI cut-off points for children (Cole et al., 2000).
**Tracking task**

A tracking task was performed from a comfortable seated position (i.e., both feet touching the ground and elbow angle around 100°). The task consisted of manually tracking an automatically generated curve presented on a computer screen that was vertically mounted in front of the participant. A graphic tablet (WACOM Ultrapad A3 E (UD-1218RE), WACOM Co. Ltd., Neuss, Germany) was horizontally mounted on the table leaf between the participant and the computer screen (see Fig. 1). Five different curves (i.e., with different Y dimensions) were presented to each participant. Based on the Western writing style, participants drew from left to right with their dominant hand.

![Figure 1. Schematic view of the experimental setup. Solid lines represent the curve generated by the computer and dotted lines exemplify a possible curve generated by a subject.](image)

Participants were instructed to focus on the computer screen and to follow an automatically generated curve, which was visualized in red on the computer screen, as closely as possible with a wireless stylus (WACOM Ultra Pen Eraser UP 801 E, WACOM Co. Ltd., Neuss, Germany) on the graphic tablet. Participants’ pen trajectories were projected in black on the computer screen allowing for online adjustments and immediate visual
feedback. The starting point was indicated on the tablet and participants were informed that once the starting point was touched with the digital stylus the computer would start generating the curve. Children were verbally encouraged to immediately start drawing and following the curve on the graphic tablet since they only got three extra seconds to finish the curve (33s) once the computer ended the generation of the curve (30s). Children were also given the instruction to keep the distance between the endpoint location of their stylus and the target point as small as possible at the end of the tracking task. The curve could fluctuate 10.5 cm up and down in the vertical direction (Y) while a fixed distance of 29.7 cm was used in the horizontal direction (X) (i.e., comparable with the dimensions of an A4 sheet). The total distance to be covered by the pen tip from start to target point varied from 85 cm to 100 cm between the different curves (i.e., ideal pen trajectory perfectly matching the automatically generated curve).

All data were recorded at a sampling rate of 170 Hz and prior to data analysis, data were filtered by a Butterworth Low Pass Filter with a cut off frequency of 10 Hz. Data were analyzed using the Optimized Action Sequence Interpreter System (OASIS software package, KIKO Software, Doetinchem, Holland) (de Jong et al., 1996) based on the X, Y and Z (i.e., pen pressure) dimensions of the movement. From the raw data, the following dependent variables were calculated in Matlab: number of lifts (#), pen up time (s), estimated mean overall velocity (cm/s), deviation from the target point (cm), mean drawing axial pen pressure (N), and root mean square deviation (cm) (see Table 1 for a more detailed description of the dependent variables).

Table 1. Detailed description of the variables explored in the tracking task.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Detailed description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lifts (#)</td>
<td>Number of times that the stylus was lifted from the tablet</td>
</tr>
<tr>
<td></td>
<td>Defined by number of periods in which the position of the coordinates (X and Y) of</td>
</tr>
<tr>
<td></td>
<td>the pen were zero</td>
</tr>
<tr>
<td>Pen up time (s)</td>
<td>The total amount of time (s) that the stylus was lifted from the tablet</td>
</tr>
<tr>
<td>Estimated mean overall velocity</td>
<td>Mean drawing velocity with the stylus, calculated as the total distance covered</td>
</tr>
<tr>
<td>(cm/s)</td>
<td>divided by the time needed to reach the target point</td>
</tr>
<tr>
<td>Deviation from the target point</td>
<td>Distance between the target point and the endpoint location of the stylus at the</td>
</tr>
<tr>
<td>(cm)</td>
<td>end of the tracking task</td>
</tr>
<tr>
<td>Mean drawing axial pen pressure</td>
<td>Mean pen pressure exerted on the writing surface by the subject while drawing (i.e.</td>
</tr>
<tr>
<td>(N)</td>
<td>the vertical force (Z-dimension of the movement) applied by the stylus on the surface</td>
</tr>
<tr>
<td>Root mean square deviation (cm)</td>
<td>The mean deviation from the ideal curve also frequently reported in the literature</td>
</tr>
<tr>
<td></td>
<td>as root mean square error which indicates the mean error between the automatically</td>
</tr>
<tr>
<td></td>
<td>generated curve and the curve produced by the participants. In the case of a set of</td>
</tr>
<tr>
<td></td>
<td>( n ) values, the root mean square deviation is given by this formula: ( \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \ldots + x_n^2)} ).</td>
</tr>
</tbody>
</table>
Statistical analysis

Data from the first trial were excluded from all analyses as this trial was considered a practice trial. Statistical analysis was performed using SPSS software for Windows (version 21.0). Significance level was set at $p < 0.05$, whereas $p$-values varying between 0.05 and 0.10 were considered as a trend towards statistical significance. Between-group differences in anthropometric characteristics were evaluated by means of independent samples $t$-tests. For the tracking task, the mean values for each dependent variable were calculated based on the four test trials completed by each participant. The mean values for number of lifts (#), pen up time (s), estimated mean overall velocity (cm/s), deviation from the target point (cm), mean drawing axial pen pressure (N), and root mean square deviation (cm) were implemented as dependent variables in a Multivariate ANOVA analysis with BMI group included as a fixed factor. Age was not included in the analysis as it seemed to be a non-significant covariate ($F = 1.510; p = 0.182$).

RESULTS

Detailed anthropometric characteristics are presented in Table 2. There were no significant differences between BMI groups in terms of age ($p = 0.774$) and body height ($p = 0.188$). With respect to body weight, BMI, and percentage body fat, between-group differences were found at the $p < 0.001$ significance level, with higher values for the obese participants as compared to their healthy-weight peers.

<table>
<thead>
<tr>
<th>Anthropometric characteristics</th>
<th>BMI group</th>
<th>Independent samples $t$-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HW ($N = 34$)</td>
<td>OB ($N = 34$)</td>
</tr>
<tr>
<td>Gender</td>
<td>18 ♂ - 16 ♀</td>
<td>18 ♂ - 16 ♀</td>
</tr>
<tr>
<td>Age (years)</td>
<td>10.1 ± 1.3</td>
<td>10.0 ± 1.4</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>143.6 ± 9.3</td>
<td>146.5 ± 8.6</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>34.6 ± 6.8</td>
<td>67.5 ± 12.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.58 ± 1.60</td>
<td>31.56 ± 4.14</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>18.1 ± 3.9</td>
<td>43.9 ± 6.1</td>
</tr>
</tbody>
</table>

BMI, body mass index; HW, healthy-weight; OB, obese; NS, not significant. $^{***}p < 0.001$. 

Table 2. Anthropometric characteristics as a function of BMI group: means, standard deviations and summary of comparative statistics.
Table 3 depicts all measurement outcomes (means ± standard deviations) of the tracking task as a function of BMI group together with the univariate F-values.

Overall, significant differences in tracking performance were found according to BMI group ($F_{\text{BMIgroup}} = 2.526; \ p = 0.024$). When focusing on the univariate effects, however, there were no differences in speed of movement execution between healthy-weight and obese children ($p = 0.349$). Additionally, there were no differences between the BMI groups for mean drawing axial pen pressure (N) ($p = 0.852$) meaning that obese and healthy-weight children did not differ in the force exerted on the pen while performing the tracking task. On the other hand, a significant main effect of BMI-group was revealed for pen up time (s) ($p = 0.040$), deviation from the target point (cm) ($p = 0.027$) and root mean square deviation (cm) ($p < 0.001$). Pen up time (s) was found to be significantly higher in the obese compared to the healthy-weight children. This is in line with a trend towards statistical significance for number of lifts (#) ($p = 0.075$) revealing more lifts for the obese compared to the healthy-weight children. The obese children also displayed a significantly higher deviation from the target point (cm) and a significantly higher root mean square deviation (cm) (i.e., a higher mean deviation from the ideal curve) compared to their healthy-weight peers.

Table 3. Measurement outcomes on the tracking task as a function of BMI group: means, standard deviations and summary of statistics.

<table>
<thead>
<tr>
<th>Measurement outcomes</th>
<th>BMI group</th>
<th>ANOVA analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HW (N = 34)</td>
<td>OB (N = 34)</td>
</tr>
<tr>
<td>Number of lifts (#)</td>
<td>0.47 ± 0.65</td>
<td>0.79 ± 0.78</td>
</tr>
<tr>
<td>Pen up time (s)</td>
<td>0.21 ± 0.36</td>
<td>0.54 ± 0.82</td>
</tr>
<tr>
<td>Estimated mean overall velocity (cm/s)</td>
<td>3.00 ± 0.14</td>
<td>3.06 ± 0.33</td>
</tr>
<tr>
<td>Deviation from the target point (cm)</td>
<td>0.77 ± 0.94</td>
<td>1.75 ± 2.37</td>
</tr>
<tr>
<td>Mean drawing axial pen pressure (N)</td>
<td>1.88 ± 0.77</td>
<td>1.85 ± 0.85</td>
</tr>
<tr>
<td>Root mean square deviation (cm)</td>
<td>1.51 ± 0.55</td>
<td>2.27 ± 1.05</td>
</tr>
</tbody>
</table>

BMI, body mass index; HW, healthy-weight; OB, obese.
NS, not significant; *$0.10 > p \geq 0.05$; **$p < 0.05$; ***$p < 0.001$. 

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DISCUSSION

The aim of this study was to compare the use of online visual feedback between obese and healthy-weight children while performing a tracking task.

There were no differences in mean drawing axial pen pressure and estimated mean overall velocity between both BMI groups. However, obese children displayed a trend towards a higher number of lifts resulting in a higher amount of their time spend with the stylus not touching the graphic tablet. The obese children did also have a higher deviation from the target point as well as from the ideal curve than the healthy-weight children. In this tracking task, obese children show less accurate performance in comparison with their gender and age matched peers. Therefore, it can be argued that the healthy-weight children have mastered an efficient and more precise movement strategy compared to the less accurate response strategy in the obese children. This finding could be a first indication that both groups use different movement strategies in executing a tracking task.

The response to visual feedback is less efficient in obese children compared to their healthy-weight peers which could point to the use of a different movement strategy in both BMI groups. This may partially be explained by the obese children's reduced feedback capacities limiting their possibility to detect and/or adapt movement errors while performing the tracking task. Additionally, it was already demonstrated that obese children are intrinsically slower than their healthy-weight peers (Gentier et al., 2013b). Hence, they need more time to process information, and more time before they can start the execution of their motor response. For the tracking task, the time needed to perceive and accurately adapt movement as response to a deviation from the ideal curve is probably higher in obese than in healthy-weight children, which gives them less time to react and adapt their movement pattern. Consequently, this results in higher deviations from the target point and from the ideal curve in the obese children compared to their healthy-weight peers.

Our research findings confirm that obese children experience more difficulties with the online integration of visual information in comparison with their healthy-weight peers while performing a tracking task. Mastery of appropriate feedback capacities is mandatory to detect movement errors and to correct the ongoing movement in order to produce an accurate and acceptable movement outcome. Furthermore, the appropriate use of sensory information is also important to carry out both recreational activities and activities of daily living. It could be that obese children's reduced accuracy is the result of sensory-related difficulties and therefore more in depth research is warranted. It would also be valuable to investigate if the cautious suggestion of an altered movement strategy in obese children is an
adaptation to their limited feedback capacity or if there are some other underlying factors causing these differences.

These findings confirm that differences in motor behavior cannot solely be explained from the mechanical point of view and reinforces previous findings indicating qualitatively worse performance in fine motor tasks for obese compared to healthy-weight children (i.e., the perceptual-motor hypothesis) (D’Hondt et al., 2008, 2009; Gentier et al., 2013a, 2013b). To develop targeted prevention and intervention initiatives, it is crucial to explore both hypotheses. Experimental research for a better understanding of the widely accepted mechanical hypothesis is currently lacking and would be of great value. On the other hand, exploring differences in brain structures and functions in the brain regions involved in motor control and coordination in children (obese vs. healthy-weight) would serve to get a better understanding of the perceptual-motor hypothesis.

Overall, our findings suggest that obese children might encounter difficulties with programming appropriate motor responses which might hinder their ability to adapt to demanding and changing environments, often found during physical activity. Consequently, this could offer a possible explanation why obese children struggle to engage in physical activities besides the increased mechanical demands associated with their excess weight. Dropping out of physical activity results in less movement experiences and opportunities to learn and develop adequate perceptual-motor skills and general motor competence. Furthermore, it is crucial that children develop adequate perceptual-motor skills otherwise basic academic skills as reading and/or writing will be perceived as too challenging and will be difficult to master for these children.

When interpreting these results, some limitations have to be acknowledged. It could be that a lack of attention significantly influenced our study results and that obese children suffer from attentional problems which could cause problems in the registration, integration and interpretation of sensory information (Cserjési et al., 2007). A decreased focus could hinder obese children’s motor control processes to detect deviations in their movement execution. Consequently, the obese children could have difficulties with selecting and programming an appropriate motor response. Nevertheless, further studies have to validate the explanations in terms of cognitive attention focus and motor responses. Another gateway for future research is to include confounding factors possibly affecting tracking performance like the amount and kind of physical activities experienced by the child, which was not monitored in the present study.
CONCLUSION

In conclusion, obese children show a less accurate movement strategy performing a tracking task as illustrated by a higher deviation from the target point as well as the ideal curve in comparison with healthy-weight peers. These accuracy problems may partially be explained by the obese children’s reduced online visual feedback capacities limiting their possibility to detect and/or adapt movement errors. It can be argued that obese children need more time and/or have more difficulty turning sensory information into appropriate motor actions in comparison with their healthy-weight peers. This suggests that obese children might encounter difficulties with programming appropriate motor responses using online visual feedback, which might hinder their ability to adapt to demanding and changing environments, often found during physical activity. It would be valuable to know if the cautious suggestion of an altered movement strategy in obese children is an adaptation to their limited feedback capacities or if there are other underlying factors causing the reported differences.

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CHAPTER 4:

Weight loss and improved gross motor coordination in children as a result of multidisciplinary residential obesity treatment
ABSTRACT

This study evaluated the short-term effectiveness of a multidisciplinary residential obesity treatment program by describing changes in body weight, related measures, and gross motor coordination. Secondarily, it examined to what extent the amount of relative weight loss achieved by overweight and obese participants explained the projected improvement in gross motor coordination. Thirty-six overweight and obese children (aged 10.5 ± 1.4 years, 12 girls and 24 boys) were recruited at the Zeepreventorium VZW (De Haan, Belgium), where they followed a specific program consisting of moderate dietary restriction, psychological support, and physical activity. For reference purposes, an additional group of 36 age- and gender-matched healthy-weight children were included in the study. Anthropometric measures were recorded and gross motor coordination was assessed using the Körperkoordinationstest für Kinder (KTK) on two occasions with an interval of 4 months. Regardless of the test moment, overweight and obese participants displayed significantly poorer KTK performances \( (P < 0.001) \). However, treatment was found to be efficacious in decreasing body weight \( (\Delta 17.9 \pm 3.1\%, \ P < 0.001) \) and generating a significant progress in gross motor coordination performance, with a greater increase in KTK score(s) from baseline to re-test as compared to healthy-weight peers \( (P < 0.01) \). Within the overweight and obese group, the amount of relative weight loss explained 26.9% of the variance in improvement in overall KTK performance. Therefore, multidisciplinary residential treatment and concomitant weight loss can be considered an important means to upgrade overweight and obese children’s level of gross motor coordination, which in turn may promote physical activity participation.

KEYWORDS

Children; Body mass index; Weight Status; Treatment Outcomes; Weight Loss

INTRODUCTION

The prevalence of childhood overweight and obesity has been rapidly increasing worldwide (Wang & Lobstein, 2006). This global epidemic is alarming because overweight and obesity in children has been associated with a number of negative outcomes concerning physical health and psychosocial well-being along with an increased risk for persistence into later adulthood (Daniels, 2006; Malecka-Tendera & Mazur, 2006). In recent years, the adverse implications of being overweight or obese on children’s level of motor skill competence has received increasing attention given the potential role of this factor in both development (prevention) and treatment (intervention) of the condition (Cliff et al., 2011; Hills et al., 2002; Lubans et al., 2010; Morgan et al., 2008; Okely et al., 2004).

Successful engagement in everyday activities requires that children master different motor skills, ranging on a continuum from gross to fine motor coordination (Henderson & Sugden, 1992; Piek et al., 2006). Furthermore, motor skill competence is considered a key determinant of physical activity engagement (Barnett et al., 2009; Castelli & Valley, 2007; Lopes et al., 2011). Children with a high level of motor competence may find it easier to participate in physical activity, whereas children with a low(er) level of motor competence may prefer more sedentary pastimes in order to avoid movement difficulties (Bouffard et al., 1996; Cairney et al., 2005; Wrotniak et al., 2006). Such activity deficit may lead to limited movement experiences, which impedes the necessary practice and further development of motor skills as well as health-related benefits (Bouffard et al., 1996; Cairney et al., 2005; Lubans et al., 2010). Because adequate motor competence may assist in maintaining a physically active lifestyle, a lack thereof puts less skilled children at risk for developing overweight or obesity (Cairney et al., 2005; Stodden et al., 2008).

At the same time, a growing body of evidence has shown that excess body weight imposes significant constraints on children’s motor competence (D’Hondt et al., 2009, 2011; Graf et al., 2004, 2007; Kastner et al., 2010; Marshall & Bouffard, 1994; Okely et al., 2004; Southall et al., 2004). The majority of available studies within this particular area of research have predominantly focused on gross motor skills and associated body coordination, which clearly seemed to be affected. Graf et al. (2004), for example, demonstrated an inverse relationship between BMI and gross motor development in a large sample of first-grade children. Childhood overweight and especially obesity were found to result in poorer gross motor coordination performance as compared to healthy-weight peers. Moreover, D’Hondt et al. (2011) reported a more pronounced detrimental effect of excess body weight on gross motor coordination with increasing age in 5- to 12-year old children. Remarkably, most overweight and obese children do not only show motor skill competence that deviates from the normative standards, but that can also be classified as impaired requiring special
Weight loss and improved gross motor coordination

Attention (D’Hondt et al., 2011; Kastner et al., 2010). As overweight and obesity are strongly associated with nonoptimal motor development, weight status proves to be an important factor explaining variation in children’s motor competence levels.

Accordingly, obesity treatment (and concomitant weight loss) may have a beneficial effect on motor skill in overweight and obese children. It seems increasingly apparent from adult and adolescent literature that weight loss is associated with significant improvements in muscle function, motor control, and performance (Maffiuletti et al., 2004; Sartorio et al., 2001). In children, however, research has mainly focused on the effectiveness of weight reduction programs in decreasing body fat levels and improving measures of (mental) health, physical activity, and physical fitness performance (Braet et al., 2004; Cliff et al., 2010; Deforche et al., 2003; Knöpfli et al., 2008). Studies examining whether (relative) weight loss achieved by following a multidisciplinary obesity treatment program may also improve overweight and obese children’s motor skill competence and coordination are currently lacking.

The main purpose of the present preliminary study was to evaluate the short-term effectiveness of an existing multidisciplinary residential treatment program for overweight and obese children in terms of changing body weight and other weight-related measures as well as gross motor skill coordination. It was hypothesized that improvements would occur in both areas relative to the baseline measures at the start of treatment. Given that the amount of (relative) weight loss achieved can be considered as a key outcome measure of the program, our secondary purpose was to describe the extent to which this factor explained the projected increase in participant’s gross motor coordination performance. The greatest progress in gross motor coordination was expected in those children who lost the largest percentage of their original body weight during treatment.

METHODS AND PROCEDURES

Study population

A total of 72 children (aged 7–13 years, 24 girls and 48 boys) participated in this study. Half of the children (N = 36) were recruited through a local rehabilitation center (Zeepreventorium VZW, De Haan, Belgium), where they attended a multidisciplinary residential obese treatment program (between January 2008 and July 2009). Based on internationally accepted cut-off points for BMI in children (Cole et al., 2000), these participants could be identified as overweight (N = 2) or obese (N = 34) and were assigned to the overweight and obese group. All of the overweight and obese children were referred to the program by their family physician, but had no underlying endocrine disease and were
free from any serious comorbidities. A normal intelligence quotient (i.e., IQ >70) was an additional criterion for entry in the program. The other 36 children included in this study were recruited through a local primary school (in October 2009) and selected from a larger pool of around 200 pupils in order to match the overweight and obese participants based on gender and age. These participants could all be classified as healthy-weight and represented the healthy-weight group, which was not involved in any kind of treatment. The study sample was further divided into a younger (aged 7–9 years, \( N = 26 \)) and an older group (aged 10–13 years, \( N = 46 \)), with weight status evenly distributed in both age groups (50% healthy-weight and 50% overweight or obese).

**Obesity treatment program**

Participants in the overweight and obese group followed a multidisciplinary residential treatment program at the Zeepreventorium VZW, with a standard duration varying from 6 to 10 months and a minimal treatment period of 4 months. The program consisted of three major components, including moderate dietary restriction (i.e., 1,400–1,600 kcal/day from three main meals and two healthy snacks), psychological support (i.e., cognitive behavioral modification and individual psychotherapy), and regular physical activity. Concerning this latter component, each child received 4 h/week of individual guided exercises with a focus on aerobic activities such as walking, running, swimming, cycling, or fitness training. Activities were performed at an exercise intensity of 20% lower than the theoretical maximal heart rate and exercise duration gradually increased during treatment. Besides improving endurance, exercise sessions were also focused on the correction of posture and the maintenance of flexibility and muscular strength. In addition, children participated in organized/supervised team sports and/or group games for 2 h/day or 10 h/week and had also sufficient opportunity to be physically active in their free time.

**Measurements**

All children were assessed on two occasions, with a time interval of 4 months. Evaluation at baseline occurred during the first month of the residential treatment program for those participants included in the overweight and obese group. At both testing sessions, children wore light sportswear and were barefoot. Anthropometric measures were always recorded prior to the assessment of gross motor coordination. All tests were administered by a team of trained examiners. The study protocol was approved by the Ethics Committee of the Ghent University Hospital, and written informed consent was obtained from the parent(s) of each of the participants prior to data collection.
Anthropometric measurements

Height was measured to the nearest 0.1 cm using a portable stadiometer (Harpenden; Holtain, Crymych, UK). Body weight (0.1 kg) and percentage body fat (0.1%) were computed using a digital balance scale provided with foot-to-foot bioelectrical impedance analysis technology (Tanita BC-420; Weda, Naarden, Holland), which has been shown to be a reliable and accurate tool for the measurement of body composition in children (Tyrrell et al., 2001; Goldfield et al., 2006). From the recorded height and weight measures, BMI (kg/m2) was calculated and used to classify the subjects according to the age- and gender-specific BMI cut-off points for children recommended by the International Obesity Task Force (Cole et al., 2000). Waist circumference was measured with 0.1 cm accuracy at 4 cm above the umbilicus using a flexible nonelastic tape (Rudolf et al., 2007).

Assessment of gross motor coordination

Gross motor coordination was assessed by means of the KörperkoordinationsTest fur Kinder (Body Coordination Test for Children) (KTK). It is a standardized product-oriented test, developed and recently revised by Kiphard and Schilling (Kiphard & Schilling, 1974, 2007). Being a highly reliable and valid instrument, the KTK is commonly used to assess gross motor and dynamic balance skills in children aged 5–15 years (Kiphard & Schilling, 1974, 2007, Smits-Engelsman et al., 1998). The test battery was also designed to identify children facing gross motor coordination problems.

Administration of the KTK requires four subtests to be completed: (i) walking backwards along balance beams of decreasing width: 6.0 cm, 4.5 cm, 3.0 cm (KTK\textsubscript{BEAM}), (ii) moving sideways on wooden boards during 20 s (KTK\textsubscript{BOARD}), (iii) one-legged hopping over a foam obstacle with increasing height in consecutive steps of 5 cm (KTK\textsubscript{HOP}), and (iv) two-legged jumping from side to side during 15 s (KTK\textsubscript{JUMP}).

Based on the performance of a German standardization sample, the KTK manual provides tables containing normative data. Hence, the raw performance score of each subtest can be converted into a standardized score adjusted for age (all four subtests) and gender (KTK\textsubscript{HOP} and KTK\textsubscript{JUMP}). Adding together all standardized scores results in an overall motor quotient (MQ), that can be converted into a percentile score. Not only does this allow the comparison of a child’s performance with regard to that of peers in the reference population, the KTK manual also provides a classification into five different levels of gross motor coordination: (i) “high” (≥ 99th percentile), (ii) “good” (85th-98th percentile), (iii) “normal” (16th-84th percentile), (iv) “moderate motor impairment” (3rd-15th percentile),
and (v) “severe motor impairment” (< 3rd percentile). Accordingly, a child with an overall KTK performance equal or below the 15th percentile faces gross motor coordination problems and is actually in need of special attention (Kiphard & Schilling, 1974, 2007).

**Statistical analysis**

Data were analyzed using the statistical package SPSS 16.0 for Windows (SPSS, Chicago, IL). Descriptive statistics (mean ± s.d.) were calculated for anthropometric measurements and KTK outcome, including the raw performance score on each subtest as well as the overall KTK MQ. Anthropometric characteristics were analyzed in a 2 (Time: baseline vs. after 4 months) × 2 (BMI group: healthy-weight vs. overweight and obese) ANOVA with repeated measures on the first factor in order to determine BMI group differences and to verify the effectiveness of the residential treatment program. Significant effects were further examined by means of independent- or paired-samples t-tests. To examine the change in gross motor coordination performance over time and to investigate the effects of BMI group, age, and gender, all KTK variables were implemented in a 2 (Time: baseline vs. after 4 months) × 2 (BMI group: healthy-weight vs. overweight and obese) × 2 (Age: 7–9 years vs. 10–13 years) × 2 (Gender: boys vs. girls) ANOVA with repeated measures on the first factor. Significant effects were further examined by means of independent- or paired-samples t-tests. In addition, Pearson χ² analyses were conducted to have a closer look at the proportion of children in each BMI group showing motor impairment at baseline and the moment of retesting, using the 15th percentile as a cut-off point for overall KTK performance. Finally, within the overweight and obese group, simple linear regression analysis was performed to investigate the variance in improvement in gross motor coordination performance explained from the amount of relative weight loss as a result of multidisciplinary residential treatment. Therefore, the absolute value of the difference in overall KTK MQ (Δ KTK MQ) was implemented as the dependent variable, whereas the amount of weight loss expressed relative to the children’s original weight at baseline (%) was used as the independent variable. For all analyses, values of P < 0.05 were considered statistically significant.

**RESULTS**

**Anthropometric measurements**

Detailed anthropometric characteristics are presented in Table 1. There was a significant interaction between Time and BMI group for weight (F(1,70) = 496.260, p < 0.001),
Weight loss and improved gross motor coordination

BMI ($F_{(1,70)} = 745.580, p < 0.001$), BMI z-score ($F_{(1,70)} = 168.038, p < 0.001$), percentage body fat ($F_{(1,70)} = 278.201, p < 0.001$), and waist circumference ($F_{(1,70)} = 66.468, p < 0.001$). Results indicated a significant decrease for each of these weight-related measures in the overweight and obese group ($t_{(35)} = 8.174 - 28.672, p < 0.001$) after 4 months of residential treatment. In the healthy-weight group, weight ($t_{(35)} = 7.444, p < 0.001$) and BMI ($t_{(35)} = 3.173, p = 0.003$) slightly increased, whereas BMI z-score ($t_{(35)} = 1.050, p = 0.301$), percentage body fat ($t_{(35)} = 1.090, p = 0.283$), and waist circumference ($t_{(35)} = 1.315, p = 0.197$) remained constant over time.

All children that were classified as healthy-weight at baseline maintained the same weight status after the set time interval of 4 months between testing sessions. After a mean weight loss of $11.7 \pm 3.3$ kg among participants within the overweight and obese group at the moment of retesting, four children (i.e., two overweight and two obese) could now be identified as healthy-weight, 21 children could be classified as overweight, and 11 children were still obese (Cole et al., 2000). (In the interest of clarity, the original BMI-related group names (i.e., healthy-weight group and overweight and obese group) were used throughout the paper even though the weight status of some overweight and obese participants changed over time).

Table 1. Descriptive statistics (mean ± standard deviation) for the healthy-weight and the overweight and obese group.

<table>
<thead>
<tr>
<th>Antropometric characteristics</th>
<th>Baseline</th>
<th>After 4 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HW</td>
<td>OW/OB</td>
</tr>
<tr>
<td>Age (years)</td>
<td>10.5 ± 1.4</td>
<td>10.5 ± 1.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>142.6 ± 9.7 $^a$</td>
<td>149.0 ± 9.6 $^b$</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>35.0 ± 6.7 $^a$</td>
<td>65.0 ± 13.4 $^b$</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.08 ± 1.72 $^a$</td>
<td>29.08 ± 3.60 $^b$</td>
</tr>
<tr>
<td>BMI z-score</td>
<td>-0.05 ± 0.68 $^a$</td>
<td>2.41 ± 0.34 $^b$</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>16.98 ± 4.39 $^a$</td>
<td>38.24 ± 7.72 $^b$</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>60.0 ± 4.9 $^a$</td>
<td>89.3 ± 13.9 $^b$</td>
</tr>
</tbody>
</table>

HW: healthy-weight group; OW/OB: overweight/obese group; BMI: body mass index.

a,b,c,d Means with different letters are significantly different from each other (resulting from independent-samples or paired-samples t tests).
Change in gross motor coordination over time

Descriptive statistics of the raw performance scores on each of the four subtests as well as the overall KTK MQ are presented in Table 2. As no significant four- or three-way interactions were found, Table 3 only shows the F-values of main and two-way interaction effects resulting from the repeated measures ANOVA analysis. Only the statistical outcomes most pertinent to our main research question are discussed below.

Each of the KTK variables was featured by a significant main effect of Time, indicating that all participants’ gross motor coordination performance had improved from baseline to re-test. More importantly, significant interactions between Time and BMI group (except for KTK\textsubscript{BOARD}) demonstrated that the increase in KTK scores over time was larger for the overweight and obese participants, who participated in multidisciplinary residential treatment during the 4-month period between testing sessions (see Figure 1 for overall KTK MQ). There was also a significant main effect of BMI group for each of the four subtests as well as overall KTK MQ. Regardless of the test moment, poorer gross motor coordination performance was observed among participants in the overweight and obese group compared to peers in the healthy-weight group.

Using the 15th percentile as a cut-off point, the proportion of children who showed moderate to severe motor impairment at baseline was 16.7% in the healthy-weight group and 94.4% in the overweight and obese group ($\chi^2 = 44.100, p < 0.001$). At the moment of retesting, only one child within the healthy-weight group and five children within the overweight and obese group made the transition from impaired to normal or high levels of gross motor coordination. Nevertheless, ratios were still significantly different between BMI groups after a (treatment) period of 4 months with 13.9% of the participants in the healthy-weight group and 80.6% of the participants in the overweight and obese group facing gross motor coordination problems ($\chi^2 = 32.099, p < 0.001$).

Weight loss (%) and improved gross motor coordination within the overweight and obese group

Simple linear regression analysis was performed to investigate the relationship between the amount of relative weight loss (i.e., independent variable) and the degree of change in overall KTK performance (i.e., dependent variable) from baseline to re-test in the participants following the multidisciplinary residential treatment program. Additional residual analysis revealed that model assumptions for linear regression were met. After 4 months of obesity treatment, the overweight and obese children had lost on average 17.9 ± 3.1% of their original weight at baseline. The amount of relative weight loss achieved explained
26.9% of the variance in improvement observed in overall KTK performance ($f_{\Delta KTK MQ} = -17.032 + 1.814$ weight loss (%), $R^2 = 0.269$, $P = 0.001$).

**DISCUSSION**

The present preliminary study evaluated the short-term outcomes of an existing multidisciplinary residential treatment program for overweight and obese children in terms of body weight, other weight-related measures, and gross motor skill coordination. Results demonstrate that the specific program provided by the Zeepreventorium VZW (De Haan, Belgium) is efficacious in realizing considerable weight loss as well as generating a significant progress in gross motor coordination performance after 4 months of residential treatment. In addition, verification of a linear relationship between both changes suggests that the degree of improvement in overweight and obese children’s gross motor coordination can be partly explained by the amount of relative weight loss achieved.
Table 2. KTK performance (mean ± standard deviation) for participants in the HW and the OW/OB group.

<table>
<thead>
<tr>
<th>Gender</th>
<th>KTK variables</th>
<th>7-9 years (N = 26)</th>
<th>10-13 years (N = 46)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HW</td>
<td>OW/OB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>After 4 months</td>
</tr>
<tr>
<td>Boys</td>
<td>KTK_{BEAM}</td>
<td>35.00 ± 9.27</td>
<td>51.50 ± 4.89</td>
</tr>
<tr>
<td></td>
<td>KTK_{BOARD}</td>
<td>39.67 ± 5.96</td>
<td>39.17 ± 6.24</td>
</tr>
<tr>
<td></td>
<td>KTK_{HOP}</td>
<td>58.50 ± 11.61</td>
<td>63.83 ± 13.39</td>
</tr>
<tr>
<td></td>
<td>KTK_{JUMP}</td>
<td>49.83 ± 8.98</td>
<td>53.50 ± 5.86</td>
</tr>
<tr>
<td></td>
<td>Overall KTK MQ</td>
<td>99.17 ± 15.24</td>
<td>102.50 ± 12.11</td>
</tr>
<tr>
<td>Girls</td>
<td>KTK_{BEAM}</td>
<td>47.43 ± 13.18</td>
<td>54.71 ± 11.01</td>
</tr>
<tr>
<td></td>
<td>KTK_{BOARD}</td>
<td>46.29 ± 7.91</td>
<td>50.57 ± 7.30</td>
</tr>
<tr>
<td></td>
<td>KTK_{HOP}</td>
<td>59.29 ± 14.00</td>
<td>62.71 ± 11.60</td>
</tr>
<tr>
<td></td>
<td>KTK_{JUMP}</td>
<td>71.00 ± 15.93</td>
<td>70.43 ± 12.83</td>
</tr>
<tr>
<td></td>
<td>Overall KTK MQ</td>
<td>113.29 ± 21.63</td>
<td>113.14 ± 23.13</td>
</tr>
</tbody>
</table>

HW: healthy-weight group; OW/OB: overweight/obese group; KTK: Körperkoordinationstest für Kinder; MQ: motor quotient.
Table 3. Main and two-way interaction effects for KTK performance according to Time, BMI, Age, and Gender.

<table>
<thead>
<tr>
<th>KTK variables</th>
<th>$F_{TIME}$</th>
<th>$F_{BMI}$</th>
<th>$F_{AGE}$</th>
<th>$F_{GENDER}$</th>
<th>$F_{TIME} \times BMI$</th>
<th>$F_{TIME} \times AGE$</th>
<th>$F_{TIME} \times GENDER$</th>
<th>$F_{BMI} \times AGE$</th>
<th>$F_{BMI} \times GENDER$</th>
<th>$F_{AGE} \times GENDER$</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTK&lt;sub&gt;BEAM&lt;/sub&gt;</td>
<td>39.42</td>
<td>80.33*</td>
<td>4.57†</td>
<td>1.70</td>
<td>8.54†</td>
<td>0.88</td>
<td>0.19</td>
<td>0.20</td>
<td>4.67†</td>
<td>0.01</td>
</tr>
<tr>
<td>KTK&lt;sub&gt;BOARD&lt;/sub&gt;</td>
<td>20.13*</td>
<td>57.75*</td>
<td>17.09*</td>
<td>6.17‡</td>
<td>1.02</td>
<td>0.89</td>
<td>1.54</td>
<td>0.06</td>
<td>5.63‡</td>
<td>0.03</td>
</tr>
<tr>
<td>KTK&lt;sub&gt;HOP&lt;/sub&gt;</td>
<td>176.97*</td>
<td>116.62*</td>
<td>17.06*</td>
<td>1.12</td>
<td>85.67*</td>
<td>0.21</td>
<td>6.55‡</td>
<td>0.97</td>
<td>1.15</td>
<td>0.01</td>
</tr>
<tr>
<td>KTK&lt;sub&gt;JUMP&lt;/sub&gt;</td>
<td>43.39*</td>
<td>68.75*</td>
<td>11.33†</td>
<td>2.53</td>
<td>18.17*</td>
<td>1.63</td>
<td>0.35</td>
<td>0.54</td>
<td>7.64†</td>
<td>2.02</td>
</tr>
<tr>
<td>Overall KTK MQ</td>
<td>44.93*</td>
<td>98.15*</td>
<td>0.23</td>
<td>0.22</td>
<td>18.06*</td>
<td>0.01</td>
<td>2.95</td>
<td>0.05</td>
<td>4.38‡</td>
<td>0.01</td>
</tr>
</tbody>
</table>

* p < 0.001; † p < 0.01; ‡ p < 0.05.

KTK: Körperkoordinationstest für Kinder; MQ: motor quotient; BMI: body mass index.
In first instance, this study adds to the evidence from previous reports regarding the effectiveness of multidisciplinary residential treatment in the specific setting of the Zeepreventorium VZW in substantially decreasing levels of overweight and body fat (Braet et al., 2004; Deforche et al., 2003; Verhulst et al., 2009). After an initial treatment period of 4 months, we found a significant reduction in all weight-related measures (i.e., body weight, BMI (z-score), percentage body fat, and waist circumference) for participants in the overweight and obese group. The program, which consisted of moderate dietary restriction, psychological support, and regular physical activity, resulted in a mean absolute weight loss of 11.7 kg, corresponding to 17.9%, of these children’s original weight at baseline. Previous studies have shown that the particular obesity treatment program provided by the Zeepreventorium VZW is also successful in enhancing psychosocial well-being (Braet et al., 2004), improving aerobic fitness (Deforche et al., 2003), and treating sleep-disordered breathing through weight loss (Verhulst et al., 2009). Hence, our study provides additional information since it was not yet investigated whether and to what extent this kind of multidisciplinary residential treatment and the amount of weight loss achieved may have a beneficial effect on overweight and obese children’s gross motor skill coordination.

Using the KTK as an assessment tool, it was demonstrated that all participants’ gross motor coordination performance significantly progressed within the timeframe of 4 months. This gradual improvement in gross motor skill coordination is not surprising as it appears to be a general phenomenon across developmental time (Ahnert et al., 2009). More importantly, a closer inspection of our data revealed a significantly greater increase in KTK outcome scores from baseline to re-test for the overweight and obese group of children as compared to their peers included in the healthy-weight group. In other words, the improvement in gross motor coordination performance among the overweight and obese participants exceeded the progress that can be expected with reference to normal motor development. This is a key finding in view of previous cross-sectional research indicating a widening gap between the KTK performances of healthy-weight and overweight and obese children, with a more pronounced detrimental effect of childhood overweight and obesity with increasing age if no action is taken (D’Hondt et al., 2011). Accordingly, our results are a first indication that the likely further deterioration of overweight and obese children’s gross motor coordination over developmental time can be stopped and even compensated for by means of an overall multidisciplinary residential treatment.

Although participants in the overweight and obese group were able to partially catch up their gross motor coordination deficit compared to healthy-weight peers, they still showed significantly poorer KTK performances after 4 months of treatment, regardless of the subtest under study. Looking at the proportion of children that could be classified as being motor
impaired based on the set standards, 94.4% of the overweight and obese participants had an overall KTK performance equal or below the 15th percentile at the start of the program. After 4 months of residential treatment, this proportion was only reduced to 80.6%. The fact that the majority of children within the overweight and obese group did not achieve normalization of their body weight at the moment of retesting may have contributed to this finding. Regardless of the test occasion (i.e., at baseline or after 4 months), the observed percentages exceed the previously reported 70.8% of overweight and obese children facing gross motor coordination problems in a study investigating the relationship between weight status and motor impairment using the same KTK standards in a school based setting (D’Hondt et al., 2011). However, it should be noted that in the present study the prevalence of gross motor impairment was estimated in a clinical setting of overweight and obese participants. As hypothesized and previously suggested, the degree of excess weight and/or corpulence appears to be a crucial factor adversely affecting motor competence in children when performing the tasks that are part of motor skill assessment batteries (D’Hondt et al., 2009).

Therefore, it seemed appropriate to verify whether the amount of relative weight loss achieved by following the multidisciplinary residential treatment program at the Zeepreventorium VZW had an impact on the degree of improvement in gross motor coordination within the group of overweight and obese children. Results of the corresponding simple linear regression analysis pointed out that 26.9% of the variance in improvement in overall KTK performance may be explained by the percentage of weight loss achieved after 4 months of residential treatment. Based on the regression equation, each lost percentage of overweight and obese participants’ original weight at baseline predicted an improvement of approximately two points in their overall KTK MQ. Furthermore, it can be assumed that the greatest improvement in gross motor coordination performance does indeed occur in the overweight and obese children with the largest relative weight reduction. To our knowledge, this is the first study to show a beneficial effect of multidisciplinary obesity treatment on overweight and obese children’s gross motor coordination, also describing the extent to which the amount of concomitant weight loss (%) achieved by the participants may explain part of their significant progress in performance. The observed positive relationship between the degree of weight reduction and the improvement in overall KTK MQ indicates that weight loss represents an important factor in promoting overweight and obese children’s motor skill competence.

A number of limitations need to be considered when interpreting the findings of the present preliminary study. Participants included in the overweight and obese group were involved in a specific multidisciplinary residential treatment program, with gradually
increasing physical activity as one of the key components in support of achieving a healthy weight. In view of previous research establishing a reciprocal positive relationship between physical activity and motor competence (Bouffard et al., 1996; Graf et al., 2004; Marshall & Bouffard, 1994; Stodden et al., 2008; Wrotniak et al., 1996), it should be noted that the increased involvement in various physical activities during the course of treatment provided the overweight and obese children with great opportunities for the development of their (gross) motor skill coordination. Therefore, the amount of physical activity included in the program may have interacted with the outcome measure (relative) weight loss in explaining (part of) the improvement in overall KTK performance within the overweight and obese group. Unfortunately, the actual level of participants’ physical activity participation was not effectively measured. This lack of objective quantitative data prevented to control for this likely confounder in our statistical analyses. However, it must be acknowledged that motor competence and motor skills do not naturally emerge but are the result of many factors that influence a child’s motor skill development including motor skill instruction, repetition and encouragement (Gabbard, 2008; Goodway et al., 2003). Therefore, the increased physical activity opportunities provided by the obesity treatment program are probably not the only factor contributing to the improvement in obese children’s gross motor coordination. Future research is thus necessary to further explore the separate and/or combined effect of the factors potentially contributing to the reported progress in motor skill competence among children treated for obesity. The absence of an additional control group of free-living children also matched for weight status (overweight and obesity) represents another shortcoming of this study. More than likely, the inclusion of a no treatment group of overweight and obese children would have added to its demonstrative power in attributing the considerable increase in gross motor coordination performance to participation in multidisciplinary residential treatment (and concomitant weight loss) in contrast to growth induced motor development. Furthermore, the previous assumption of a widening disparity between the gross motor coordination performance of healthy-weight and overweight and obese children not being involved in treatment could have been confirmed because of the longitudinal nature of the present study (D’Hondt et al., 2011). In this respect, there would be a considerable surplus value in the evaluation of the longer-term effectiveness of the examined multidisciplinary obesity treatment program in terms of decreasing body weight and improving gross motor skill coordination. Further follow-up studies will need to verify the occurrence and the persistence of the beneficial effects established after an initial treatment period of 4 months. In addition, the impact of maintained or continued weight loss vs. potential weight gain after the full program on children’s level of motor competence remains to be investigated. The present study only focused on gross motor coordination as this aspect of motor competence seems to be the most affected by excess weight. However,
there are recent indications for a possibly detrimental effect of childhood overweight and obesity on object control and/or fine motor skill performance too (D'Hondt et al., 2009; Kastner et al., 2010; D'Hondt et al., 2008). Given that both features of motor competence determine a child’s well-being, general development, and (later) physical activity behavior (Barnett et al., 2009; Henderson & Sugden, 1992; Morgan et al., 2008; Piek et al., 2006; Smits-Engelsman et al., 1998), future research in this specific area should explore motor functioning in all its aspects. Finally, it should be mentioned that our preliminary findings thus far only apply to the specific clinical setting of the local rehabilitation center Zeepreventorium VZW (De Haan, Belgium), in which our study was conducted.

In conclusion, an existing multidisciplinary residential treatment program for overweight and obese children was shown to be successful in realizing substantial weight loss and bringing about a remarkable increase in gross motor coordination performance in the short-term. The extent of improvement in gross motor coordination reflected in KTK scores was found to be linearly related to the amount of relative weight loss achieved by following the program for 4 months. Although the impact of other treatment related factors that might contribute to the observed progress in motor competence was not specifically investigated in the present preliminary study, significant weight loss may be considered an important means to upgrade the level of gross motor skill in overweight and obese children. Regardless thereof, the finding of improved gross motor coordination as a result of multidisciplinary residential obesity treatment is paramount in view of the fact that it may assist in promoting sustained participation in physical activities.

ACKNOWLEDGMENTS

This study was funded by Ph.D. fellowships of the Research Foundation–Flanders (FWO) awarded to E.D. and I.G. The authors thank the staff of the local school and the treatment center (Zeepreventorium VZW) for supporting this study, and the members of the Flemish Sports Compass team for their assistance in collecting the data.
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Weight loss and improved gross motor coordination


CHAPTER 5:

Effects of a multidisciplinary residential treatment program on perceptual-motor function in obese children
ABSTRACT

This study evaluated the effects of a 10-month multidisciplinary residential treatment program on obese children’s perceptual-motor function as compared to healthy-weight children not involved in any kind of treatment. Twenty-six obese children (aged 10.1 ± 1.4 yrs., 10 girls and 16 boys) followed a treatment program consisting of moderate dietary restriction, psychological support and physical activity offered by the Zeepreventorium VZW (De Haan, Belgium). Twenty-six age- and gender-matched healthy-weight children were included as a control group. Both groups’ anthropometrics and performance on a simple and choice reaction time task (i.e., SRT and CRT), and a tracking task were assessed on two occasions 10 months spread apart. Time by BMI group interactions were investigated using repeated measures ANCOVAs, with age included as covariate. No significant interaction effect occurred for the SRT and CRT task. In contrast, obese participants showed a significant improvement in tracking performance over time for number of lifts (#), pen up time (s) and mean deviation from the ideal curve (cm), whereas no difference in performance between baseline and follow-up was observed in the healthy-weight controls. Multidisciplinary residential treatment can be considered an important means to partly upgrade obese children’s perceptual-motor function.

KEYWORDS:
Body mass index, BMI; Childhood; Motor competence; Perceptual-motor function; Weight loss

INTRODUCTION

Recent studies indicate that childhood obesity hinders gross motor competence (Deforche et al., 2009a; D’Hondt et al., 2009, 2011a; Gentier et al., 2013a; Graf et al., 2004; Hills et al., 2002; Hue et al., 2007; McGraw et al., 2000; Tsiros et al., 2011). The heavier the child, the higher the inertial characteristics of the body (segments) and the load on the musculoskeletal system. In contrast to this mechanical point of view, obese (OB) children also perform worse than their healthy-weight (HW) peers on fine motor tasks in which their excess mass hardly plays a role. Being obese was shown to be detrimental for fine motor competence in different field-based tests such as a peg placing task (D’Hondt et al., 2008), the fine motor tasks from the Bruininks-Oseretsky Test of Motor Proficiency (second edition) (Gentier et al., 2013a) and the manual dexterity cluster of the Movement Assessment Battery for Children (D’Hondt et al., 2009), although in the latter only a trend towards statistical significance was found.

In order to further explore these differences, Gentier et al. studied obese children’s perceptual-motor function in laboratory settings. Obese children not only displayed less accurate performance in a tracking task compared to their healthy-weight peers (Gentier et al., 2014) but they also experienced difficulties with processing information and decision making during reaction time tasks, reflected by significantly higher reaction time in the obese children than the healthy-weight children (Gentier et al., 2013b). Given that these fine motor tasks involved only limited movement of the hand and/or arm(s), the lower motor competence in obese children cannot solely be explained from a mechanical perspective. Hence, it can be postulated that obese children have more difficulties turning sensory information into appropriate motor actions in comparison with their healthy-weight peers while performing (gross and) fine motor tasks (i.e., perceptual-motor hypothesis) (D’Hondt et al., 2008; Gentier et al., 2013b; Petrolini et al., 1995).

From the previous results, it can be concluded that weight status is an important factor in explaining differences in children’s gross and fine competence. Consequently, weight loss could have a beneficial effect on obese children’s (fine) motor performance. Recently, it has been demonstrated that an existing treatment program provided by the Zeepreventorium VZW (De Haan, Belgium) and concomitant weight loss not only induces significant improvements in obese children’s body composition, mental health, physical activity levels and physical fitness (Braet et al., 2003; Deforche et al., 2003) but also in their level of gross motor coordination (D’Hondt et al., 2011b). From the above mentioned perceptual-motor perspective, the improvement is not necessarily due to the obese children’s weight loss but might additionally be explained by an improvement in perceptual-motor
Weight-related changes in perceptual-motor function. However, studies examining whether this treatment program may also improve obese children’s perceptual-motor function are currently lacking. Nevertheless, to gain greater insight in the contributing factors of obese children’s reduced motor competence, it could be of great value to explore the effect of this existing treatment program on tasks relying on well-known principles of perceptual-motor function.

Therefore, the aim of this study was to evaluate the effectiveness of a 10-month treatment program for obese children in terms of perceptual-motor function. The outcomes of interest were changes in fine motor competence according to weight status on a simple and choice reaction time task, and a tracking task. It was expected that fine motor competence in these tasks would improve more in the obese children as a result of the treatment program.

**METHODS**

**Participants**

A total of 52 children (20 girls and 32 boys) took part in this study. Half of the children (N = 26, 10 girls and 16 boys) was recruited through a local rehabilitation center (Zeepreventorium VZW, De Haan, Belgium), where they attended a 10 months multidisciplinary residential obesity treatment program (between August 2011 and June 2013). Every child starting treatment in August 2011 or August 2012 received an information letter to participate in this study, resulting in a sample of 32 children for the pretest. Six children dropped out of the study because of sickness at the moment of retesting (N = 4) or leaving the center because of their family situation (N = 2) resulting in 26 obese children. The number of obese children participating in this study was rather limited since the intake of children in the program is restricted to a maximum of 20 children each year. All of the obese children were referred to the program by their family physician, but had no underlying endocrine disease and were free from any serious comorbidities. A normal intelligence quotient (i.e., IQ > 70) was an additional criterion for entry in the program. Based on internationally accepted cut-off points for Body mass index (BMI) in children (Cole et al., 2000), these participants could be identified as obese and were assigned to the obese group. For each of these 26 obese children, a healthy-weight control child which was not involved in any kind of treatment was recruited through a local primary school (EDUGO, Oostakker, Belgium) and selected from a larger dataset (N = 150) with attention to age and gender to accurately match the obese children. These participants were classified as healthy-weight based on internationally accepted BMI cut-off points relative to age and gender (Cole et al., 2000). Each child’s parent(s) and the school or rehabilitation center staff signed informed consents. The study was approved by the Ethics Committee of the Ghent University Hospital.
Obesity treatment program

The OB group followed a treatment program at the Zeepreventorium VZW which consisted of three major components, including moderate dietary restriction (i.e., 1.450-2.050 kcal/day), psychological support and regular physical activity. Each child received 3h/week of individual exercises focusing on aerobic activities (e.g., running, swimming, or fitness training). In addition, children participated in supervised team sports and group games for approximately 1h/day or 5h/week and had also sufficient opportunity to be physically active in their free time.

Measurements

Children’s anthropometric characteristics and perceptual-motor function were assessed on two occasions with a 10-months’ time interval. Baseline measurements were collected during the first month of obese children’s residential stay. Baseline and follow-up measurements in the obese group were conducted in a classroom at the Zeepreventorium, whereas assessments in the healthy-weight group took place in the school’s gymnasium during physical education classes. At both test occasions, children wore light sportswear and were barefoot.

Anthropometric measurements

Height was measured (0.1 cm) using a portable stadiometer (Harpenden; Holtain, Crymych, UK). Body weight (0.1 kg) and an estimation of percentage body fat (0.1%) were computed using a digital balance scale with bioelectrical impedance analysis (Tanita BC-420; Weda, Naarden, Holland). BMI (kg/m²) was calculated and used to classify participants as obese or healthy-weight (Cole et al., 2000).

Assessment of perceptual-motor function

Speed of information processing, decision making and movement execution were assessed by means of a simple and choice reaction time task (Luce, 1986), and the use of online visual feedback by a tracking task (Magill, 2011; Smits-Engelsman et al., 2001), which were performed from a comfortable seated position (i.e., both feet touching the ground and elbow angle of about 100°).

For the simple and choice reaction time task, visual stimuli (i.e., highlighting green circles) were projected at eye level on a laptop screen (diagonal size of 39.6 cm) in front of the children (Figure 1). A wooden board (30 cm x 45 cm) with touch-sensitive metal plates was positioned on the table desk in front of the laptop screen. Participants were instructed to put their left hand on the bigger plate (5 cm x 10 cm) on the bottom left of the board and their right hand on Plate 0 (5 cm x 5 cm). In both tasks the inter-stimulus interval randomly ranged
Weight-related changes in perceptual-motor function

between 2 and 4 s. When a circle highlighted in green, children tapped Plate 2 in the simple reaction time task condition or the corresponding plate in the choice reaction time task condition as quickly as possible with their right hand. The SRT task consisted of three practice trials, followed by ten test trials. During the choice reaction time task, four possible stimuli could be highlighted corresponding to either Plate 1, 2, 3, or 4 (each centered 15 cm from the midpoint of Plate 0). This latter task consisted of four practice trials, followed by 16 test trials. For each response, the reaction time (ms) (i.e., time interval between stimulus presentation and participant releasing Plate 0) as well as the movement time (ms) (i.e., time interval between releasing Plate 0 and tapping the target plate) were recorded together with the correctness of the response in the choice reaction time task. Reaction time (ms) and movement time (ms) were added together to obtain an overall response time (ms).

Subsequently, a tracking task was performed in a similar set-up (Figure 2). A digitizer (WACOM Ultrapad A3 E (UD-1218RE), WACOM Co. Ltd., Neuss, Germany) was positioned on the table desk between the participant and the computer screen, on which an automatically generated curve was presented. The curve could fluctuate 10.5 cm up and down in the vertical direction (Y) over a horizontal (X) distance of 29.7 cm.

Figure 1. Schematic view of the experimental setup of the reaction time tasks.
The protocol consisted of manually tracking five different curves for which participants drew from left to right with their dominant hand. The first curve was a practice trial, followed by four test trials. Participants were instructed to focus on the computer screen and follow an automatically generated curve, which was visualized in red on the computer screen, as closely as possible with a wireless stylus (WACOM Ultra Pen Eraser UP 801 E, WACOM Co. Ltd., Neuss, Germany) on the graphic tablet. At the same time, participants’ pen trajectories were also projected on the computer screen in black allowing for online adjustments and immediate visual feedback. The children were further instructed to immediately start drawing and following the curve on the tablet since they only got three extra seconds to finish the curve (33s) once the computer ended the generation of the reference curve (30s), and to keep the distance between the endpoint location of their stylus and the target point as small as possible. Data were recorded at a sampling rate of 170 Hz and filtered by a Butterworth Low Pass Filter with a cut off frequency of 10 Hz, prior to data analysis. Data were analyzed using OASIS software package (KIKO Software, Doetinchem, Holland) (de Jong et al., 1996) based on the X, Y and Z (i.e., pen pressure) dimensions of the movement. From the raw data, the following dependent variables were calculated: number of lifts (#), pen up time (s), estimated mean overall velocity (cm/s), deviation from the target (cm), mean drawing axial pen pressure (N), and root mean square deviation (cm) (Table 1).

Figure 2. Schematic view of the experimental setup of the tracking task. Solid lines represent the curve generated by the computer and dotted lines exemplify a possible curve generated by a subject.
Statistical analysis

Data from the practice trials were excluded from all analyses. Remaining data were analyzed using the statistical package SPSS 21.0 for Windows (SPSS, Chicago, IL). Values of $p < 0.05$ were considered statistically significant.

For the simple and choice reaction time task, mean reaction time (ms), movement time (ms) and response time (ms) (i.e., sum of reaction time and movement time) were calculated together with the error rate (%) on the choice reaction time task. Mean values for each dependent tracking variable were calculated based on the four test trials.

Anthropometric characteristics were analyzed in a 2 (Time: baseline vs. follow-up) x 2 (BMI group: healthy-weight vs. obese) ANOVA with repeated measures on the first factor; To investigate the change in simple and choice reaction time task performance over time and to examine the effects of BMI group, condition, and age, reaction time (ms), movement time (ms) and response time (ms) were separately implemented in a 2 (Time: baseline vs. follow-up) x 2 (BMI group: healthy-weight vs. obese) x 2 (condition: simple reaction time vs. choice reaction time task) repeated measures ANCOVA, with age as a covariate. All tracking measurement outcomes were separately implemented in a 2 (Time: baseline vs. follow-up) x 2 (BMI group: healthy-weight vs. obese) ANCOVA with repeated measures on the first factor and age as a covariate.

Table 1. Detailed description of the variables explored in the tracking task.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Detailed description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lifts (#)</td>
<td>Number of times that the stylus was lifted from the tablet Defined by number of periods in which the position of the coordinates (X and Y) of the pen were zero</td>
</tr>
<tr>
<td>Pen up time (s)</td>
<td>The total amount of time (s) that the stylus was lifted from the tablet</td>
</tr>
<tr>
<td>Estimated mean overall velocity (cm/s)</td>
<td>Mean drawing velocity with the stylus, calculated as the total distance covered divided by the time needed to reach the target point</td>
</tr>
<tr>
<td>Deviation from the target point (cm)</td>
<td>Distance between the target point and the endpoint location of the stylus at the end of the tracking task</td>
</tr>
<tr>
<td>Mean drawing axial pen pressure (N)</td>
<td>Mean pen pressure exerted on the writing surface by the subject while drawing (i.e. the vertical force (Z-dimension of the movement) applied by the stylus on the surface)</td>
</tr>
<tr>
<td>Root mean square deviation (cm)</td>
<td>The mean deviation from the ideal curve also frequently reported in the literature as root mean square error which indicates the mean error between the automatically generated curve and the curve produced by the participants. In the case of a set of $n$ values, the root mean square deviation is given by this formula: $\sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \ldots + x_n^2)}$</td>
</tr>
</tbody>
</table>
RESULTS

Only the results associated with the longitudinal aspect of the study will be discussed in detail below.

Detailed anthropometric characteristics are presented in Table 2. There was a significant interaction between Time and BMI group for weight ($F_{(1,50)} = 177.137, p < 0.001$), BMI ($F_{(1,70)} = 189.121, p < 0.001$), and percentage body fat ($F_{(1,50)} = 111.684, p < 0.001$). Results indicated a significant decrease for each of these weight-related measures in the obese group over time, while there was a small increase in weight and BMI and decrease in body fat percentage in the healthy-weight children. All children classified as healthy-weight at baseline maintained the same weight status over time. After an absolute mean weight loss of $14.7 \pm 6.5$ kg (i.e., $21.7 \pm 7.9\%$) within the obese group at the moment of retesting, five children could be identified as healthy-weight, fifteen children as overweight, and six children were still obese\(^1\).

Table 2. Descriptive statistics (mean $\pm$ standard deviation) for the HW and the OB group at baseline and follow-up.

<table>
<thead>
<tr>
<th>Antropometric characteristics</th>
<th>Baseline</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HW (N = 26)</td>
<td>OB (N = 26)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>10.2 $\pm$ 1.3 (^a)</td>
<td>10.1 $\pm$ 1.4 (^a)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>143.9 $\pm$ 9.8 (^a)</td>
<td>145.8 $\pm$ 8.4 (^a)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>34.8 $\pm$ 7.3 (^a)</td>
<td>66.3 $\pm$ 12.3 (^b)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.63 $\pm$ 1.66 (^a)</td>
<td>31.40 $\pm$ 4.37 (^b)</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>18.18 $\pm$ 4.18 (^a)</td>
<td>43.36 $\pm$ 6.38 (^b)</td>
</tr>
</tbody>
</table>

HW, healthy-weight group; OB, obese group; BMI, body mass index.

\(^{a,b,c,d}\) Means with different letters are significantly different from each other (resulting from independent-samples or paired-samples t tests).

\(^1\) The original BMI-related group names (i.e., HW vs. OB) were used throughout the paper even though the weight status of some OB participants changed over time.
Tables 3 and 4 provide an overview of all measurement outcomes on the simple and choice reaction time task and the $F$-values resulting from the repeated measures ANCOVA analysis. There was no significant three way interaction effect between Time, BMI group and Condition and no significant interaction effect between Time and Condition, and Time and BMI group occurred. None of the outcomes on the SRT and CRT task showed a main effect of Time. These results indicate that obese and healthy-weight children’s performance on both the simple and choice reaction time task did not change significantly over time. Finally, no interaction or main effect for the error rate (%) emerged.

The outcomes on the tracking task are presented in Table 5. Significant interactions between Time and BMI group for number of lifts (#) ($p = 0.047$), pen up time (s) ($p = 0.042$) and RMSD (cm) ($p = 0.006$) demonstrate that obese children show a significant decrease for these three variables over time, while there was no significant change from baseline to follow-up in the healthy-weight children.
Table 3. Performance on the SRT and CRT task (mean ± standard deviation) for participants in the HW and the OB group

<table>
<thead>
<tr>
<th>Measurement outcomes</th>
<th>SRT task</th>
<th>BMI group</th>
<th>CRT task</th>
<th>BMI group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HW</td>
<td>OB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>Follow-up</td>
<td>Baseline</td>
</tr>
<tr>
<td>RsT (ms)</td>
<td></td>
<td>899.89 ± 95.93</td>
<td>913.68 ± 190.95</td>
<td>1109.23 ± 199.14</td>
</tr>
<tr>
<td>RT (ms)</td>
<td></td>
<td>376.50 ± 41.47</td>
<td>363.21 ± 80.31</td>
<td>457.76 ± 70.88</td>
</tr>
<tr>
<td>MT (ms)</td>
<td></td>
<td>522.17 ± 61.84</td>
<td>550.19 ± 119.57</td>
<td>653.39 ± 134.69</td>
</tr>
<tr>
<td>Error rate (%)</td>
<td></td>
<td>_</td>
<td>_</td>
<td>_</td>
</tr>
</tbody>
</table>

SRT, single reaction time; CRT, choice reaction time; BMI, body mass index; HW, healthy weight group; OB, obese group; RsT, response time; RT, reaction time; MT, movement time.

Table 4. Main, two-way and three-way interaction effects for SRT and CRT performance according to Time, Condition and BMI group (with age included as a covariate).

<table>
<thead>
<tr>
<th>Measurement outcomes</th>
<th>RM ANCOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F_{TIME}</td>
</tr>
<tr>
<td>RsT (ms)</td>
<td>0.740</td>
</tr>
<tr>
<td>RT (ms)</td>
<td>0.159</td>
</tr>
<tr>
<td>MT (ms)</td>
<td>0.949</td>
</tr>
<tr>
<td>Error rate (%)</td>
<td>0.183</td>
</tr>
</tbody>
</table>

SRT, single reaction time; CRT, choice reaction time; BMI, body mass index; RM, repeated measures; ANCOVA, analysis of covariance; RsT, response time; RT, reaction time; MT, movement time.

**p < 0.01; ***p < 0.001
Table 5. Measurement outcomes on the tracking task as a function of BMI group (and time): means, standard deviations and summary of statistics.

<table>
<thead>
<tr>
<th>Measurement outcomes</th>
<th>HW (N = 26)</th>
<th>OB (N = 26)</th>
<th>RM ANCOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Follow-up</td>
<td>Baseline</td>
</tr>
<tr>
<td>Number of lifts (#)</td>
<td>0.52 ± 0.70</td>
<td>0.48 ± 0.64</td>
<td>0.80 ± 0.79</td>
</tr>
<tr>
<td>Pen up time (s)</td>
<td>0.25 ± 0.40</td>
<td>0.28 ± 0.48</td>
<td>0.63 ± 0.92</td>
</tr>
<tr>
<td>Estimated mean overall velocity (cm/s)</td>
<td>2.99 ± 0.14</td>
<td>3.01 ± 0.12</td>
<td>3.07 ± 0.31</td>
</tr>
<tr>
<td>Deviation from the target (cm)</td>
<td>0.84 ± 1.06</td>
<td>0.70 ± 0.99</td>
<td>1.44 ± 1.70</td>
</tr>
<tr>
<td>Mean drawing axial pen pressure (N)</td>
<td>1.89 ± 0.84</td>
<td>1.76 ± 0.77</td>
<td>1.95 ± 0.90</td>
</tr>
<tr>
<td>Root mean square deviation (cm)</td>
<td>1.56 ± 0.53</td>
<td>1.36 ± 0.63</td>
<td>2.36 ± 1.11</td>
</tr>
</tbody>
</table>

BMI, body mass index; HW, healthy-weight group; OB, obese group; RM, repeated measures; ANCOVA, analysis of covariance.

*, p < 0.05; **, p < 0.01.
DISCUSSION

The present study evaluated the effectiveness of an existing 10-month treatment program for obese children provided by the Zeepreventorium VZW on weight-related measures and perceptual-motor performance. The program realized a considerable amount of weight loss among the participants in the obese group. Furthermore, no significant difference in changes in measurement outcomes on both the simple and choice reaction time task were observed according to BMI group. In contrast, significant improvements in obese children’s tracking task performance were found, reflected in a significantly higher decrease in their number of lifts, pen up time and mean deviation from the ideal curve compared to their healthy-weight peers.

Despite the finding that the obese children already displayed significantly poorer performance on both the simple and choice reaction time task compared to their healthy-weight peers at baseline, no improvements occurred after the treatment program and they still showed inferior performance compared to the healthy-weight children. Obese children’s performance in both the simple and choice reaction time task did not benefit from participating in the treatment program, although the program induced significant weight loss and increased physical activity (PA) levels. A possible explanation for the lack of improvement in reaction time due to treatment could be that obese children still experience difficulties with the processing of sensory information under time constraints and therefore generally need more time for the motor preparatory phase of relatively easy and discrete motor actions (Christina & Rose, 1985; Luce, 1986), confirming an earlier study on this issue (Gentier et al., 2013b). The possible reasons explaining the significantly longer movement time in obese compared to healthy-weight children, before and after treatment, are less clear. It could be implicitly assumed that the inertial characteristics associated with moving a heavier arm impose significant constraints on obese children’s movement execution, especially at the start of the treatment program. After treatment, it was expected that the reduced inertial properties associated with a lighter arm would induce an improvement in obese children’s movement execution phase; however, no improvement in obese children’s movement time occurred. Nevertheless, in this study, weight loss and loss of fat mass were determined for the whole body and not per body segment (i.e., not separately for the arm). This restricts any (causal) statements about whether or not weight loss affected the inertial characteristics of obese children’s arm. Altogether, the fact that obese children continue to encounter difficulties with the execution of both tasks over time is in line with the current knowledge that the construct of planning and executing reaction time tasks is hardly subject to change, even by extensive practice (Beashel et al., 2001; Clark, 1982; Vickers, 2007). It can be questioned why obese children suffer from these perceptual-motor difficulties...
compared to their healthy-weight peers. Is this deficit already present from birth and can it be considered an innate characteristic of obese children? Could it be possible that this deficit hampers obese children’s movement execution which could, in turn, be an explanation for obese children’s initial lower physical activity levels (Deforche et al., 2009b; Haerens et al., 2007; Page et al., 2005)? During their early life, obese children’s lower physical activity levels result in less movement opportunities to develop an effective motor control system. On the other hand, it is also reasonable to assume that increased fat accumulation affects neuromotor functions in the brain. However, insights in the effect of obesity on human’s brain structure and function are less well understood. Only recently, it has been demonstrated that obesity is associated with decreased white matter integrity throughout the brain (Verstynen et al., 2012), which can result in reduced neural transmission speed and slowed information processing (Gunning-Dixon & Raz, 2000), as well as executive dysfunction (Tullberg et al., 2004; Vannorsdall et al., 2009). Up to now, evidence is restricted to adult populations and the susceptibility to physical activity remains unknown (Verstynen et al., 2012). The increase in physical activity induced by the treatment program is maybe not sustained over a sufficient amount of time to reverse or improve the obese group’s affected motor control system in planning discrete motor actions. However, differences in brain function in response to exercise need to be further explored, especially within this population.

With respect to the tracking task, the improvement in number of lifts, pen up time and mean deviation from the ideal curve (i.e., root mean square deviation) among the obese participants exceeded the progress that could be expected with reference to the healthy-weight group which was subject to typical motor development. After the treatment program, the obese and healthy-weight children’s number of lifts, pen up time and root mean square deviation was at the same level indicating that the treatment program had a positive effect in reversing obese children’s difficulties to use online visual feedback during movement execution. In contrast to the simple and choice reaction time task, the tracking task relies on more complex perceptual-motor processes. It is a continuous task with lower temporal pressure compared to a reaction time task, and heavily relies on the capacity to detect and/or adapt to movement errors by using online visual feedback (Magill, 2011). Obese children were exposed to a significant increase in physical activity during treatment as compared to their activity level before entrance in the program (Deforche et al., 2004). The increase went along with more opportunities for practicing and learning motor skills. It is reasonable to assume that the increased opportunities to participate in physical activity offer the obese group the possibility to develop their feedback capacities because these perceptual-motor skills are needed in continuously adapting movements to changing environments like during physical activity. After 10 months of treatment, obese children’s tracking performance
seemed to benefit from the increased physical activity opportunities in which the continued use of feedback is essential.

Some limitations have to be acknowledged when interpreting the present findings. Obese children involved in a treatment program were compared with healthy-weight children not involved in any kind of treatment. It would also be interesting to investigate the change in perceptual-motor function in an obese control group after 10 months of ‘normal’ development. Furthermore, children’s actual level of physical activity was not objectively measured. Accordingly, we could not control for this likely confounder in our statistical analyses. Additionally, a significant limitation of this study is the issue of dose-response of the intervention. The intervention study was essentially a black box study with a lack of data or understanding about the content, dose and intensity of the intervention. This makes it difficult to explain the findings based on the effectiveness of the intervention. Future research is needed to explore the separate and/or combined effect of uncontrolled or unexplored factors potentially contributing to the reported differences in feedback capacities among children treated for obesity.

It can be concluded that obese children’s suboptimal motor planning and control processes of discrete motor actions do not benefit from weight loss and increased physical activity opportunities associated with the treatment program. However, obese children’s tracking performance significantly improved pointing to a catch-up with their healthy-weight peers. Although the impact of separate treatment related factors contributing to the observed progress in perceptual-motor performance was not specifically investigated in the present study, multidisciplinary treatment in total may be considered an important factor to improve obese children’s feedback capacities.

ACKNOWLEDGEMENTS

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BD and ML conceived this study and contributed significantly to the set-up of the study. IG, ED and MA were involved in data collection. AT en EB were involved in the collection of the data. IG, ED, IDB, BD and ML contributed to the analysis and interpretation of the data. IG drafted the manuscript, and all other authors critically revised the manuscript and had final approval of the submitted and published versions.
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PART 3:

GENERAL DISCUSSION
1. OVERVIEW OF THE GENERAL DISCUSSION

The main aim of this doctoral thesis was to obtain a better understanding of the two mechanisms used to explain lower motor competence in obese compared to healthy-weight children. A first mechanism claims that differences in motor competence between obese and healthy-weight children can be explained by the mechanical constraints associated with moving excess mass. However, an alternative mechanism states that obese children encounter difficulties with the integration of sensory information in the planning and control of movement. Therefore, perceptual-motor difficulties may also (partly) explain poorer motor competence among obese children. To further explore both explanations, different studies with their own specific research questions were conducted to target three sub aims. The first sub aim was to extend the existing knowledge concerning the relationship between childhood obesity and both gross and fine motor skill competence in children (i.e., chapter 1). The second sub aim was to gain greater insight in those aspects of perceptual-motor function that are affected in obese compared to healthy-weight children (i.e., chapter 2 and 3). The third sub aim was to examine the effect of a multidisciplinary treatment program on both gross and fine motor skill competence, including aspects of the underlying perceptual-motor function (i.e., chapter 4 and 5). Accordingly, the original research of this dissertation aimed to provide answers on the following research questions:

1) Do obese and healthy-weight children differ in gross and fine motor skill competence? (chapter 1)
2) Do obese and healthy-weight children differ in speed of information processing, decision-making and movement execution while performing a simple and choice reaction time task? (chapter 2)
3) Do obese and healthy-weight children differ in fine motor performance and more specifically in the use of online visual feedback during a manual tracking task? (chapter 3)
4) Does a multidisciplinary residential obesity treatment program have a beneficial effect on obese children’s gross motor coordination? (chapter 4)
5) Does a multidisciplinary residential obesity treatment program positively influence perceptual-motor function in obese children? (chapter 5)

In this final part of the thesis, the main results of the different studies are highlighted and discussed, followed by a general discussion and overall conclusion. Subsequently, an overview of implications for practice together with a discussion of the limitations and strengths of the original research are presented. Finally, several guidelines for future research are discussed.
2. SUMMARY AND DISCUSSION OF THE MAIN RESEARCH FINDINGS

2.1. Examining the relationship between weight status and gross and fine motor skill performance

Most previous studies exclusively focused on gross motor skills when examining the link between motor competence and weight status in children. However, fine motor skills are equally important and can be seen as prerequisites to successfully engage in activities of daily living (Henderson & Sugden, 1992). Children who lack adequate fine motor skills are also more likely to fall behind in other academic areas (Cameron et al., 2012; Grissmer et al., 2010; Son & Meisels, 2006). Therefore, the purpose of the first study (chapter 1) was to investigate and compare gross as well as fine motor skill performance between obese and healthy-weight children using the Bruininks-Oseretsky Test of Motor Proficiency – second edition (BOT-2; Bruininks & Bruininks, 2005). This study confirmed the detrimental effect of excess weight (and body fat) on the execution of gross motor tasks since obese children performed worse on all subtests requiring gross motor competence (i.e., bilateral coordination, balance, upper-limb coordination, running speed and agility, and strength). This is in line with a growing body of evidence indicating that excess body weight (and body fat) impose(s) significant constraints on children’s gross motor competence, which is more than likely due to their additional mass and different mass distribution (Deforche et al., 2009b; D’Hondt et al., 2009, 2011; Graf et al., 2004, 2007; Hue et al., 2007; Lopes et al., 2012; Marshall & Bouffard, 1994; McGraw et al., 2000; Mond et al., 2007; Morano et al., 2011; Okely et al., 2004; Southall et al., 2004; Tsiros et al., 2011).

However, this dissertation is of added value to the field and unique in its kind because it also explores the effect of weight status on fine motor competence. Up to now, evidence concerning the impact of excess weight on children’s fine motor competence is rather speculative and conclusive evidence is lacking. Two studies of D’Hondt et al. (2008, 2009) provided a first indication that childhood obesity also imposes significant constraints on obese children’s fine motor skill performance compared to healthy-weight children. This was demonstrated by a trend towards poorer performances of obese children on the manual dexterity cluster of the Movement Assessment Battery for Children performed from a seated position (D’Hondt et al., 2009). Additionally, lower performance scores of obese children on a peg placing task were found relative to the normal-weight and overweight children both from a standing (i.e., in tandem stance on a balance beam) and sitting position (D’Hondt et al., 2008). The latter finding is remarkable since in the seated position a larger base of support
was offered and less degrees of freedom needed to be regulated, which substantially reduced the complexity of postural organization. Consequently, this (partly) excludes that the mechanical constraints associated with moving excess body weight are the only factor explaining the lower motor performance in obese children. In line with these two studies, our work presented in chapter 1, confirmed that childhood obesity is detrimental for manual dexterity which could be seen in the lower outcomes on the transferring pennies task for the obese compared to the healthy-weight children. Furthermore, fine motor precision differences according to weight group were also demonstrated in poorer performances among the obese children for the drawing lines and folding paper tasks in comparison with their healthy-weight peers. This study confirmed that motor difficulties in obese children are not limited to gross motor skills alone but that childhood obesity is also associated with impaired fine motor skills. Even though in these fine motor tasks the non-contributory mass that participates in the movement is restricted and outcome is mainly determined by the quality of information processing and the integration of sensory information.

2.2. A more detailed understanding of the perceptual-motor difficulties associated with weight status

Because of the preliminary evidence adding to the limited literature in this area of research (i.e., chapter 1), a more comprehensive understanding of the exact nature of obese children's poorer perceptual-motor function is mandatory. Therefore, two studies explored obese children's fine motor competence as an expression of perceptual-motor function by means of a variety of fine motor tasks in which few body segments are involved. The fine motor tasks were performed from a seated position, thereby excluding the role of excess mass for the most part (chapter 2 and 3).

The research presented in chapter 2 investigated weight status related differences in speed of information processing, decision making and movement execution to determine to what extent childhood obesity is associated with impaired perceptual-motor function. For this purpose, performance in a simple and a four choice reaction time task was compared between obese and healthy-weight children. When performing the simple reaction time task, involving only one possible response to a single visual stimulus and not requiring any response selection process, obese children displayed a considerably higher absolute response time reflected in a higher reaction time as well as increased movement time as compared to their healthy-weight peers. This finding indicates that obese children have a lower speed of information processing in reaction to a single visual stimulus and therefore need more time before they can start the execution of a simple motor response. This
suggests and confirms that differences in obese and healthy-weight children’s motor behavior cannot solely be explained from a mechanical viewpoint (Bernard et al., 2003; D’Hondt et al., 2008, 2009; Petrolini et al., 1995). Furthermore, obese children also needed more time for the movement execution phase which might, in turn, be partly explained by the additional mass, different mass distribution and inertial properties associated with moving their heavier hand and/or arm to the target (Berrigan et al., 2006). All participants needed more time to perform the choice reaction time task since greater stress is put on the decision making process (i.e., four possible stimuli) compared to the simple reaction time task (i.e., only one possible stimulus). However, between-group differences were only present for response time and reaction time, whereas absolute movement time was comparable among both BMI groups (i.e., in contrast to the simple reaction time task). However, it was suggested that a different temporal structure in response time occurred when more complex decision-making was needed to initiate and execute the motor response during the choice reaction time task as compared to the simple reaction time task. In the choice reaction time task, the obese children spend a relatively smaller percentage of their time in the movement phase compared to their healthy-weight peers. This can probably be explained by the fact that obese children await final decision-making with regard to the execution of their response movement, which indicates the use of a more conservative strategy within the obese group.

To the best of our knowledge, no research on the concept of reaction times has been conducted within the obese childhood population which makes it difficult to compare our findings with the available literature. Our findings confirmed that being obese imposed significant limitations on children’s reaction time tasks performance. It can be argued that obese children’s motor behavior is planned and controlled with a perceptual-motor function of less(er) quality because it is intrinsically slower and more conservative compared to healthy-weight children.

To obtain a more thorough understanding of the underlying perceptual-motor processes involved in fine motor skill performance, exploration of performance in a greater range of tasks is necessary. An interesting task to investigate is a manual tracking task (i.e., drawing) which can be seen as one of the most complex and demanding fine motor tasks. Manual tracking requires a high level of coordination and accuracy and results from both cognitive and perceptual-motor processes (Magill, 2011; Smits-Engelsman et al., 2001). Evidence on the relationship between weight status and tracking performance in children is virtually non-existent. Therefore, in chapter 3, the use of online visual feedback of obese and healthy-weight children was assessed and compared by means of a manual tracking task. Analysis of tracking performance among 6- to 12-year-old children in our study revealed significant BMI-related differences in tracking accuracy illustrated by a higher deviation from
the target and a higher mean deviation from the ideal curve in obese children in comparison with their healthy-weight peers. This finding could be a first indication that both groups use different movement strategies in executing a manual tracking task. Our research findings confirm that obese children experience more difficulties with the online integration of visual information to control and adjust their (pen) movement in comparison with their healthy-weight peers while performing a manual tracking task. Mastery of appropriate feedback capacities is, however, mandatory to detect movement errors and to correct the ongoing movement in order to produce an accurate and acceptable movement outcome. This suggests that obese children might encounter difficulties with programming appropriate motor responses, which might hinder their ability to adapt to demanding and changing environments often found during physical activity. Consequently, this could explain why obese children struggle to engage in physical activity in addition to the general accepted idea of increased mechanical demands.

It would be valuable to know whether this altered movement strategy seen in obese children in both the simple and choice reaction time task as well as in the manual tracking task can be considered an adaptation to their limitations (i.e., limited processing speed and limited feedback capacities) encountered in the fine motor skills under study. Or maybe there are also some additional factors underlying the reported differences such as sensory-related difficulties in processing information, higher levels of noise in the neuromotor system, or other neuromotor disorders (Smits-Engelsman et al., 2001). It could be possible that poorer fine motor skills reflect a failure of the neuromotor system to keep the natural degree of movement variability or ‘neuromotor noise’ within appropriate limits. It could also be possible that minor neuromotor disorders impacted significantly on obese children’s fine motor performance as for example Developmental Coordination Disorder (DCD) or Attention Deficit Hyperactivity Disorder (ADHD).

2.3. **Examining the effect of a multidisciplinary treatment program on both gross and fine motor competence.**

After examining fine motor differences from a cross-sectional perspective, the last two chapters with original research data explored the effect of a multidisciplinary treatment program (and concomitant weight loss) on obese children’s gross (chapter 4) and fine motor competence (chapter 5). Both longitudinal studies were executed in collaboration with a local pediatric rehabilitation center (Zeepreventorium VZW, De Haan, Belgium) offering a multidisciplinary residential treatment program to obese children. During our first longitudinal
study from 2008 to 2010, the policy of the rehabilitation center entailed that children were allowed to leave the center and return to their home environment when they achieved a healthy-weight status, with a minimal treatment period of 4 months. During the second longitudinal study (2011-2013), the treatment program had a standard duration of 10 months corresponding to the duration of a school year. The program consisted of three major components, including moderate dietary restriction (i.e., 1,450–2,050 kcal/day from three main meals and two healthy snacks), psychological support (i.e., cognitive behavioral modification and individual psychotherapy), and regular physical activity. The obese children were referred to the program by their family physician because of their obese weight status and past difficulties dealing with their excess weight. They had no underlying endocrine disease and were free from any serious comorbidities. A normal intelligence quotient (i.e., IQ > 70) was an additional criterion for entry into the program. A healthy-weight group, not involved in any kind of treatment, was selected with attention to age and gender to accurately match the obese group and served as the control group.

In chapter 4 details were provided on the effect of this particular treatment program on obese children’s gross motor skill coordination assessed by means of the Körperkoordinationstest für Kinder (KTK) on two occasions with an interval of 4 months. In the first place, results indicated that the treatment program is efficacious in establishing considerable absolute weight loss of 11.7 ± 3.3 kg (i.e., relative weight loss of 17.9 ± 3.1%) and an absolute decrease in BMI of 5.90 ± 1.28 kg/m² (i.e., mean decrease in BMI z-score of 0.78 ± 0.14) in the obese group. Studies investigating the effect of weight loss on children’s gross motor coordination are currently limited and most studies focus specifically on improvements in muscle function in adolescents and adults (Maffiuletti et al., 2004; Sartorio et al., 2001). In chapter 4, a significantly greater increase in KTK outcome scores from baseline to re-test was demonstrated for the obese group as compared to their healthy-weight peers. In other words, the improvement in gross motor coordination performance among the obese participants exceeded the progress that could be expected with reference to normal motor development. It was found that the weight loss was effective in bringing about a remarkable increase in obese children’s gross motor coordination in the short-term as each lost percentage of original weight at baseline was associated with a significant improvement of approximately two points in overall KTK MQ. However, the obese children still showed significantly poorer KTK performances after 4 months of treatment. This could probably be explained by the fact that most of the children within the obese group had not yet achieved a healthy-weight status at the moment of follow-up. Nevertheless, these findings are a first indication that the likely further deterioration of obese children’s gross motor
coordination over developmental time (D’Hondt et al., 2011, 2013) can be stopped and even compensated for by means of an overall multidisciplinary residential treatment.

The observed positive relationship between the degree of weight reduction and the improvement in overall KTK MQ indicated that weight loss represented an important factor in increasing obese children’s (gross) motor skill competence. This was also reflected in the fact that 26.9% of the improvement in obese children’s gross motor coordination could be explained by their relative weight loss. Obviously, adherence to multidisciplinary treatment program, with gradually increasing physical activity as one of the key components, will also play an important role in explaining the enhancement in gross motor coordination within the obese group after 4 months of treatment. The increased physical activity opportunities as part of the treatment program offered obese children an important means to upgrade their gross motor coordination.

In chapter 5, the effect of the obesity treatment program as in chapter 4 was evaluated but this time on the performance in a simple and four choice reaction time task as well as a manual tracking task. Conclusions regarding the effect of the multidisciplinary treatment program on the fine motor outcomes are twofold as performance on both tasks was differently affected after 10 months of treatment. In the interest of clarity, different groups of obese children participated in the studies described in chapter 4 and 5.

Despite the fact that the obese children already demonstrated significantly poorer performance on both the simple and choice reaction time task (i.e., higher reaction time, movement time and response time) compared to their healthy-weight peers at baseline (see chapter 2), they continued to display poorer performances in comparison with their healthy-weight peers after the treatment program. Obese children still experienced difficulties with the processing of sensory information under time constraints (i.e., longer reaction time) and the movement of a (heavier) arm during the execution of relatively easy and discrete motor actions in comparison with their healthy-weight peers. The multidisciplinary treatment program consisting of moderate dietary restriction and increased physical activity did not impact on children’s performance in both the simple and choice reaction time task. The fact that obese children continued to encounter difficulties with the execution of both the simple and choice reaction time task over time, is in line with the current knowledge that the construct of planning and executing relatively easy and discrete motor actions (i.e., reaction time tasks) is hardly subject to change, even by extensive practice (Clark, 1982). This indication confirms the existence of perceptual-motor difficulties among the obese children and points to difficulties when sensory information is needed to produce appropriate motor actions in obese compared to healthy-weight children.
In contrast to the relatively easy and discrete simple and choice reaction time task, the manual tracking task relied on more complex perceptual-motor processes and can be considered a continuous task with lower temporal pressure in which the use of online visual feedback to detect and/or adapt movement errors is evaluated. After only 10 months of treatment, obese children’s tracking performance improved significantly as reflected in the decrease in number of lifts, pen up time and mean deviation from the ideal curve, whereas no differences over time were observed in the healthy-weight participants. After the treatment program, the obese and healthy-weight children’s root mean square deviation was at the same level indicating that the multidisciplinary residential treatment program had a positive effect in reversing obese children’s accuracy problems over developmental time. In this short period of time, obese children seem to have developed a more accurate movement strategy through the more effective integration of online visual feedback in their movement pattern.

In conclusion, the effect of the multidisciplinary treatment program differed according to the task used to evaluate children’s perceptual-motor function. Obese children’s suboptimal motor planning and control of discrete motor actions did not benefit from the weight loss and increased physical activity opportunities associated with the treatment program. In contrast, the increased physical activity opportunities probably offered the obese group the possibility to improve their feedback capacities and (partially) catch-up with their healthy-weight peers, although this feature was not specifically targeted. During the treatment, obese children can develop these capacities by continuously adapting movements to changing environments as is the case in physical activity or sports. Although the impact of separate treatment related factors contributing to the observed progress in perceptual-motor performance was not specifically investigated in the present study, multidisciplinary residential treatment may be considered an important means to improve obese children’s feedback capacities.
3. OVERALL DISCUSSION, REFLECTIONS AND CONCLUSION

3.1. Mechanisms of lower motor competence in obese compared to healthy-weight children: not only a matter of excess mass?

Previous studies confirmed the inverse relationship between childhood obesity and gross motor competence and relied on the **mechanical hypothesis** to explain lower motor competence implying that the mechanical constraints associated with excess weight and body fat account for the poorer performances in obese children compared to their healthy-weight peers (Deforche et al., 2003; D’Hondt et al., 2009, 2011; Graf et al., 2004; Hills et al., 2002; Hue et al., 2007; McGraw et al., 2000; Tsiros et al., 2011).

However, from our data (chapter 2 and 3), it could be concluded that childhood obesity also has a detrimental effect on perceptual-motor function as shortcomings were found in processing speed, decision making and movement execution as well as in the use of online visual feedback in obese compared to their healthy-weight peers. These findings are novel and strongly suggest that the mechanical hypothesis can be questioned as the only explanation for the diminished motor competence in obese compared to healthy-weight children. This adds evidence to the limited information that a possible **perceptual-motor deficit** could also partly explain the differences in motor competence between obese and healthy-weight children (Bernard et al., 2003; D’Hondt et al., 2008, 2009; Petrolini et al., 1995).

To obtain a more detailed understanding of both hypotheses, the effect of a multidisciplinary residential treatment program (and concomitant weight loss) on both gross and fine motor competence was investigated in chapter 4 and 5. A novel finding in chapter 4, pointed to the fact that the detrimental effect of obesity in performing gross motor tasks could be counterbalanced by losing a substantial amount of weight. For gross motor skills, it is reasonable to assume that weight loss could influence the inertial characteristics of the body and the body segments and could therefore be seen as an important factor in upgrading obese children’s motor competence. Because 73.1% of the variance in improvement in obese children’s gross motor coordination remained unexplained, it should be questioned whether obese children’s lower gross motor competence is just a **matter of excess mass** or is/are there (an)other factor(s) contributing to the inverse relationship between motor competence and childhood obesity which is/are possibly missed or overlooked.

From the perceptual-motor perspective, the improvement in gross motor coordination is not solely due to the obese children’s weight loss in se, but might additionally be explained
by an improvement in obese children’s perceptual-motor function. To gain greater insight in the mechanisms at play in explaining obese children’s reduced motor competence (i.e., mechanical vs. perceptual-motor hypothesis), the effect of multidisciplinary treatment (and concomitant weight loss) in tasks relying on well-known principles of perceptual-motor function was explored in chapter 5. From chapter 5, it could be concluded that the multidisciplinary treatment program induced significant improvements in specific aspects of obese children’s perceptual-motor function. The fact that improvements occur in obese children’s tracking performance but not in their reaction time task performance raises important questions.

First of all, it can be questioned why obese children’s perceptual-motor performance improved in one specific fine motor task (i.e., manual tracking task) and not in another task (i.e., simple and choice reaction time task) after following the treatment program. It could be assumed that both perceptual-motor tasks are differently affected by the multidisciplinary treatment program. Lower performance in the relatively easy and discrete reaction time tasks appears to be associated with the occurrence of obesity and the extensive practice (i.e., increased physical activity opportunities) offered by the treatment program did not affect performance. Although, it has to be mentioned that the specific constructs (i.e., reaction time, movement time and response time) measured in the fine motor tasks under study in this doctoral thesis, were not specifically trained or targeted by the treatment program. These findings are in line with the available literature which suggested that the construct of planning and executing a discrete motor action, like a reaction time task, is hardly subject to change (Beashel et al., 2001; Clark, 1982; Vickers, 2007). Contrarily, after only 10 months, obese children’s performance in a more continuous tracking task already benefited from the increased opportunities to participate in activities in which the continued use and integration of online visual feedback is essential, like in physical activity or sports. It is inherent to physical activity that online visual feedback constantly has to be used to detect changes in the environment and to adjust or adapt movements to changing environments. However, because of the multidisciplinary nature of the treatment program, it is very hard to understand which components of the program are mediating the observed changes in specific aspects of perceptual-motor function.

Second, it can be questioned why obese children are more susceptible to suffer from these (perceptual-)motor difficulties compared to their healthy-weight peers. To begin with, it could be assumed that the processing and integration of sensory information is impaired in obese children because of possible (neuro)physiological changes due to excess fat accumulation affecting both muscle and brain function. It is important to explore the possible relationships between body composition, muscle impairments, and possible functional
Besides the increased visceral and subcutaneous fat accumulation in obese subjects, obesity is also associated with increased fat accumulation and infiltration in other parts of the body as for example in skeletal muscle fibers. The increased fatty infiltration in muscle fibers may have a detrimental effect on muscle performance, ultimately leading to poorer performance of activities of daily living (Hilton et al., 2008). The size of fat aggregates in muscle fibers is not affected by obesity but obese individuals seem to have an increased fat infiltration or concentration of fat droplets (i.e., twice as much than non-obese individuals) both intramyocellulair as well as intermyocellulair (Hilton et al., 2008; Malenfant et al., 2001). It can be assumed that muscle fibers will contract less efficiently because of these changes associated with fat accumulation. In adults, it was already demonstrated that excess fat infiltration in skeletal muscles of the leg is indeed associated with impaired muscle strength and power, and with reduced physical function (Hilton et al., 2008). The findings of increased fatty infiltration and the association with a less qualitative muscle performance is only demonstrated in adults. Besides impacting on muscle function, excess fat accumulation could also negatively impacts on children’s brain structure and function. Only recently, it has been actually demonstrated that obesity is associated with decreased white matter integrity throughout the brain (Stanek et al., 2011; Verstynen et al., 2012), which can result in reduced neural transmission speed and slowed information processing (Gunning-Dixon & Raz, 2000) as well as executive and working memory dysfunction (Tullberg et al., 2004; Vannorsdall et al., 2009). Presumably, these (neuro)physiological mechanisms could also (partly) explain obese children’s suboptimal motor performance in both gross and fine motor tasks.

On the other hand, this perceptual-motor deficit may already be present from birth and could be considered a characteristic inextricably associated with the development of obesity. Children suffering from perceptual-motor difficulties already at a very young age will be hampered in interpreting (i.e., integration of sensory information) their environments and adapting and producing acceptable motor outcomes. Challenging environments requiring a sophisticated perceptual-motor function, as is the case in physical activity or sports, may be perceived as too challenging by these children. Consequently, these children are less likely to participate in important movement opportunities (i.e., organized and recreational activities) which could place these children at much greater risk for becoming overweight or obese (Bouffard et al., 1996; Gabbard, 2008; Stodden et al., 2008). It must also be mentioned that perceptual-motor difficulties could be related with Developmental Coordination Disorder (DCD) which is a motor impairment in the absence of an overt neurological disease or intellectual disorder (American Psychiatric Association, 1994). This disorder has been shown to be a risk factor for the development of childhood obesity (Cairney et al., 2005). Because
children in our studies were not systematically screened for DCD, it is difficult to make any statements about the relationship between DCD and obesity in our study population.

However, it must be mentioned that the vicious circle could also be run in the opposite direction. It is equally possible that less physically active children are more likely to develop an impaired perceptual-motor function. Children who are less physically active lack adequate movement stimuli and have fewer opportunities to develop an effective motor control center, and will also be at risk for the development of overweight and obesity.

Whatever the causality of this issue, adequate physical activity levels are necessary to provide movement opportunities and stimuli to develop an effective motor control and planning system. Physical activity builds neural pathways which are the connections by which information travels to and through the brain. It is crucial that children are offered movement opportunities already early in life. Children not mastering proper fundamental movement skills (e.g., running, jumping, throwing, catching) tend to encounter problems because neural pathways in the brain have not been developed optimally. The optimal time to develop these pathways is between ages three and eight (Gabbard et al., 2008; Riethmuller et al., 2009), after which it is hard to obtain significant improvements (Vandorpe et al., 2012). This critical developmental period (i.e., window of opportunity) represents a period in which experience may be most effective and plasticity of the nervous system is high (Malina et al., 2004; Gabbard, 2008).

Physical activity is not only mandatory to achieve an adequate level of motor development but there may also be a link between physical activity and cognitive development. Neuroimaging and neuroanatomy studies already demonstrated that motor and cognitive development are inextricably linked because the same neural structures (i.e., cerebellum and basal ganglia) are used for both cognitive and motor activities (Diamond, 2000; Grissmer et al., 2010). For example, Adolph (2008) suggested that the neural infrastructure needed to control motor skills is also used when solving cognitive problems. The cognitive capacity has its most dynamic phase of development during the elementary school years (Welsh et al., 2006). Thus, by the time children reach preschool age, they have already developed a sophisticated cognitive capacity (Grissmer et al., 2010). However, the complexity and the level of children’s cognitive capacity will depend greatly on the challenges encountered during (motor) development. As already mentioned, physical activity is an important means offering children the opportunities and stimuli needed to develop the brain’s circuitry to its full potential (Gabbard, 2008). Physical activity is not only proven to be a strong determinant for early motor development but also for children’s cognitive and neural development, which seem particularly sensitive to the influence of physical activity (Carlson, 2005; Diamond, 2000; Hillman et al., 2008; Kolb & Whishaw, 1998; Nelson, 1999).
studies examining cognitive development in children focus on executive functions, which can be defined as the ability to plan, initiate, and carry out activity sequences that make up goal-directed behavior (Churchill et al., 2002). Different studies confirm the beneficial effect of regular exercise or physical activity on children’s executive function and their cognitive abilities (Davis et al., 2007; Davis et al., 2011; Liang et al., 2013). The mechanisms responsible for improved cognition capacity resulting from regular exercise remain to be determined. However, animal studies showed that aerobic exercise (i.e., physical activity) induced physiological brain changes resulting in an increase of growth factors such as brain derived neurotrophic factor, leading to increased capillary blood supply to the cortex and growth of new neurons and synapses, resulting in better learning and performance (Dishman et al., 2006). Several experiments conducted with adults demonstrated that physical activity performed on a regular basis altered brain functions that underlie cognition and behavior (Colcombe et al., 2004; Weuve et al., 2004). Physical activity resulted in numerous biological responses in both muscles and organs that, in turn, modify and regulate the structure and functions of the brain (Dishman et al., 2006). The cognitive changes due to exercise may be a direct result of neural stimulation by movement. Although conclusive evidence for the exact mechanism in children is currently lacking, physical activity may be an important method to improve children’s cognitive development. Children missing these challenges (offered by physical activity) may lag behind and experience difficulties with (both motor and) cognitive development. If action is not taken, this will ultimately lead to problems with academic achievement and future learning.

3.2. Conclusion

In conclusion, our findings confirm that being obese imposes significant limitations on the execution of gross (and fine) motor skill tasks. As a positive relationship between the degree of weight reduction and the improvement in gross motor competence was found (i.e., greatest improvement in those obese children with the largest relative weight reduction), it could be argued that the reduced inertial constraints associated with losing weight are positively impacting on obese children’s gross motor competence. However, a significant part of the improvement in obese children’s gross motor competence could not be explained by weight loss alone (i.e., 73.1% was explained by other factors than weight loss). Therefore, it would be reasonable to assume that the obese children’s poorer motor performance is not just a matter of mass. Our studies confirm that the processing and integration of sensory information is also affected in obese children, resulting in a poorer perceptual-motor function compared to their healthy-weight peers. It can be assumed that the excess fat accumulation
(and infiltration) in obese children induces possible (neuro)physiological changes affecting both muscle and brain function. These (neuro)physiological changes could partly assist in explaining obese children’s suboptimal motor performance in both gross and fine motor tasks. It was also tentatively suggested that the perceptual-motor deficit could be considered an innate characteristic associated with the development of obesity. In addition, it could also be possible that less physically active children develop an impaired perceptual-motor function possible associated with the co-occurrence of childhood obesity. Because motor and cognitive development also seem to be linked, the development of an adequate motor competence is necessary to perform well at school. In the next section, some guidelines will be given to reverse obese children’s poorer motor competence.
4. PRACTICAL IMPLICATIONS

As indicated by our findings and previous research, the level of motor competence is inversely related to weight status in childhood and differences between obese and healthy-weight children seem to emerge already early in life (Castetbon et al., 2012; Cawley et al., 2008; Deforche et al., 2009b; D’Hondt et al., 2009; Logan et al., 2011; Lubans et al., 2010; Mond et al., 2007; Morano et al., 2011; Nervik et al., 2011; Slining et al., 2010; Tsiros et al., 2011). In order to prevent a decrease in obese children’s motor competence and to prevent a possible further deterioration, targeted motor skill initiatives have to be implemented already during early childhood (D’Hondt et al., 2011, 2013). The need to intervene in preschoolers is further supported by the fact that motor skill competence largely develops between the age of three and eight (i.e., window of opportunity) (Gabbard et al., 2008; Riethmuller et al., 2009), after which it is hard to obtain significant improvements (Vandorpe et al., 2012). Furthermore, childhood obesity also seems to be associated with a decreased perceptual-motor function, which could be seen in poorer performances on fine motor tasks in obese compared to healthy-weight children in our studies. Because of the importance of perceptual-motor function for children’s cognitive development and later academic achievement (Cameron et al., 2012; Grissmer et al., 2010; Son & Meisels, 2006), specific action has to be taken to reverse obese children’s decreased motor competence and its negative (health) effects. Based on the findings of the studies described in this doctoral thesis, some practical and research-related implications can be given. We suggest to focus on different strategies to be implemented in the childhood obese population targeting different purposes with different practical guidelines.

Physical activity is an important energy-balance related behavior and its importance in achieving a healthy-weight status by burning calories and inducing weight loss (i.e., if energy expenditure exceeds energy intake) is a key component in all obesity treatment programs. Offering tailored physical activity programs can be seen as a first important strategy to reverse obese children’s motor difficulties by different pathways.

Physical activity and motor competence cannot be seen apart from each other since they act as reciprocal determinants. Obese children are generally considered to be less active than their normal-weight peers (Deforche et al., 2009a; Haerens et al., 2007; Trost et al., 2001). Consequently, the decreased physical activity levels could negatively impact on motor skill performance through the established relationship between both parameters (Cliff et al., 2009; Okely et al., 2001; Wrotniak et al., 2006). Targeting obese children’s motor competence may therefore be a promising strategy to increase their levels of physical activity.
in order to induce a positive spiral of engagement (Stodden et al., 2008). Intervention programs should aim at improving children’s actual motor competence level which will be associated with an increase in children’s perceived motor competence, ultimately leading to a greater enjoyment while playing or participating in physical activity. According to the Self-determination Theory, which is a model for changes in (health-related) behaviors, there are three psychological needs that need to be satisfied to yield enhanced autonomous motivation which is related to long term physical activity participation. These needs are competence, autonomy and relatedness (Ryan & Deci, 2000). Opportunities must be created to satisfy the need for competence in obese children while participating in physical activity or sports. If these children perceive that they can succeed in performing certain motor tasks, their autonomous motivation to be physically active might increase which is a possible mediating factor in adhering to a physically active lifestyle throughout the lifespan. Deforche et al. (2011) suggested that perceived competence in physical activities could be increased by offering activities tailored to the capabilities of the obese child, helping children set realistic goals, learning children self-management skills, providing children with appropriate feedback and organizing separate exercise sessions for obese children. Autonomous motivation to be physically active could be a protective factor against the development of further obesity and even tackle the excess weight problem in obese children as they might become more intrinsically motivated while becoming more motor proficient (Barnett et al., 2009; Lubans et al., 2010; Morgan et al., 2008). Thus, developing adequate actual and perceived motor competence could play a pivotal role in the prevention of childhood obesity and there is a crucial need for an early focus on motor skill development and improvement in children. Therefore, obese children should be offered numerous opportunities to develop both gross and fine motor skills in challenging environments (Bardid et al., 2013; Sothern, 2001). In the next paragraphs, guidelines and useful tips and tricks will be presented for specifically tailoring physical activity programs to the characteristics, capabilities and interests of obese children.

The intervention program should focus on improving both fine and gross motor skills through tailored physical activities. At the beginning of the intervention program, weight-bearing activities should be avoided because of the high inertial load associated with these activities and focus should be put on activities that can be performed successfully and without exhaustion. Therefore, fine motor skill training seems a promising gateway to improve children’s motor competence level, especially at the beginning of an intervention program. Our findings indicate that is difficult to change the outcome on discrete motor tasks such as reaction time tasks. However, continuous motor task outcomes did improve after treatment. In the tracking task evaluated, the efficient use of online visual feedback was
necessary to create an acceptable motor outcome. The increased physical activity opportunities offered by the treatment program could provide a first explanation for an enhancement in the performance outcomes on the tracking task. Both physical activity and the tracking task rely on the same principles (i.e., the use of online visual feedback) in continuously adapting motor outcomes to changing environments. Because possible improvements in other constructs targeted by the treatment program were not objectively assessed in our studies, it must be mentioned that the increased physical activity opportunities are probably not the only factor contributing to obese children’s increased feedback capacities. However, physical activity can be considered an important means to upgrade obese children’s perceptual-motor function. To improve perceptual-motor skills relying on the integration of sensory information in continuous rather than discrete movement situations, obese children need extensive practice which is not restricted to fine motor skills alone. To put this into action, improvements in fine motor competence and perceptual-motor function must be encouraged by activities that are enjoyable, not boring and trigger the central nervous system. Computer games are a possible means to improve perceptual-motor abilities, because they are mostly played in dynamic virtual worlds where the integration of online visual feedback is mandatory to move efficiently through virtual computer space. However, it must be mentioned that the recommendation to increase the use of computer games in obese children can be considered a contradiction (i.e., increased screen time). An alternative method targeting the same purpose could be found in serious video games for health. These video games include both entertainment and behavior change components which makes it an ideal means to induce changes in health related behaviors (Baranowski et al., 2008). Not only virtual games offer a gateway but also fine motor skills relying on visual, cognitive and manual dexterity demands such as making puzzles, playing with building blocks, coloring, painting, pasting, copying figures, etc. Since today’s technology is rapidly evolving and children already become familiar with new devices as iPhone, iPad or tablets from a young age, it would also be interesting to develop specific apps to enhance children’s fine motor skills with these devices. Because of the possible link between motor and cognitive behavior, enhancing obese children’s fine motor skills may also be suited to improve cognitive development. (i.e., future academic learning). The development of fine motor skills plays a crucial role in school readiness and children who lack adequate fine motor skills are likely to fall behind in other academic areas (Grissmer et al., 2010).

Besides targeting improvement in fine motor skills at the beginning of the program, **gross motor activities** that exclude the excess weight to be moved against gravity will also be suited to start the program with such as swimming, cycling, fitness exercises or resistance training, because of the great static strength in obese children (Deforche et al., 2003). After
this initial phase, the intensity rate of the program must increase gradually. This could be
done in supervised movement sessions which rely on instruction and adequate feedback in
order to shape the optimal movement pattern and enough repetitions to acquire the skills
needed for an adequate movement repertoire to handle daily life activities (Goodway et al.,
2003). Emphasis should be placed on those movement patterns necessary to induce a
change, no matter how small, in obese children’s everyday life activities as it seems easier
for these children to incorporate these activities in daily routines than for example adhere to a
schedule of programmed exercise (Epstein et al., 1982). By inducing a behavioural change in
obese children’s daily routines and physical activity, a good start is made to motivate obese
children to stay physically active throughout the lifespan and (possibly) to achieve a healthy-
weight status. By maintaining adequate levels of physical activity, (obese) children achieve
sufficient movement experiences for the appropriate development of motor competence
(Stodden et al., 2008).

Not only children’s motor competence and physical activity level should be targeted
but also the awareness should arise that a good level of motor competence is a prerequisite
for a physically active lifestyle (i.e., second strategy). All significant others (e.g., family,
schools, etc.) have the responsibility to teach children healthy lifestyle habits concerning
nutrition, physical activity, motor competence, etc. Not only do they have to point at which
decisions are best to be made but also ‘why’ one option is better than the other. By
increasing children’s health-related knowledge, their autonomous motivation will also
increase. Only if children possess the values and knowledge to make the right decisions and
to adhere to a healthy lifestyle throughout the life span, they can consciously choose for
health-related behaviors.

In conclusion, appropriate intervention programs must be designed with respect to
both gross and fine motor development in obese children. This doctoral thesis provides the
first indication to target fine motor tasks with a continuous nature rather than discrete motor
actions. However, insights in the underlying factors are still limited and further research into
the exact nature of poorer perceptual-motor function in obese children is required. Finally, it
must be noted that the different strategies mentioned above should be implemented by
different actors because we think that both the home and the school environment are the
most important in influencing the daily life health-related habits of the child. These actors are
not only important in providing obese children adequate levels of both gross and fine motor
competence but also in increasing their physical activity levels in order to achieve a healthy-
weight status and lifestyle. They are also important in increasing obese children’s awareness
that the other side of the energy balance (i.e., energy intake and eating behaviors) must also
be targeted to tackle the childhood overweight and obesity epidemic.
5. LIMITATIONS & STRENGTHS

In this section the most pertinent limitations and strengths of our original research presented in this doctoral thesis will be discussed.

Several LIMITATIONS have to be acknowledged:

- The first and most important limitation can be found in the fact that we cannot rule out to what extent children’s **physical activity level** affected our results. Unfortunately, the actual level of children’s physical activity participation was not objectively measured in none of the studies (chapter 1 to 5). For example, the children included in the obese group in chapter 4 and 5 of this thesis were involved in a specific multidisciplinary residential treatment program, with gradually increasing physical activity as one of the key components. Individual adherence to this program and actual physical activity levels may have interacted with the outcome measure of relative weight loss in explaining (part of) the improvement in overall KTK performance (chapter 4) and in mean deviation from the ideal curve within the obese group (chapter 5). The lack of objective quantitative physical activity data prevented to control for this likely contributor in our statistical analyses.

Other possible **confounding factors** affecting both gross and fine motor performance as well as childhood obesity were also possibly missed. For example, we did not control for children’s socioeconomic status (SES), their home environment or possible neurophysiological factors affecting motor performance. Nevertheless, these factors could have a significant effect on both motor competence and the development of obesity in children. Previous studies have already shown that a lower SES could be related to obesity (Lioret et al., 2007, 2009; Rosengren & Lissner, 2008; Shrewsbury & Wardle, 2008; Stamatakis et al., 2005) and is likely to be associated with lower levels of gross and especially fine motor skill performance as well (Bobbio et al., 2007; de Barros et al., 2003).

- A significant limitation of the intervention studies (i.e., chapter 4 and 5) is the issue of “dose-response” of the intervention (i.e., weight loss and increase in motor competence). The intervention studies were essentially “black box studies” with a lack of data or understanding about the content, dose and intensity of the intervention. This makes it difficult to explain the findings based on the effectiveness of the
intervention. Furthermore, there were no data provided on intervention fidelity for the participants.

- The obese children included in the studies of chapter 4 and 5 were involved in a residential treatment program and their motor competence was compared with a control group of healthy-weight children not involved in any kind of treatment. However, the absence of an additional control group of obese children not involved in a weight control program could be seen as a shortcoming of this thesis. Due to practical difficulties, the recruitment of a no-treatment group of obese children was difficult. Normally, the Zeepreventorium (VZW, De Haan, Belgium) puts children on a waiting list when the maximum intake of children for the next treatment year is reached. In the age group included in our studies (i.e. 6- to 12-year-old children), the number of children entering the program is restricted to a maximum of 20 children each year. However, in this particular (young) age group, no children exceeding the number of 20 were referred to the center for treatment. Consequently, there were no children on the waiting list and a no-treatment group of obese children could not be recruited in collaboration with the Zeepreventorium; however valuable these data could have been for the present doctoral thesis.

- It should also be mentioned that our preliminary findings from our longitudinal studies (chapter 4 and 5) thus far only apply to the specific clinical setting of the local rehabilitation center (Zeepreventorium VZW, De Haan, Belgium), which makes it difficult to generalize these findings to the entire (obese) childhood population. It is also difficult to predict if these results would also apply to other settings. Further investigation in a larger sample of obese children outside a clinical setting would be valuable.

- Another limitation can be found in the set-up of the SRT, CRT and tracking task. The set-up could be critiqued from a developmental standpoint because children had to move different distances when scaling the distances by varying arm length.

- In this dissertation, only a few (basic) fine motor skills of the entire fine motor skill continuum have been examined. Therefore, generalization of the fine motor findings discussed in this dissertation should be made with caution.
The presented studies also have several STRENGTHS:

- A first important strength can be found in the fact that the studies presented in this doctoral thesis are **one of the first** to explore perceptual-motor function in obese compared to healthy-weight children. Most studies have focused exclusively on gross motor competence when examining the relationship between motor competence and weight status in children. These studies have consistently shown that the level of motor competence is inversely related to weight status in childhood. Therefore, obese children’s reduced motor function is generally believed to be the mechanical consequence of their excess noncontributory mass that needs to be stabilized or moved against gravity children (confirmed in chapter 1). However, recently, poorer performance in fine motor tasks for obese compared to healthy-weight children was suggested and the idea of a possible perceptual-motor deficit in obese children was put forward (Bernard et al., 2003; D’Hondt et al., 2008, 2009; Petrolini et al., 1995). This dissertation is highly innovative and of added value to the field because it explores this other possible pathway in explaining poorer motor competence in obese compared to healthy-weight peers by focusing on fine motor skills which rely on well-known principles of perceptual-motor control (chapter 2 and 3) and even on the effect of multidisciplinary residential treatment (and concomitant) on both gross and fine motor competence (chapter 4 and 5).

- A second strength is the design of the weight loss papers (chapter 4 and 5) including a **pre-test post-test design** with an intervention group (obese children) and a control group (healthy-weight). The children were matched according to age and gender. However, no random assignment to the intervention or the control group was possible.

- In our studies, internationally accepted age- and gender-specific BMI cut-off points for children were used to classify the children as healthy-weight, overweight or obese (Cole et al., 2000), which facilitates the comparison of our findings with other (international) studies using the same assessment method. The fact that **objective measurements** of height and body weight were used excludes the possibility of bias, frequently encountered with self-reported measures (i.e., underestimation of body weight). Furthermore, both the BOT-2 and the KTK are highly reliable and valid assessment methods for both gross and fine motor competence (Cools et al., 2009; Bruininks & Bruininks, 2005; Kiphard & Schilling, 1974, 2007).
6. FUTURE RESEARCH

This dissertation was conducted to gain greater insight in obese children’s motor (in)competence and to obtain a better understanding of its contributing factors. Although, this thesis made substantial contributions to the existing literature concerning the relationship between motor competence and childhood obesity, many opportunities still lie ahead and need to be explored in this emerging field of research. Some suggestions and recommendations for future research are therefore formulated in the following section.

- Our studies seem to indicate that it is probably not just a matter of excess mass, but there are possibly alternative explanations. However, further research is needed to explore the hypotheses assumed in this dissertation and additional lines of thought. In literature, it is generally assumed that the lower motor competence in children with obesity is primarily due to extra weight that has to be moved against gravity and the higher load on the musculoskeletal system and altered inertial characteristics of moving a heavier body. However, experimental and fundamental research into this generally accepted mechanical assumption is currently lacking but would be of great value. A possible strategy could be to not only explore the impact of weight loss, but also the effect of excess body weight (body-own) and added extra weight (not body-own) on the movement coordination and control in children while performing functional motor tasks. It could also be useful to examine the effects of short vs. long term excess fat accumulation and infiltration in both brain and muscles on obese children’s functional performance because different mechanisms will probably apply in explaining these short vs. long term differences.

Secondly, it has been shown that excess weight is not the only factor that hinders obese children’s movement execution. A second hypothesis referred to as the perceptual-motor hypothesis could also (partly) explain the reduced motor function in both gross and fine motor skills in these children. There are some significant differences in the processing and integration of sensory information between obese and their healthy-weight peers. Further insight must be gained into the effects of childhood obesity (i.e., excess fat accumulation) on human brain structure and function which remains less well understood. Evidence suggests that obesity is associated with decreased white matter integrity in the brain but these findings are restricted to adult populations. Possible differences in brain structure and function in obese children and possible responses to exercise warrant further investigation using
advanced neuroimaging techniques, as for example MRI, to map both brain structure and function. It would also be valuable to determine whether the duration of being obese would have greater consequences on brain structure and function. Therefore, prospective studies are needed for a more detailed examination of the white matter microstructure and to clarify the nature of the relationships and elucidate underlying mechanisms.

- It would also be valuable to investigate the effect of **continued weight loss vs. potential weight gain** on obese children’s gross and fine motor competence after their participation in the residential obesity treatment program (Zeepreventorium VZW, De Haan, Belgium). It would be worthwhile investigating the effect of continued weight loss on obese children’s gross and fine motor competence. For example, do obese children come at a ‘normal’ level of gross motor coordination and completely catch up with their healthy-weight peers as they already caught up partially after 4 months of treatment? Does obese children’s fine motor performance benefit from further weight loss and continued physical activity opportunities?

Furthermore, it would also be valuable to examine the possible continued effect of the intervention once children return to their home environment. By scrutinizing those behaviors and characteristics of those children succeeding to adhere to a healthy-weight status, more effective intervention programs can be developed and tailored to this specific population under study.

**Longitudinal studies** investigating motor competence (both gross and fine) in children who are naturally gaining weight over developmental time would also provide valuable insights in the causality of this issue. This could make (causal) statements about whether childhood obesity is a cause or a consequence of lower motor competence possible. One very important question that needs to be answered is: does obesity lead to a poor motor competence performance or is it the other way around? It must be kept in mind that studies with a longitudinal design are time-consuming and possibly yield low response rates as drop out is common practice in longitudinal studies. Furthermore, following children who are gaining weight over developmental time may also raise important ethical questions as it may be considered unethical to only register children’s weight development without giving any health-related advice to those children requiring special health-related attention (i.e., weight management techniques, nutrition and physical activity guidelines, screen time recommendations, etc.).
Conclusions in this dissertation are (mainly) based on product-oriented motor outcomes, although, **process-oriented motor outcomes** would be more valuable to gain further insight into the possible causes of perceptual-motor difficulties encountered by the obese group to produce an acceptable motor outcome. Therefore, it could be helpful to collect three-dimensional kinematic data using infrared cameras by attaching a set of reflective markers to the participants’ body (segments). Detailed kinematic analysis of children’s movement pattern together with video recordings of participants’ test trials and electromyography-data would allow a greater insight in the perceptual-motor control processes involved in planning and adapting the movement patterns in obese compared to healthy-weight children.

A suggestion for future research could be to more clearly identify the dose of the intervention (i.e., chapter 4 and 5) in order to examine the magnitude of the response. Although there were no data for intervention fidelity, it can be considered a valuable recommendation for future research.

This work is only an initial attempt and offers a **little piece of the ‘big’ puzzle** in understanding the mechanisms underlying perceptual-motor function in (obese) children. To complete this incomplete puzzle, in-depth analysis of basic fine motor skills is warranted.

Despite the contribution of this doctoral thesis to gain greater insight in obese children’s motor (in)competence and to obtain a better understanding of the factors contributing to the lower motor competence in obese compared to healthy-weight children, future research on this topic is required. Given the growing awareness that children’s motor competence level plays a crucial role in physical and psychological health in childhood and even throughout the lifespan, a greater insight in the impact of overweight and obesity on children’s motor competence and development would be of great value in both prevention and treatment of the condition.
REFERENCES


BACKGROUND

Prevalence levels of childhood obesity have increased dramatically in the last decades. It is even estimated that the global number of children with overweight or obesity will increase to nearly 60 million by 2020. This expected increase is alarming and boosted research concerning the adverse (health) effects of this (childhood obesity) epidemic. Previous studies emphasized the negative impact of obesity on multiple serious health conditions (e.g., diabetes type 2, hypertension, dyslipidemia, sleeping disorders and orthopedic complications). Surprisingly, many of these chronic diseases expected to be seen in adulthood already emerge in childhood. Besides the adverse health outcomes, the psychosocial consequences of an obese weight status at a (very) young age cannot be neglected. The detrimental impact of excess fatness on obese children’s health and psychosocial well-being has been extensively documented. However, greater insight in obese children’s motor competence is warranted because of its potential importance in combating the childhood obesity epidemic. Evidence confirms that obese children have difficulties while participating in weight-bearing activities more than likely due to their excess noncontributory mass that needs to be stabilized or moved against gravity. Findings concerning fine motor skills are less conclusive but it has been tentatively suggested that obese children may also suffer from perceptual-motor difficulties because the mechanical load to the system is greatly diminished in the execution of such tasks. However, fundamental evidence confirming possible differences in perceptual-motor function according to weight status in children is currently lacking. Therefore, greater insight into the exact nature of lower motor competence among obese children is required.

THE RESEARCH

The overall objective of the present doctoral thesis was to gain greater insight in the motor difficulties experienced by obese children compared to healthy-weight children and to obtain a better understanding of the underlying mechanisms. More specifically, it was questioned to what extent the mechanical constraints associated with moving excess mass exclusively account for the reported lower motor competence associated with childhood obesity. In addition, it was examined whether the tentative and alternative hypothesis of a poorer perceptual-motor function in obese children also applies to (partly) explain BMI-related differences in gross and fine motor competence.
The first study investigated differences in gross and fine motor competence between obese and healthy-weight children by means of the Bruininks-Oseretsky Test of Motor Proficiency - second edition. The negative effect of excess weight and body fat was most pronounced for the gross motor skills requiring propulsion or lifting of the body against gravity. The results for the fine motor tasks were less strong and obese children only performed significantly worse on fine motor precision and manual dexterity when compared to their healthy-weight peers. In spite of the moderate effects sizes for fine motor skills, this study provides evidence that lower motor competence in obese children is not limited to gross motor skills alone. Childhood obesity is also associated with fine motor skill problems, strengthening the tentative suggestion of a possible perceptual-motor deficit in obese children.

The subsequent two studies focused on two different fine motor tasks relying on well-known principles of perceptual-motor function. In chapter 2, BMI-related differences in speed of information processing, decision making and movement execution were examined by means of a simple and a four choice reaction time task. Obese children were found to be intrinsically slower in information processing and decision-making in order to plan and control movement as compared to their healthy-weight peers. Using a manual tracking task in chapter 3, obese children displayed less accurate movement execution in comparison with their healthy-weight peers. Therefore, it can be concluded that the capacity to use online visual feedback to adapt movement execution efficiently is diminished in obese children.

From the last two studies, evaluating the effect of a multidisciplinary residential obesity treatment program, it can be concluded that the program is not only effective and successful in improving obese children’s body composition but also their gross motor coordination using the Körperkoordinationstest für Kinder (KTK) (chapter 4). Obesity treatment provided by the Zeepreventorium VZW (De Haan, Belgium) was found to be efficacious in generating a significant progress in gross motor coordination, with a greater increase in KTK scores from baseline to follow-up in the obese children as compared to healthy-weight peers. Each percentage of relative weight loss achieved, predicted an improvement of approximately two points in obese children’s total motor quotient. In the last study, details were provided on the impact of the treatment program on the fine motor skills studied in chapter 2 and 3. Multidisciplinary treatment and concomitant weight loss resulted in a significant increase in accuracy level in the obese children through the more effective integration of online visual feedback in their movement pattern on the manual tracking task, whereas no evolution was observed in obese children’s performance on both reaction time tasks (i.e., chapter 5).
CONCLUSION(S)

The research presented in this dissertation was conducted to obtain greater insight in the contributing factors of lower motor competence in obese children. It can be concluded that excess weight and fatness impose significant constraints on both gross and fine motor skill performance. Furthermore, evidence could be provided for difficulties with the processing and integration of sensory information needed to plan and control movement, indicating to poorer perceptual-motor function in obese children. Based on these findings, it is reasonable to assume that the obese children’s poorer motor performance is not just a matter of mass. It can also be assumed that excess fat accumulation (and infiltration) in obese children induces possible (neuro)physiological changes affecting both muscle and brain function, which could partly assist in explaining obese children’s suboptimal motor performance in both gross and fine motor tasks. It remains crucial to explore obese children’s motor (in)competence from a broader perspective. Only by a more detailed understanding of the underlying factors, intervention programs aimed at enhancing perceptual-motor function and motor skill competence can be developed and implemented within the obese childhood population, entailing indirect benefits in health-related behaviors and outcomes.
ACHTERGROND

De prevalentie van obesitas bij kinderen is de voorbije decennia drastisch toegenomen. Er wordt zelfs voorspeld dat het aantal kinderen met overgewicht of obesitas wereldwijd zal stijgen tot ongeveer 60 miljoen tegen 2020. Deze verwachting wordt door velen als alarmerend ervaren en heeft er voor gezorgd dat onderzoek naar de negatieve gezondheidseffecten van de obesitas epidemie een grote boost kende. Eerdere studies benadrukten de negatieve invloed van overgewicht en obesitas op verschillende ernstige gezondheidsaandoeningen (vb. diabetes type 2, hypertensie, dislipidemie, slaapstoornissen, en orthopedische complicaties). Veel van deze chronische aandoeningen, die normaliter pas op volwassen leeftijd tot uiting komen, manifesteren zich (mogelijks) al op jongere leeftijd bij kinderen met obesitas. Naast de negatieve gezondheidseffecten mogen ook de psychosociale gevolgen, waar kinderen reeds op (zeer) jonge leeftijd mee af te rekenen krijgen, niet over het hoofd gezien worden. De (negatieve) invloed van overtollig lichaamsgewicht op de gezondheid en de gemoedstoestand van kinderen met obesitas werd reeds uitvoerig gedocumenteerd. Nochtans blijkt ook een beter inzicht in het motorisch vaardigheidsniveau van deze kinderen van groot belang, aangezien dit als een essentiële factor gezien kan worden in de bestrijding van het obesitasprobleem. Het werd ondertussen reeds meermaals bewezen dat kinderen met obesitas moeilijkheden hebben met het uitvoeren van gewichtsdragende taken doordat hun overtollig lichaamsgewicht gestabiliseerd of verplaatst moet worden tegen de zwaartekracht. De bewijsvorming met betrekking tot fijn motorische vaardigheden is minder eensgezind, maar toch kan er voorzichtig gesuggereerd worden dat kinderen met obesitas ook fijn motorische moeilijkheden ondervinden niettegenstaande de mechanische belasting in deze taken grotendeels gelimiteerd wordt. Fundamenteel bewijsmateriaal om deze mogelijke verschillen in perceptueel-motorisch functioneren op basis van gewichtsstatus te bevestigen of te ontkrachten, ontbreekt echter. Verder onderzoek naar de basis van een lager motorisch vaardigheidsniveau bij kinderen met obesitas is dan ook vereist.

ONDERZOEK

De hoofddoelstelling van dit doctoraat was om meer inzicht te verwerven in de motorische moeilijkheden die ervaren worden door kinderen met obesitas. Daarnaast werd getracht een beter begrip te krijgen in de mechanismen die aangewend worden om deze moeilijkheden te verklaren. Er werd meer bepaald nagegaan tot op welke hoogte de mechanische beperkingen, geassocieerd met het bewegen van overtollig lichaamsgewicht, uitsluitend aangewend kunnen worden om het lager motorisch vaardigheidsniveau van
kinderen met obesitas te kunnen verklaren. Mogelijkheîertijs kunnen ook perceptueel-motorische moeilijkheden bij kinderen met obesitas deels de verschillen in zowel groot als fijnmotorisch vaardighedsniveau verklaren.

In een eerste studie werden zowel groot als fijn motorische verschillen onderzocht tussen kinderen met obesitas en kinderen met een gezond gewicht door middel van de Bruininks-Oseretsky Test of Motor Proficieny (tweede editie). De negatieve invloed van overtollig lichaamsgewicht en lichaamsvet kwam het sterkst tot uiting bij het uitvoeren van groot motorische vaardigheden die een verplaatsing van het lichaamsgewicht tegen de zwaartekracht in vereisen. De resultaten voor de fijn motorische vaardigheden waren echter minder sterk en de kinderen met obesitas presteerden enkel beduidend slechter dan leeftijdsgenoten met een gezond gewicht bij taken fijn motorische precisie en handvaardigheid primeerden. Niettegenstaande deze verschillen in fijn motorische prestatie eerder gering waren, levert deze studie toch preliminaris bewijsmateriaal voor het feit dat een lager motorisch vaardighedsniveau bij kinderen met obesitas zich niet enkel beperkt tot groot motorische vaardigheden. Obesitas bij kinderen lijkt eveneens gerelateerd met problemen in het fijn motorisch vaardighedsniveau wat een bevestiging vormt voor het optreden van een mogelijk perceptueel-motorisch tekort bij kinderen met obesitas.

De twee volgende studies hadden als doel twee verschillende en meer demonstratieve fijn motorische taken te onderzoeken die beiden beroep doen op goed gekende principes van het perceptueel-motorisch functioneren. Verschillen in de snelheid van het verwerken van informatie, het maken van beslissingen en het uitvoeren van beweging werden onderzocht bij kinderen met een gezond gewicht en kinderen met obesitas aan de hand van een enkelvoudige en een meervoudige reactietijdtaak in hoofdstuk 2. Er kan geconcludeerd worden dat kinderen met obesitas intrinsieke träger zijn in het verwerken van informatie en dus meer tijd nodig hebben om een beslissing te maken en om hun beweging te plannen en te controleren in vergelijking met leeftijdsgenoten met een gezond gewicht. In hoofdstuk 3 werd gebruik gemaakt van een tracking taak en werd aangetoond dat kinderen met obesitas gebruik maken van een minder nauwkeurige bewegingsuitvoering in vergelijking met kinderen met een gezond gewicht. Er kan besloten worden dat kinderen met obesitas minder efficiënt gebruik maken van online visuele feedback om hun bewegingspatroon aan te sturen en aan te passen.

De laatste twee studies, die het effect van een multidisciplinair residentieel behandelingsprogramma voor kinderen met obesitas evalueren, tonen aan dat het programma niet enkel effectief en succesvol is in het verbeteren van de lichaamssamenstelling bij kinderen met obesitas, maar ook in het verbeteren van hun groot
motorische coördinatie geëvalueerd aan de hand van de Körperkoordinationstest für Kinder (KTK) (hoofdstuk 4). Het behandelingsprogramma van het Zeepreventorium VZW (De Haan, België) bleek een significante vooruitgang in groot motorische coördinatie te genereren waarbij de kinderen met obesitas een grotere toename in KTK scores kennen van baseline tot re-test dan de kinderen met gezond gewicht. Elk percentage relatief gewichtsverlies voorspelde een vooruitgang van ongeveer twee punten bij kinderen met obesitas op hun totaal motorisch quotiënt. In de laatste studie wordt de invloed van het behandelingsprogramma op de perceptueel-motorische vaardigheden die onderzocht werden in hoofdstuk 2 en 3, nagegaan. Het multidisciplinair behandelingsprogramma en het daarmee gepaard gaande gewichtsverlies resulteerden in een significante toename in de nauwkeurigheid van kinderen met obesitas dankzij de efficiëntere integratie van online visuele informatie in hun bewegingspatroon tijdens het uitvoeren van de tracking taak. Er werd echter geen evolutie waargenomen in de prestaties van de kinderen met obesitas op beide reactietijd taken (hoofdstuk 5).

CONCLUSIE(S)

Het onderzoek beschreven in dit proefschrift was gericht op het verruimen van het huidige inzicht in de factoren die bijdragen tot een lager motorisch vaardigheidsniveau bij kinderen met obesitas. Er kan geconcludeerd worden dat een overmaat aan lichaamsgewicht een aanzienlijke beperking vormt voor zowel het groot- als fijn motorische vaardigheidsniveau. Verder is er ook bewijs geleverd dat kinderen met obesitas problemen ervaren bij het verwerken en integreren van sensorische informatie die nodig is voor het plannen en controleren van hun beweging, wat duidt op een verminderde perceptueel-motorische functie bij kinderen met obesitas. Op basis van deze resultaten kan er verondersteld worden dat het verminderde motorisch vaardigheidsniveau van kinderen met obesitas niet enkel verklaard kan worden door hun overmatig lichaamsgewicht. Er wordt eveneens aangenomen dat de accumulatie van overmatig lichaamsgewicht en lichaamsvet bij kinderen met obesitas bepaalde (neuro)fysiologische veranderingen veroorzaakt die zowel een invloed hebben op de spier- als hersenfunctie van deze kinderen. Deze (neuro)fysiologische veranderingen zouden dan ook zowel het verminderde groot als fijn motorisch vaardigheidsniveau bij kinderen met obesitas gedeeltelijk kunnen helpen verklaren. Toch blijft het aangeraden om (problemen met) het motorisch vaardigheidsniveau bij kinderen met obesitas vanuit een breder perspectief te onderzoeken. Alleen door het verwerven van een grondige kennis in de onderliggende mechanismen die het motorisch vaardigheidsniveau bepalen, kunnen interventieprogramma’s gericht op het verbeteren van
de perceptueel-motorische functie en het motorisch vaardigheidsniveau ontwikkeld en geïmplementeerd worden bij kinderen met obesitas. Deze programma’s zullen naar alle waarschijnlijkheid ook indirecte voordelen in gezondheidsgerelateerd gedrag en gezondheidsparameters met zich mee brengen.
LIST OF PUBLICATIONS AND PRESENTATIONS


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“The only time success comes before work is in the dictionary” – Vince Lombardi

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