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Evaluation of energy expenditure during walking in typically developed children and children with cerebral palsy

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Abstract

Background: Cerebral palsy (CP) is caused by a lesion in the brain before, during or shortly after birth and can lead to activity limitations. Children with CP generally walk slower and have higher energy expenditure (EE) than typically developed (TD) children. EE and energy cost (EC) can say something about how physically demanding walking is for an individual. Finding out how age, gender and walking speed affects EE and EC in TD and CP children is desirable.

Aim: The overall aim of this master thesis was to gain more insight in the evaluation of EE and EC during walking in TD children and children with CP. The specific aim of this thesis was twofold; First, to evaluate the effect of age, gender and walking speed on EE and EC. Second, to investigate differences in the effect of walking speed on EE and EC between well-functioning children with CP and TD children.

Method: Forty-four TD children (age 7 - 15) and five CP children (age 8 - 17) with GMFCS level 1 performed three 3-5 minutes walking tests on self-selected slow, normal and fast walking speed wearing portable indirect calerometry equipment (Metamax II). VO2 and respiratory exchange ratio (RER) were extracted from a 1-minute period of steady state. Distance travelled during the same period was also measured and used to calculate walking speed. Together with body weight these measures were used to calculate EE and EC.

Results: EE and EC both decreased with age ($p < 0.001$), EE increased with walking speed ($p < 0.001$), EC decreased with walking speed ($p < 0.001$), but there were no gender effects (EE $p = 0.4$ and EC $p = 0.6$) in TD children. The CP group had very similar EE and EC values compared to the TD group (all differences had a $p > 0.7$). Also the change in EE and EC with walking speed was similar in CP compared to TD.

Conclusion: Both EE and EC decreases with age in TD children, while they are not dependent on gender. EE increases with higher walking speed for both TD and CP, but within each speed instruction the differences in chosen walking speed between the participants on average gives the same EE. EC is higher during slow walking speed compared to normal and high walking speed in both TD and CP.

Abstrakt

Introduksjon: Cerebral parese (CP) forårsakes av en skade i hjernen før, under eller rett etter fødsel og kan føre til aktivitetsbegrensninger. Barn med CP går generelt på lavere hastighet og har høyere energiforbruk (EE) enn funksjonsfriske (TD) barn. EE og energikostnad (EC) kan si noe om hvor fysisk krevende det er å gå for et individ. Det ville være en klar fordel å finne ut hvordan alder, kjønn og ganghastighet påvirker EE og EC hos TD- og CP-barn.

Mål: Den overordnede målsetningen med denne masteroppgaven var å få bedre innsikt i evaluering av EE og EC under gange hos TD- og CP-barn. Den spesifikke målsetningen med oppgaven var todelt; for det første å evaluere effekten av alder, kjønn og ganghastighet på EE og EC. For det andre å undersøke forskjeller i effekt av ganghastighet på EE og EC mellom velfungerende barn med CP og TD-barn.

Metode: Førtifire TD-barn (7 – 15 år) og fem CP-barn (8 – 17 år) med GMFCS nivå 1 utførte tre 3 – 5 minutter lange gangtester på selvvalgt sakte, normal og rask hastighet med portabelt indirekte kalerometriutstyr (Metamax II). VO2 og respiratoriskutvekslingsratio (RER) ble hentet ut fra en 1 minutts periode med "steady state" og gangdistanse under samme periode ble målt og brukt til å kalkulere ganghastighet. Sammen med kroppsvekt ble disse verdiene brukt til å kalkulere EE og EC.

Resultat: Både EE og EC ble redusert med alder ($p < 0,001$), EE økte med ganghastighet ($p < 0,001$), EC ble redusert med ganghastighet ($p < 0,001$), men det var ingen effekt av kjønn ($p = 0,4$ og $p = 0,6$) hos TD-barn. CP-gruppen hadde tilnærmet like EE- og EC-verdier sammenlignet med TD-gruppen (alle ulikheter hadde en $p > 0,7$). I tillegg var endringer i EE og EC med ganghastighet veldig like hos CP sammenlignet med TD.

Konklusjon: Både EE og EC ble funnet å gå ned med alder hos TD barn, mens ingen kjønnseffekt ble funnet. EE øker ved høyere ganghastighet for både TD og CP, men innad i hver hastighetsinstruksjon ga forskjeller i valgt ganghastighet mellom deltagerne gjennomsnittlig samme EE. EC er høyere på sakte ganghastighet sammenlignet med normal og rask gange for både TD og CP.

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Lastly, I would like to extend a special thanks to all the children who participated in this study for their great efforts and attitude, and to their parents for allowing them to participate.

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Abbreviations

TD = typically developed

CP = cerebral palsy

EE = energy expenditure

EC = energy cost

WS = walking speed

GMFCS = Gross Motor Function Classification System

N = study population

CI = confidence interval

Introduction

Cerebral palsy (CP) is caused by a lesion in the brain before, during or shortly after birth. It can lead to activity limitations as a result of several permanent disorders of movement and posture development (Rosenbaum et al. 2006). CP is the most common cause of disability in children, affecting 2 – 3 out of every 1000 neonatal children (Johnson 2000). The core features of CP are abnormal fine and gross motor control leading to difficulty in walking, musculoskeletal function and participation in society (Rosenbaum et al. 2006). In the 'Reference and Training Manual of the Surveillance of Cerebral Palsy in Europe (SCPE)', CP is divided into three groupings based on the predominant neuromotor abnormality; spastic, ataxic and dyskinetic (Cans 2000).

The varying disabilities of CP are classified using the Gross Motor Function Classification System (GMFCS). It is split into 5 levels where level 1 indicates the lowest level of disability while 5 is the highest level. In level 1 – 3 the person can generally walk on their own with or without the assistance of walking aids. In level 4 - 5 the person is normally dependent on a wheelchair in order to move around. Those classified as GMFCS level 1 are often very close to the mobility of typically developed people and are generally in very good physical shape. Those classified as GMFCS level 3 generally need walking aids such as walkers in order to help them maintain their balance (Rosenbaum et al. 2006).

Impaired gait due to disability can result in reduced walking speed and increased energy expenditure (EE) where EE increases with disability level. EE indicates the amount of energy a person uses per minute (Bell et al. 2010). Another way of expressing energy expenditure during walking is the amount of energy a person uses per meter, called energy cost (EC) (Kamp et al. 2014). EE and EC can say something about how physically demanding it is to walk and is connected to daily activity and participation. The GMFCS is quite crude with each level encompassing a large range of symptoms and severities. This is not a problem as it is used to classify disability, but it cannot say anything about differences or changes within one level. EE and EC are scale variables that can detect differences and changes within one GMFCS level, or they can be used to detect differences between GMFCS levels or between CP and TD. EC can be used to compare how energy efficient a person's gait is compared to others, where a higher EC would indicate that the gait is less efficient and more energy is used for other things than propelling the person forward.

The impaired gait of children with CP means their gait patterns are different, with less energy efficient movements than TD children (Furukawa et al. 1998). CP children also have slower walking speeds than TD children (Rose et al. 1989). These two factors may have an effect on EE and EC. It is also unclear how walking speed affects EE and EC in children with CP. This lack of knowledge means the effects in TD children are used as the basis for how it affects CP children as well, but these effects may differ between TD and CP due to differences in gait pattern.

EE (Ekelund et al. 2004) and EC (DeJaeger et al. 2001) have been found to become lower with age in TD children. Ekelund et al. also looked at gender differences and found that males have higher EE than females. However, the study population in both Ekelund et al. and DeJaeger et al. is very small. Therefore more studies ought to be done in order to verify these results. Ekelund et al. also only looked at daily EE and does not give any information about differences between intensity levels for different types of physical activity.

For the age effects on EE and EC for children with CP, some studies have found that EE and EC decrease with age (Bell et al. 2010, Kamp et al. 2014). This conflicts with findings that physical condition deteriorates after the age of 13, which leads to higher disability in CP children (Kerr et al. 2011). When combined with findings that the amount of energy used increases with disability (Kerr et al. 2008), this seems to indicate that EE and EC should increase after the age of 13. Therefore, the age effects on EE and EC in children with CP are unclear; it might increase or decrease after the age of 13. None of the mentioned CP studies looked at gender effects on EE and EC.

The overall aim of this master thesis was to gain more insight in the evaluation of EE and EC during walking in TD children and children with CP.

The specific aim of this thesis was twofold:

- First, to evaluate the effect of age, gender and walking speed on EE and EC.
- Second, to investigate differences in the effect of walking speed on EE and EC between well-functioning children with CP and TD.

Hypothesis; EE and EC will decrease with age and be higher for males than females. EE will increase with walking speed, while EC will decrease with walking speed. The effect of walking speed on EE and EC will result in higher EE and EC for CP children than TD children.

Methods

Participants

A total of 56 TD participants were recruited from a school in Sør-Trøndelag. The participants were between 7 and 15 years of age with 26 being female and 30 being male. A total of 7 CP children were recruited from Stavern and Trondheim. They were between the ages of 8 and 17. Their GMFCS scores were between 1 and 2, and walking aids outside of leg braces were not permitted. The participants and their parents provided written informed consent before testing began.

Equipment

During testing, the participants wore a portable energy measuring device called Metamax II. The Metamax uses indirect calerometry to attain VO2 and Respiratory exchange ratio (RER) among other variables. Before each day of testing, the Metamax was calibrated following the manufacturer's instructions using ambulant air and a reference gas (15% O2 and 5% CO2) as well as a 3 liter cylindrical pump to calibrate the flow turbine.

A 

B 

Figure 1 Equipment setup with Metamax (A) and facemask (B).

Protocol

Before testing, the participants' weight were measured.

Each participant was instructed to walk for 3 - 5 minutes on three different self-selected walking speeds; slower than they normally walk, like they normally walk and faster than they normally walk. A stopwatch was used in order to measure the time each participant used on each lap they covered for the three walking speeds. Each participant started with slow walking speed followed by 3 minutes of sitting, then 3 minutes of standing before walking on normal walking speed and then walking on fast walking speed. The participants could take a break between each exercise if they felt the need.

Testing on TD participants was performed outside on a track and field track when the weather permitted it or else inside the school's gymnasium. The track and field track was a standard 400 meter track. In the gymnasium the participants walked on a 120 meter track, a 78 meter track or a 92 meter track due to logistical reasons of having to share the gymnasium at certain times. Laps were used to track the distance each participant walked. On the track and field track laps were set at every 100 meters. In the gymnasium laps were set at every 60 meters for the 120 meter long track, every 39 meters for the 78 meter track and every 46 meters for the 92 meter track.

Testing on CP participants

Testing in Trondheim was done in a long corridor where each lap was 30 meters long. Here the participants were asked to walk back and forth for at least 3 minutes on each of the three walking speeds, while each lap was timed.

Testing in Stavern was done outside on an asphalt walking path. Here the total distance covered was measured instead of setting down lap markers, and the total time used for each of the three walking speeds was registered.

Data analysis

Energy data was extracted from a 1 minute period for each participant during the three walking speeds where steady state could be confirmed. Steady state was found by creating a scatterplot graph containing time and VO2 and finding the 1 minute period where VO2 was stable.

From these 1 minute periods VO2 (L/min) and respiratory exchange ratio (RER = ratio between CO2 produced and O2 consumed during steady state) were extracted. Together with weight data which had been collected earlier, this data was used to calculate EE.

Distance travelled over the 1 minute period VO2 was extracted from was used to calculate walking speed (m/s and m/min). M/min was used together with EE to calculate EC.

Both EE and EC were normalized to body weight.

The following equations were used to calculate EE and EC:

- $Relative\ VO2$ (mL/kg/min) = ($VO2$ / $weight$) $*$ 1000
- EE (J/kg/min) = ((4.96 $*$ RER) + 16.04) $*$ $relative\ VO2$
- EC ($J/kg/m$) = EE / $Walking\ speed$

Statistical analysis

All statistical analysis was performed in IBM SPSS statistics version 24 (SPSS, Inc., Chicago, IL). Using a histogram with a distribution curve and descriptive statistics the data was found to have normal distribution.

Due to the number of CP participants being very low, CP data was not included in statistical analysis testing for age and gender effects. However, group differences between TD and CP were evaluated using independent-samples t-tests where equal variance was not assumed. Due to low power, and thus a high risk of getting the hypothesis rejected despite a physiological relevant effect, the group differences were presented in addition to p-values.

In order to test for age and gender effects on EE and EC in the TD group, the general linear model with repeated measures with the variables instruction, age group and gender was used. Interaction between these variables was calculated using the conservative Greenhouse-Geisser equation. The TD group was divided into 3 groups with equal age spans:

- 7 - 9 years old
- 10 - 12 years old
- 13 - 15 years old

Then a post-hoc analysis was performed using the Tukey post-hoc test to find differences between age groups as it is meant to be the most powerful equation.

The Pearson bivariate correlation test was performed to find the between subjects correlation between EE and walking speed and EC and walking speed for each of the three self-selected walking speeds.

Results

Out of the 56 TD participants tested 12 were excluded due to lack of data, leaving 44 participants.

Out of the 7 CP participants 2 were excluded due to lack of data, leaving 5 participants.

Table 1 Participant information for both groups.

	TD	CP
N (male/female)	56 (30/26)	7 (5/2)
No energy data	11	2
No time data	1	
N after exclusion (male/female)	44 (24/20)	5 (4/1)

Table 2 Participant characteristics for both groups.

	TD	CP
N (male/female)	44 (24/20)	5 (4/1)
Age (years)	7-15	8-17
Weight (kg)	44 (+/- 22.6)	43,6 (+/- 18.3)
GMFCS 1		5

Walking speed:

For both the TD and CP group the speed the participants walked increases with the instruction, where the slow WS instruction resulted in the slowest walking speed and fast WS instruction (figure 2) resulted in the fastest walking speed. The effect of the instruction was statistically significant with $p < 0.001$. There were no statistically significant differences in walking speed between TD and CP with p-values of; slow WS 0.8, normal WS 0.2 and fast WS 0.4. Although on slow WS CP is 3.1% higher than TD, while on normal WS TD is 11.9% higher than CP and on fast WS TD is 10% higher than CP.

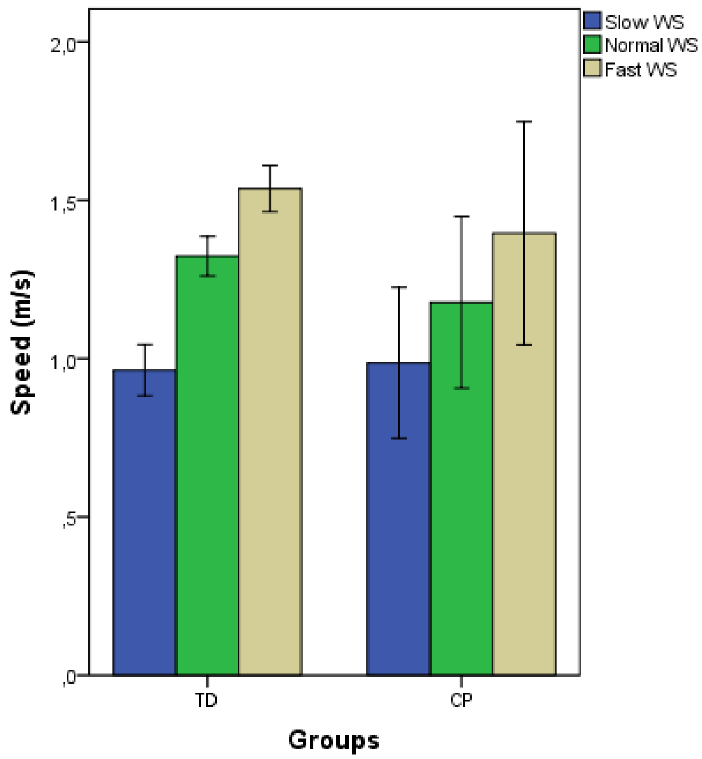

Figure 2 Average walking speed during walking with slow, normal and fast speed instructions for TD and CP. Error bars indicate 95% CI.

EE:

Figure 3 shows that EE of TD children decreases with age ($p < 0.001$) and increases with speed instruction ($p < 0.001$), but is not dependent on gender ($p = 0.4$). Interaction between instruction and age group ($p = 0.6$) and instruction and gender ($p = 0.15$) were not statistically significant. The Tukey post-hoc test shows a statistically significant difference between the 7 - 9 group and 10 - 12 group ($p = 0.02$), and 7 - 9 group and 13 - 15 group ($p < 0.001$), but no statistically significant difference between the 10 - 12 group and 13-15 group ($p = 0.3$).

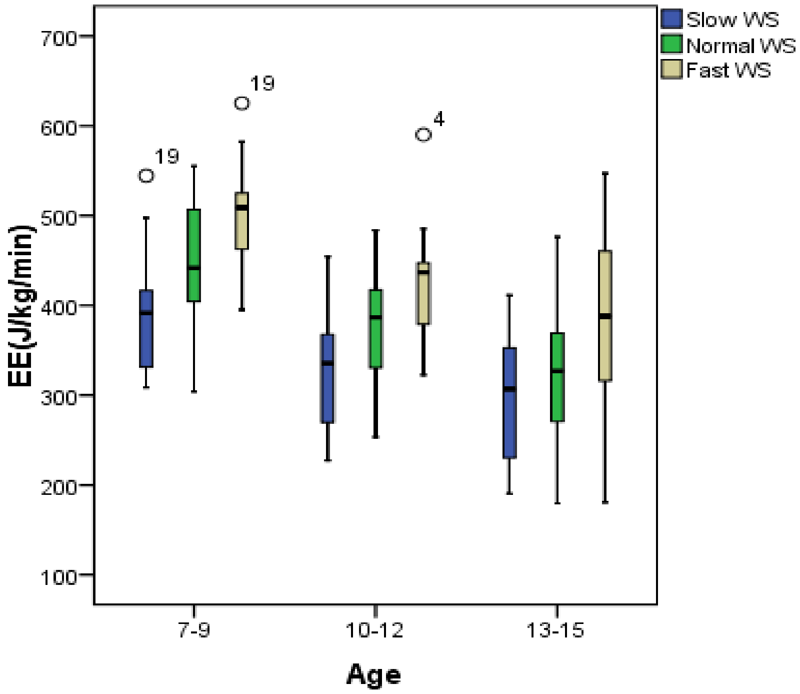

Figure 3 Energy expenditure values during walking with the three instructions slow, normal and fast walking speed for three separate age groups. Error bars indicate 95% CI.

EE increases with WS for both the TD and CP group (figure 4) but no statistically significant differences were found between the groups with p values of; slow WS 0.7, normal WS 0.9 and fast WS 0.8. The CP group has 5.4% higher EE on slow WS instruction than the TD group, while on normal WS instruction EE is 1.4% higher for TD than CP, and on fast WS instruction EE is 2.8% higher for TD than CP.

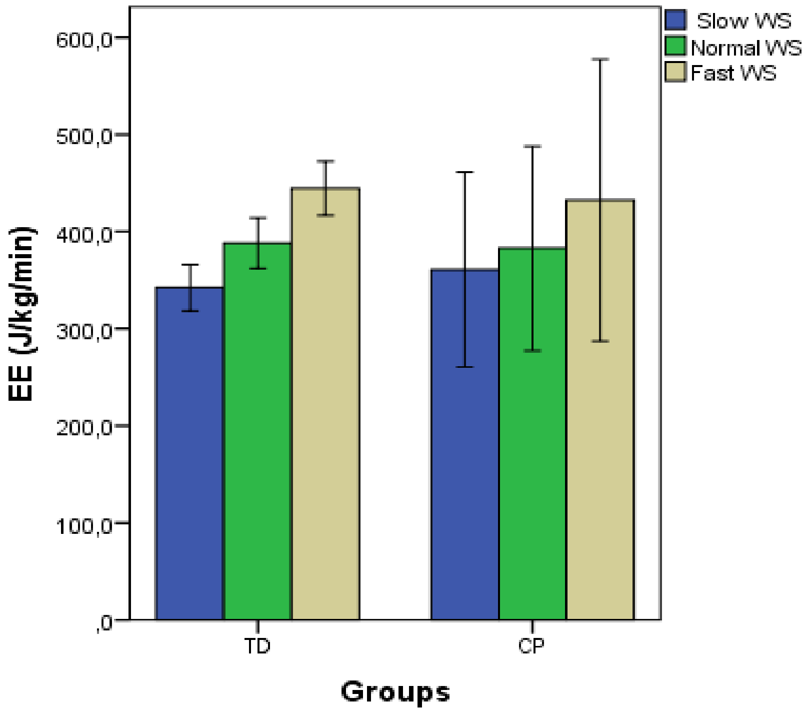

Figure 4 Energy expenditure values during walking with the three instructions slow, normal and fast walking speed for the TD and CP groups. Error bars indicate 95% CI.

EC:

Figure 5 shows that EC of TD children decreases with age ($p < 0.001$) and decreases with speed instruction ($p < 0.001$), but is not dependent on gender ($p = 0.6$). Interaction between instruction and age group ($p = 0.16$) and instruction and gender ($p = 0.17$) were not statistically significant. The Tukey post-hoc test shows a statistically significant difference between all 3 groups; 7 - 9 group and 10 - 12 group ($p = 0.001$), 7 - 9 group and 13 - 15 group ($p < 0.001$) and 10 - 12 group and 13 - 15 group ($p = 0.03$).

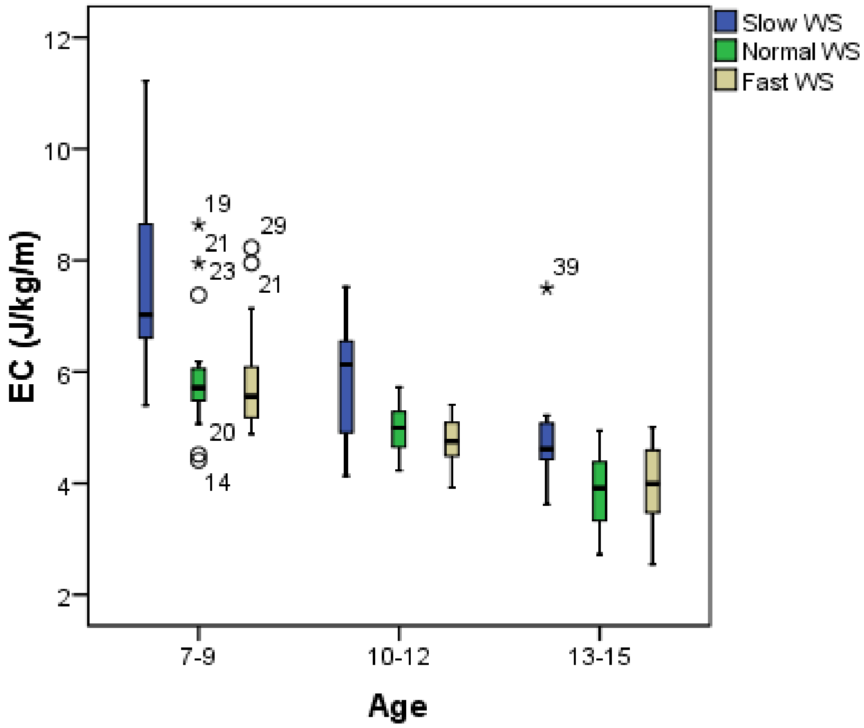

Figure 5 Energy cost values during walking with the three instructions slow, normal and fast walking speed for three separate age groups. Error bars indicate 95% CI.

EC decreases with WS for both TD and CP (figure 6) and no statistically significant differences were found between the groups with p values of; slow WS 0.9, normal WS 0.5 and fast WS 0.7. EC is 1.6% higher for TD than CP on slow WS instruction, while EC is 7.8% higher in the CP group on normal WS instruction and 6% higher in the CP group on fast WS instruction.

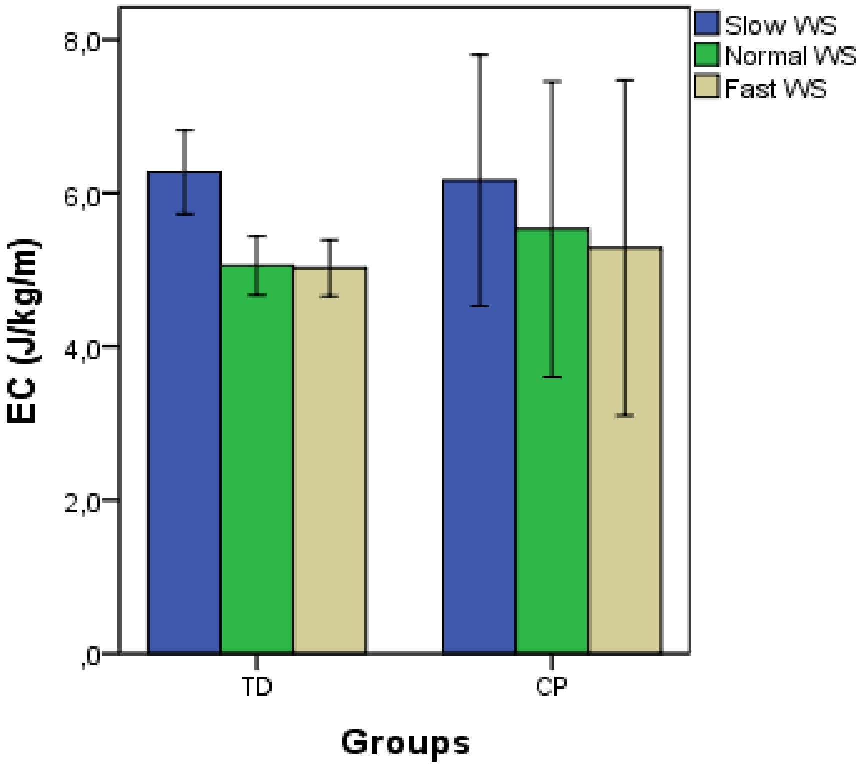

Figure 6 Energy cost values during walking with the three instructions slow, normal and fast walking speed for the TD and CP group. Error bars indicate 95% CI.

EE vs walking speed

The Pearson bivariate correlation test shows a weak correlation between EE and walking speed within the slow WS instruction with a correlation coefficient of 0.369 (p = 0.01). It shows no correlation between EE and walking speed within the normal WS instruction with a correlation coefficient 0.123 (p = 0.4) and no correlation between EE and walking speed within the fast WS instruction with a correlation coefficient 0.119 (p = 0.4).

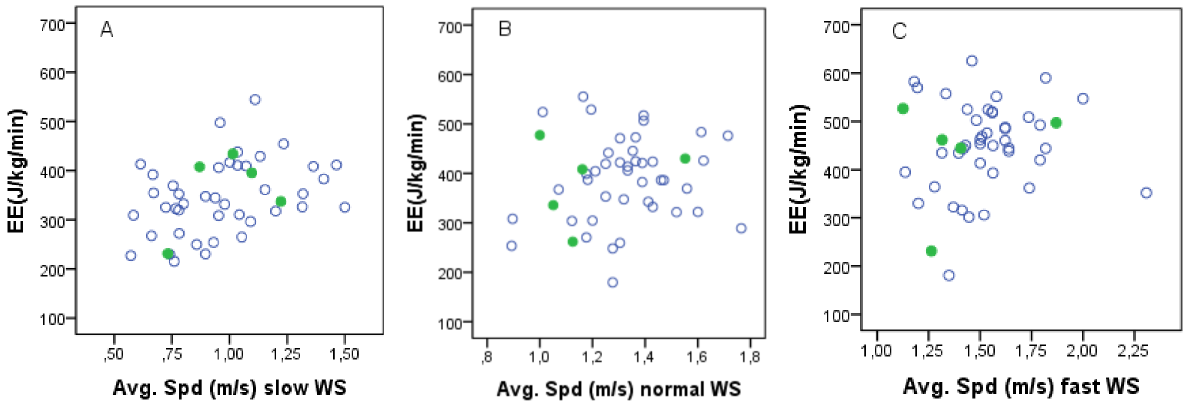

Figure 7 Individual relationship between energy expenditure and average walking speed during walking with the instructions slow (A), normal (B) and fast (C) walking speed, circles = TD, solids = CP.

EC vs walking speed

The Pearson bivariate correlation test shows a moderate-strong correlation between EC and walking speed within the slow WS instruction with a correlation coefficient of – 0.610 (p < 0.001). There are moderate correlations between both EC and walking speed within the normal WS instruction and fast WS instruction with a correlation coefficient of – 0.474 (p = 0.001) for normal WS and a correlation coefficient of – 0.465 (p = 0.001) for fast WS.

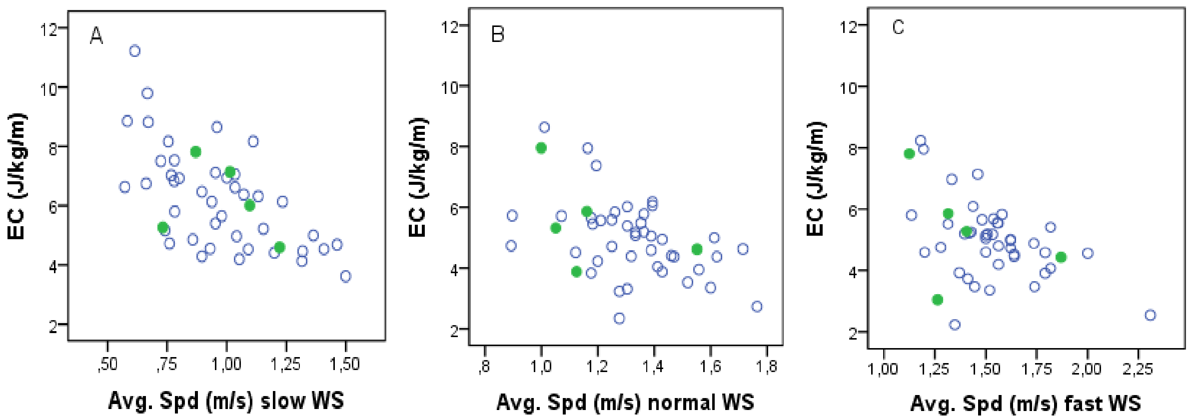

Figure 8 Individual relationship between energy cost and average walking speed during walking with the instructions slow (A), normal (B) and fast (C) walking speed, circles = TD, solids = CP.

Discussion

The overall aim of this master thesis was to gain more insight in the evaluation of EE and EC during walking in TD children and children with CP. The main results show that EE increases with walking speed, while EC decreases with walking speed for both TD and CP. In this discussion, the results will be discussed with respect to the effect of walking speed, age and gender on EE and EC, followed by differences between TD and CP for EE and EC and if EE and EC are speed dependent.

Instruction has worked as intended with a statistically significant increase on the 3 walking speeds from slow to fast instruction. In this study the participants walked between 0.6 m/s and 2.3 m/s. This is comparable to a prior study where the participants walked between 0.5 m/s and 2.3 m/s (DeJaeger et al. 2001) and encompasses another study where the participants walked between 0.7 m/s and 1 m/s (Kamp et al. 2014). This means that the results found in this study can be compared with the results from prior studies (DeJaeger et al. 2001, Kamp et al. 2014).

A statistically significant age effect was found for EE and EC in the TD group. EE gets lower with age. This is in accordance with both the hypothesis and prior research (Ekelund et al. 2004, DeJaeger et al. 2001). A statistically significant difference between the youngest group and the middle and oldest groups was found. There was no statistically significant difference between the middle and oldest group. The reason for there being no statistically significant difference between the two oldest groups is difficult to pinpoint without more specific research. Although no statistically significant differences were found it still looks like there is an age effect between the middle and oldest groups, but it is a lot less clear here compared to the youngest group. It might be that it has something to do with puberty, or it could be because the study population was very homogenous with the participants all being in very good physical shape. It is difficult to compare this to prior research as Ekelund et al. did not have any participants of the same age as the oldest group in this study. A statistically significant age effect was also found for EC in the TD group where EC gets lower with age, with a statistically significant difference between all three age groups. These findings are also in accordance with both the hypothesis and prior research (DeJaeger et al. 2001). This could be a result of the children going through physical changes in that they grow taller and get more efficient gait patterns. Unlike prior research (Ekelund et al. 2004) no statistically significant effect from gender was found in EE and the same applied for EC, which also does not fit the hypothesis. There was also no statistically significant interaction between the instruction and age group or instruction and gender for neither EE nor EC. This could indicate that gender is not something which future research need to take into account, although the fact that these findings do not match with prior research, suggests that more research into gender effects could be beneficial. It is also important to note that although no statistically significant interactions between instruction and gender were found, the relatively low p-value cannot completely rule out some interaction.

EE is found to increase with walking speed in both the TD and CP group which coincides with the hypothesis. When looking at the group differences between TD and CP for EE on the three walking speeds, a percentage difference between the groups was found where TD had a 1,4% higher EE on normal and a 2,8% higher EE on fast walking speed, although the differences found where not statistically significant. This does not coincide with neither the hypothesis nor prior research which would indicate that EE should be higher in the CP group (Bell et al. 2010). EC is found to be higher on slow walking speed for both the TD and CP group. The group differences showed a 1.6% higher EC for TD than CP on slow WS instruction. This does not coincide with neither the hypothesis nor prior research (Brehm et al. 2007). On the other hand EC is 7.8% higher in the CP group on normal WS instruction and 6% higher in the CP group on fast WS instruction, which coincides with both the hypothesis and prior research (Brehm et al. 2007). The differences on all three walking speeds were not statistically significant.

Even though a percentage difference between the groups is found on all three WS, the instruction shows no statistically significant differences between the TD and CP group. The CP group has a 3,1 % higher walking speed than the TD group when instructed to walk slower than normally. This does not fit with prior research (Rose et al. 1989) which found that CP children walk slower than TD children. Normal and fast walking speed however, is in accordance with prior findings. One could theorize that this is because of a difference in gait pattern for children with CP where higher walking speed is needed in order to maintain better balance. For them to walk any slower than they have done would simply be too tiring. The reason no statistically significant differences between the TD and CP group were found could also be a result of a small study population for CP. It could also be a result of the CP group only consisting of GMFCS level 1 leading to them being similar to the TD group. It could also be a combination of these and/or more factors.

When looking at EE versus walking speed on an individual level, weak to no correlation was found inside each of the three walking speeds. This indicates that the speed in which each individual participant walked during each instruction, whether it was the slow, normal or fast walking speed, did not affect EE. This is surprising as EE is shown to increase when comparing the three walking speeds. One would therefore assume that this would also be the case for individuals walking on different speeds within each instruction. It might be that children adjust their walking speed to EE. If this is the case, then that would mean that self-selected walking speed is a good indicator for walking ability. The weak to no correlation between EE and walking speed leads to a negative correlation between EC and walking speed. Here there is a clear trend that the slower each participant walks, the higher the EC. What we cannot see from this is cause and effect. Is it the walking speed that dictates EC or the individuals' physical fitness level that dictates the walking speed? It could be that the higher EC is purely a result of the participant walking slowly. It could also be that the participant walks slower as a result of his or her physical level, meaning that individuals with worse physical fitness could naturally walk slower, which then results in higher EC. As the CP values are within the TD values for both EE and EC, these findings should be relevant for both groups.

Strengths and limitations

Indirect calerometry is considered the gold standard for measuring VO2. The energy data calculated from these measurements should therefore have a high level of accuracy. The calibration of the equipment was not performed by the same person every time, but a detailed protocol for how the calibration was to be performed was followed by each person and should not have an impact on the results. When it came to the testing, the same person gave the instruction every time for the TD group, which insured that testing was conducted in the same way each time. This was not the case when testing on the CP group where testing was performed in two different locations by two different people, which is not ideal. The study population for both TD and CP was homogenous with the participants in the TD group generally being very active, while the CP group consisted purely of those with GMFCS level 1. This makes it hard to generalize the results for those outside the study population. There were also only 5 CP participants, which means that the variations that exist among the individuals of this population most likely is not present in this study population. When interpreting the results, this has to be taken into account and leads to a lower statistical strength for the results involving the CP group. For this reason percentage differences were included as an additional value when comparing the TD and CP group. Walking speed was also estimated and not directly measured, which could potentially have had an impact on its accuracy.

Relevance of findings

There is a clear age effect causing both EE and EC to decrease with age in TD children and should therefore be taken into account in future research. EC seems to be a better measure than EE when the goal is to identify differences on an individual level. Self-selected walking speed seems to be a good indicator of walking ability.

Further research

Further research should focus on having a higher CP population for higher statistical strength. One should also make sure that GMFCS level 1, 2 and 3 are equally represented in order to make the results more generalizable. In order to get more insight into age and gender effects for CP children, this should be a focus in the future. The effect of walking speed on both EE and EC on an individual level should also be explored in more detail for both TD and CP.

Conclusion

Both EE and EC was found to decrease with age in TD children, while no gender effects were found. EE increases with higher walking speed for both TD and CP. EC was found to be higher on slow walking speed than normal and high walking speed for both TD and CP. The CP group was found to have higher EE than the TD group on slow walking speed, but lower EE on normal and fast walking speeds. The CP group was found to have lower EC than the TD group on slow walking speed, but higher EC on normal and fast walking speeds. Within each speed instruction the differences in chosen walking speed between the participants on average gives the same EE, while higher walking speed gives lower EC.

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