THE ROLE OF VISION IN WALKING PATTERNS IN CHILDREN WITH DIFFERENT LEVELS OF MOTOR COORDINATION

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ASBTRACT: Research has shown that children with developmental coordination disorder rely more heavily on vision to perform movement skills than their typically developing (TD) peers. The purpose of the current study was to investigate information processing by restricting visual information during walking tasks between TD children and children at risk of having developmental coordination disorder (DCD_R). Thirty-two children (age: 8.9 ± 0.9 years) were asked to walk along a 10-metre walkway at a self-selected speed under four visual conditions: full-vision, visual input for 150-ms and for 100-ms within each 2 second, and non-vision. The results showed that TD children walked faster and with longer steps and strides than DCD_R, regardless of the visual condition. In addition, the speed of walking and the step and stride length decreased significantly while the occlusion time increased, regardless of the level of motor competence. The study suggests that withdrawing and limiting visual information affect the gait cycle differently in DCD_R and TD children.

KEYWORDS: Gait pattern, vision occlusion, motor coordination disorder, children.

EL ROL DE LA VISION EN EL PATRON DE LA MARCHA EN NIÑOS CON DIFERENTE NIVEL DE COORDINACIÓN MOTRIZ

RESUMEN: La investigación ha mostrado cómo los niños con problemas de coordinación motriz se apoyan más en la información visual para llevar a cabo destrezas motrices respect de sus iguales (TD). El objetivo del presente estudio fue investigar el procesamiento de la información a través de una tarea relacionada con la marcha en la que se restringe la información visual entre niños con un desarrollo motor normal y aquellos con riesgo de tener problemas evolutivos de coordinación motriz (DCD_R). A treinta y dos niños (edad: 8.9 ± 0.9 años) se les pidió que caminaran por un pasillo de 10 metros a la velocidad que quisieran en 4 condiciones: vision-completa, recibiendo información 150ms y 100ms cada dos segundos, y no-visión. Los resultados mostraton que los niños TD andaban más rápido y con pasos y zancadas más largos respecto de los $DCD_{R,}$ sin tener en cuenta la condición visual. Además, la velocidad de la marcha y la longitude de los pasos y zancadas disminuía significativamente a medida que aumentaba el tiempo de occlusion, sin tener en cuenta el nivel de competencia motriz. La investigación sugiere que eliminar o limitar la información visual afecta de manera distinta en el patron de la marcha a niños TD y auqellos DCD_R.

PALABRAS CLAVE: Patrón de la marcha, occlusion visual, problemas de coordinación motriz, niños.

O ROL DA VISÃO NO PADROEIRO DA MARCHA EM CRIANÇAS COM OUTRO NÍVEL DE COORDENAÇÃO MOTRIZ

RESUMO: A pesquisa demonstrou que as crianças com dispraxia dependem mais acentuadamente da visão para executar movimentos do que seus pares tipicamente em desenvolvimento (TD). O objetivo deste estudo foi investigar a contribuição da informação visual durante a caminhada entre crianças com TD e crianças em risco de ter dispraxia (DCD_R). Trinta e duas crianças (idade: 8.9 ± 0.9 anos) foram convidadas a caminhar ao longo de uma passagem de 10 metros a uma velocidade auto-selecionada em quatro condições visuais: visão total, visão de recebimento de 150ms e 100ms a cada 2 Seg, e não-visão. Os resultados mostraram que as crianças TD andavam mais rápido e com passos mais longos do que DCD_R, independentemente da condição visual. Além disso, a velocidade de caminhar e o passo e o comprimento da passada diminuíram significativamente enquanto o tempo de oclusão aumentou, independentemente do nível de competência motora. O estudo sugere que retirar e limitar a informação visual afetam diferentemente o ciclo de marcha em crianças DCD_R e TD.

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PALAVRAS-CHAVE Padrão de marcha, oclusão da visão, dispraxia, distúrbio de coordenação motora, crianças.

Children with difficulties in the execution of various movement skills have been referred to as children with Developmental Coordination Disorder (DCD) (American Psychiatric Association, 2013). These movement difficulties can appear in daily life, school work or in physical activity during leisure time in games or sports. A feature of this specific disorder is delays in motor development which cannot be explained as a consequence of intellectual disabilities, a diagnosed medical disease or growing up in adverse environmental conditions (Henderson & Barnett 1998). Children with DCD have manifested motor problems in a variety of motor domains such as fine motor skills (Barnett & Henderson, 2005; Bieber et al., 2016; Smits-Engelsman, Wilson, Westenberg, & Duysens, 2003), gross motor skills (Gallahue & Ozmun, 1998; Haywood & Getchell, 2001) and/or balance (Ferguson, Aertssen, Rameckers, Jelsma, & Smits-Engelsman, 2014; Forseth & Sigmundsson, 2003; Jelsma, Ferguson, Smits-Engelsman, & Geuze, 2015; Jelsma, Geuze, Mombarg, & Engelsman, 2014; Pless, Persson, Sundelin, & Carlsson,. 2001; Tsai, Wu, & Huang, 2008).

DCD is a heterogeneous syndrome. The mechanisms that underlie movement difficulties may originate from different sensorimotor impairments. Very often it has been suggested that DCD may emerge from problems involved in information processing such as visual and/or kinesthetic perception, assuming that a deficit in visual perception is common among children with DCD (Wilson & McKenzie, 1998; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). Also, the lower capacity for perception integration, both identification or differentiation of sensory stimuli, planning and selecting movement response, organizing and sequencing motor response can cause general impairment in motor coordination (Ayres, 1972; Williams, 2002). In addition, DCD can be associated with problems in the execution of movements. However, a child might be able to process information and planning of motor response (Mandich, Polatajko, Missiuna, & Miller, 2001).

While some scientific evidence have shown that there are no perceptual deficits in children with DCD (Schoemaker, Van der Wees, Flapper, Verheij-Jansen, Scholten-Jaegers, & Geuze, 2001), a general agreement in the literature assumes that a defect in motor planning or motor execution can be associated with impairments of visual perception, including visual information processing (Lord & Hulme, 1988; Ruiz, Mata, & Jimenez, 2005; Wilson & McKenzie, 1998; Wilson, Miles, Vine, & Vickers, 2012). In this regard, the importance of visual inputs for both planning and visual control of movements have been labelled as one of the most important factors of motor coordination (Schmidt & Lee, 2011; Vickers, 2007). Some studies have demonstrated that children with DCD, in comparison to typically developing (TD) peers, may rely more heavily on visual perception/information in order to perform their movements (Bair, Barela, Whitall, Jeka, & Clark, 2011; Deconinck, DeClerq, Savelsbergh, VanCoster, Oostra, Dewitte, & Lenoir, 2006a; Wilmut, 2017). It has also been shown that children with DCD have a greater deficiency in visual spatial processing both with and without motor response, suggesting that DCD children may have a deficit in visual information processing, especially visuospatial orientation (Wilson & McKenzie, 1998). Since perceptual information is crucial for motor control of most human movements, it could be assumed that movements may be impaired as a consequence of visual reduction (from full vision to non-vision), affecting the accuracy, fluency and efficiency of the execution of movements. Previous studies (Hallemans, Beccu, Van Loock, Ortibus, Truijen, & Aerts, 2009), have shown a significant influence of visual deprivation (i.e. non vision) on fundamental movement skills such as human locomotion, specifically on gait patterns. However, to date only one study has been conducted regarding DCD children, walking and visual deprivation (Deconinck et al., 2006a). In that study visual deprivation was achieved only by limitation of lightning in two conditions: with normal lighting and in darkness.

In the present study we were interested in examining the time span that is necessary for visual information processing in children at risk of having Developmental Coordination Disorder (DCD_R) in comparison with their typical peers. The children with DCD_R are characterized by moderate movement difficulties which require monitoring in ongoing motor development. In this regard, it has been suggested that 100ms is the minimum time that is necessary to recognize or become aware of visual stimuli (Vickers, 2007), while between 150ms and 180ms is necessary for the ability to see a stimulus and initiate a simple movement (Schmidt & Lee, 2011).

Therefore, the question was whether there are differences in information processing between TD and DCD_R. Potential impairments in visual information processing could be highlighted in gait patterns under limited visual time availability, such as 100ms and 150ms in DCD_R children in comparison to TD children. Normally some reduction or absence of vision can be compensated by proprioceptive input stimuli as the major source of information in order to conform to the requirements of motor control (Tremblay, 2010). Thus, manipulation of the visual conditions in an experiment can show a subject's capacity for using proprioceptive information and/or his/her dependency on visual stimuli in order to execute a given task. If children with DCD_R have difficulty only with visual perception processing, their performance should be similar in comparison with TD children when vision is withdrawn (Deconinck et al., 2006a) or limited (present study). In the opposite case, they should have a problem with kinesthetic or proprioceptive information processing in comparison with TD children. We hypothesized that some differences in gait pattern parameters could appear between TD and DCD_R children as a consequence of the differences in information processing.

METHODS

Participants

In this study sixteen typical development (TD) children (aged 9.0 ± 1.0 years, 8 boys and 8 girls), and sixteen age-matched children at risk of having developmental coordination disorder (DCD_R), (8.9 ± 0.8 years, 13 boys and 3 girls) were selected from 397 children attending typical schools. A multidisciplinary examination assessment together with a Movement Assessment Battery Test for Children-2 (MABC-2 test) (Henderson, Sudgen, & Barnett, 2007) were conducted in order to fulfil the criteria for diagnosing children with DCD_R.

Only the children with sound physical, psychological and mental health were included in the study. Children from the TD and DCD_R groups did not differ significantly from each other in body weight, height and functional leg length. Ethical approval of the present research was obtained from the review board of the university. Written informed consent was also obtained from all the parents of the children and the school principals. The children were not aware of the purpose of the study.

Material

To assess motor coordination, the MABC-2 test (Henderson, et al., 2007), was performed to measure the different levels of motor competence of the children. This test consists of eight tasks divided into three categories: manual dexterity representing fine motor coordination, throwing and catching indicating gross motor coordination, and balance tasks reflecting static and dynamic balance. According to the Manual MABC-2 (Henderson et al., 2007), the total test score (TTS) was calculated. Children with TTS > 15th percentile were included in the TD group, while children with TTS ≤ 15th percentile were placed in the DCD_R group.

Anthropometric assessment Body weight (Tanita BF-350350, Tanita Corp, Japan), and body height (Leicester High Measure MK II, Leicester, Great Britain) were assessed before the main experiment.

In addition, functional leg length (Gross, Fetto, & Rosen, 2005) was measured from the spina iliaca anterior superior to the malleolus medialis. To calculate the scaled variables of gait pattern (see below), step length (heel to heel) and walking speed were scaled by using the leg length according to the following method proposed by Hof (1996):

$$\text{Scaled step length} = \frac{\text{step length}}{\text{leg length}}$$

$$\text{Scaled speed} = \frac{\text{speed}}{\sqrt{\text{g} \cdot \text{leg length}}}$$

g: gravitational acceleration

Procedure

Experiment

The experiment was conducted inside a portable laboratory, where all children were asked to walk at a self-selected and comfortable speed along a ten-metre walkway (figure 1) under four different visual conditions (see below). In all of the walking conditions, the children were asked to stand behind the starting line that was placed two metres in front of the walkway. They were then required to walk at a self-selected and comfortable speed to the finishing line, which was located two metres beyond the walkway. The purpose of placing the starting and finishing lines two metres in front of and beyond the walkway was to minimize the effects of acceleration and deceleration in walking speed and to record only the stable gait pattern. For execution of the walking tasks, each child wore the same type of light sport shoes in the requested size.

Each child was asked to walk at a comfortable speed one time inside the walk way in order to become familiar with the task. The participants were then asked to walk in a counterbalanced order of visual conditions, wherein each child completed two trials in each visual condition.

Figure 1. Settings of the experiment

Visual conditions

In total 4 visual conditions were used. In two visual conditions the children were equipped with PLATO goggles (Translucent Technologies Inc., Toronto, Canada). PLATO goggles have an automatic shutter which allows restriction of vision at predefined intervals. In the condition of *limited vision for 150ms (LV-150),* the goggles were automatically opened for 150ms within each 2s. In the condition of *limited vision for 100ms (LV-100),* the goggles were automatically opened for 100ms within each 2s. Before the start of the trial, the goggles were closed and children were asked to start walking after the goggles opened for the first time. In the *non-vision (NV)* condition, the children wore a fabric eye mask (Prime effects sleep mask, Dunedin, USA) to cover their eyes 10 seconds before beginning of the walk. In the last *full vision (FV)* condition, the children were without any limitations for visual occlusion.

Apparatus and experimental settings

The Optojump Next instrument (Optojump Next, Version 1.3.20.0, Microgate, Bolzano, Italy) was used to measure the kinetic and kinematic variables of the steps. The Optojump was installed on the floor, with ten one-metre-long transmitting bars connected together and ten one-metre-long receiving bars connected together. The transmitting bars were placed three metres apart from receiving bars. The data were sampled at 1000 Hz and were processed into 1D footfall patterns using appropriate software.

The Optojump equipment was located inside a portable laboratory (15 m x 4 m x 2.5), which was created specifically for the study, and was installed in each schools' gym hall. This portable laboratory was built with a metallic structure completely covered by dark blue fabric on the four sides that surround the structure. The roof of the structure was uncovered. The main purpose of this equipment was to ensure that all the children in all the schools received the same visual information. This structure was used in order to prevent the effects of external stimuli (e.g., sports equipment in the schools' gyms) on directing or disrupting the attention of the participants while walking.

Data analysis

The data were recorded from the first fourteen steps, i.e. seven gait cycles. The walking pattern was assessed with the selected variables obtained by the Optojump including a) distance variables represented by scaled step length (distance from heel to heel) and stride length (distance from length of two consecutive steps) (cm); b) speed variable indicated by scaled step speed ($m.s^{-1}$); and c) time variables expressed by stance phase, swing phase, single support, load response, and pre-swing. All the time variables were expressed in seconds (s) and percentage (%), and were based on the time spent and the percentage of each phase of the whole gait cycle. The stance phase (s and %) is the supporting phase of each gait cycle, which begins with the contact of the heel and finishes with the set off of the tip of the same foot. The swing phase (s and %) begins when the tip of the foot leaves the ground and finishes with the contact of the heel. Single support (s and %) is the time between the last contact for the current support and the first contact of the following support of the same foot. Load response (s and %) is the first double support, and pre-swing (s and %) is the second double support. All of the above mentioned variables were derivates of the Opotojump measurement.

All the gait cycle variables were analysed in a 2 (groups: TD v DCD_R) x 4 (visual conditions: FV, LV150, LV100 & NV) mixed-effect (between–within) analysis of variance (ANOVA), with repeated measures on visual conditions (α = .05). Bonferroni corrections were applied for all ANOVAs (α = .01). Bonferroni adjustments and pairwise comparison post-hoc tests were used when appropriate. Greenhouse-Geisser epsilon values were used to adjust the degree of laxity in the ANOVAs with repeated measurements to compensate for deviations from the assumption of sphericity. T-test analysis was performed for the anthropometric data. All the analyses were carried out using the statistical software SPSS-22 (IBM, USA).

RESULTS

Motor coordination assessment

The results showed that the TTS of the MABC-2 test was lower in the DCD_R group (9.3 ± 4.9 %) in comparison to the TD group (61.8 ± 19.8 %).

Variables of gait pattern in different groups and visual conditions

Distance variables

TD children walked with longer scaled steps, $F(1,30) = 561.41$, $p < .001$, $\eta p^2 = 0.826$, and strides $F(1,30) = 20.69$, $p < .001$, $\eta p^2 = 0.408$, compared to DCD_R children, regardless of the visual condition. Also, regardless of the motor competency of children the scaled step length, $F(2.43,73.09) = 68.00$, $p < .001$, ηp2 = 0.949, and stride length, $F(2.44,73.35) = 95.52$, $p < .001$, $\eta p^2 = 0.761$, significantly decreased as the occlusion time increased. However, the interactions of group x vision for both variables were not significant.

Time variables

The time variables were expressed by the absolutes scores (time spent on the phase), and percentage from the whole gait cycle. Regardless of the visual condition, the results demonstrated that the variables stance phase (s) and single support (s) was longer in the TD group than in the DCD_R group. At the same time, the load response (s) and pre-swing (s) phases were shorter in the TD group than in the DCD_R group (table 1). No differences were found in swing time. In addition, only stance phase (s) and single support (s) were significantly different between the various visual conditions, regardless of the motor competence group. Upon visual restriction, the time which the participants spent in the above-mentioned phases was shorter (see table 1). Furthermore, the interactions of group x vision were not significant for any of the time variables in the absolute scores (Table 1).

Table 1
Means, standard deviations and statistical outcome of the time variables in seconds in the visual, limited vision 150, limited vision 100 and non-visual conditions.

Variable	Condition	TD children	DCD_R children	Group	Vision	Group x Vision
Single support (s)	FV	0.33 ± 0.04	0.08 ± 0.03	$F(1,30)= 14.08$	$F(2.74,82.42)= 185.45$	$F(2.74,82.42) = 2.31$
	LV150	0.33 ± 0.02	0.10 ± 0.05	$p < .001$	$p < .001$	$p = .081$
	LV100	0.30 ± 0.03	0.04 ± 0.04	$\eta p^2= 0.320$	$\eta p^2 = 0.861$	$\eta p^2 = 0.072$
	NV	0.24 ± 0.04	0.02 ± 0.03			
Stance time (s)	FV	0.58 ± 0.21	0.37 ± 0.18	$F(1,30)= 5.14$	$F(2.15,64.59)= 7.18$	$F(2.15,64.59) = 1.28$
	LV150	0.61 ± 0.25	0.41 ± 0.17	$p = .007$	$p = .012$	$p = .286$
	LV100	0.56 ± 0.21	0.37 ± 0.16	$\eta p^2 = 0.146$	$\eta p^2= 0.193$	$\eta p^2 = 0.041$
	NV	0.51 ± 0.21	0.37 ± 0.16			
Load response (s)	FV	0.13 ± 0.03	0.14 ± 0.03	$F(1,30) = 23.67$	$F(2.54,76.29)= 0.87$	$F(2.54,76.29) = 1.54$
	LV150	0.14 ± 0.03	0.15 ± 0.04	$p < .001$	$p = .444$	$p = .216$
	LV100	0.13 ± 0.02	0.16 ± 0.02	$\eta p^2= 0.441$	$\eta p^2 = 0.028$	$\eta p^2 = 0.049$
	NV	0.14 ± 0.03	0.17 ± 0.02			
Pre-swing (s)	FV	0.12 ± 0.03	0.15 ± 0.03	$F(1,30) = 38.40$	$F(2.59,77.81)= 2.41$	$F(2.59,77.81) = 1.45$
	LV150	0.14 ± 0.03	0.16 ± 0.04	$p < .001$	$p = .081$	$p = .237$
	LV100	0.13 ± 0.02	0.17 ± 0.02	$\eta p^2= 0.561$	$\eta p^2 = 0.075$	$\eta p^2 = 0.046$
	NV	0.13 ± 0.03	0.18 ± 0.02			

Table 2
Means, standard deviations and statistical outcome of the time variables in percentage of the gait cycle in the visual, limited vision 150, limited vision 100 and non-visual conditions

Variable	Condition	TD children	DCD_R children	Group	Vision	Group X Vision
Single support (%)	FV	35.83 ± 4.90	33.70 ± 2.25	$F(1,30)= 0.91$	$F(2.52,75.60)= 71.83$	$F(2.52,75.60)$
	LV150	37.29 ± 3.41	30.99 ± 1.54	$p = .437$	$p < .001$	= 3.39
	LV100	35.82 ± 3.59	32.06 ± 1.79	$\eta p^2 = 0.030$	$\eta p^2= 0.705$	$p = .011$
	NV	38.26 ± 3.58	31.77 ± 1.13			$\eta p^2 = 0.116$
Stance time (%)	FV	56.60 ±18.65	49.27 ± 18.83	$F(1,30)= 1.85$	$F(1.70,51.15) = 4.77$	$F(1.70,51.15)$
	LV150	55.02 ± 18.55	42.24 ± 18.28	$p = .171$	$p = .037$	= 10.24
	LV100	53.88 ± 18.60	40.04 ± 17.35	$\eta p^2 = 0.058$	$\eta p^2 = 0.137$	$p < .001$
	NV	52.55 ± 18.93	39.81 ± 17.84			$\eta p^2 = 0.240$
Load response (%)	FV	14.83 ± 1.75	15.29 ± 1.89	$F(1,30)=44.40$	$F(2.75,82.75) = 7.23$	$F(2.75,82.75)$
	LV150	13.44 ± 1.91	10.63 ± 2.02	$p < .001$	$p < .001$	= 7.11
	LV100	13.12 ± 1.71	7.28 ± 1.61	$\eta p^2 = 0.597$	$\eta p^2 = 0.194$	$p < .001$
	NV	12.11 ± 1.30	4.28 ± 1.81			$\eta p^2 = 0.192$
Pre-swing (%)	FV	5.94 ± 2.10	0.28 ± 2.07	$F(1,30)=65.40$	$F(2.74,82.26) = 2.92$	$F(2.74,82.26)$
	LV150	4.29 ± 1.56	0.62 ± 1.26	$p < .001$	$p = .038$	= 14.60
	LV100	4.94 ± 1.44	0.7 ± 2.03	$\eta p^2 = 0.686$	$\eta p^2 = 0.089$	$p < .001$
	NV	2.18 ± 1.73	3.76 ± 1.38			$\eta p^2 = 0.327$

Table 3
Significant results from post hoc tests for the significant variables of the time variables in percentage in the interactions of group x vision. The results are common for the variables including single support (%), stance time (%), load response (%) and pre-swing (%).

	TD children				DCD_R children			
	FV	LV150	LV100	NV	FV	LV150	LV100	NV
TD children								
FV	–							
LV150	NS	–						
LV100	*	*	–					
NV	*	*	*	–				
DCD_R children								
FV	*	NS	*	*	–			
LV150	*	NS	*	*	NS	–		
LV100	*	*	*	*	*	*	–	
NV	*	*	*	*	*	*	NS	–

Note: * $p < .05$; NS = not significant

With respect to the relative time variables, the results demonstrated that the stance phase (%), swing phase (%) and single support (%) were not significantly different between TD and DCD_R children regardless of the visual condition. However, the load response (%) and pre-swing (%) were higher in the DCD_R group than in the TD group. In addition, the stance phase (%), single support (%), load response (%) and pre-swing (%) were significantly different between visual conditions, regardless of the motor competence groups. Furthermore, the interactions of group x vision were significant in stance time (%), single support (%), load response (%) and pre-swing (%) (Table 2). Significant results from the post hoc tests are shown in Table 3. Concerning the speed, the results showed that TD children walked significantly faster than DCD_R children, $F(1,30) = 15.03$, $p < .001$, $\eta p^2 = 0.334$, regardless of the visual condition. In addition, the speed of walking decreased significantly as the occlusion time increased, regardless of the level of motor competence, $F(2.05,61.74) = 26.48$, $p < .001$, $\eta p^2 = 0.469$. However, the interactions of group x vision were not significant.

DISCUSSION

The goal of the present study was to examine the differences in information processing between TD and DCD_R children by changing visual conditions while walking. Specifically, the present study addressed the question of whether parameters related to walking pattern, including distance, speed and time variables, are different between TD and DCD_R children under different visual conditions.

Speed variables

The results of the current study demonstrated that the walking performance of the TD children was significantly different from the children with DCD_R regardless of visual conditions (Table 1). These differences while walking were found in the speed variable and also in both distance variables, showing that TD children walked faster ($m.s^{-1}$), with longer steps and strides (m) than their DCD_R peers. Support for the present results also can be found in observational studies (Larkin & Hoare, 1991; Woodruff, Bothwell-Myers, Tingley, & Albert, 2002) and in quantitative research (Palomo, Psotta, Agricola, Abdollahipour, & Valtr, 2015), in which gait characteristics were different between DCD and control groups. Also, regardless of visual conditions, the results showed that there were significant differences between the groups in some of the variables in time (s) (Table 1). For example, TD children spent more time than DCD_R children in stance phase (s) and single support (s). At the same time, the load response (s) and pre-swing (s) phases were shorter in the TD group than in the DCD_R group, supporting the idea that DCD children have balance problems (Cherng, Hsu, Chen, & Chen, 2007; Geuze, 2003; Tsai, Wu, & Huang, 2008) and spend more time in those phases related to double support (Cermak & Larkin, 2002; Deconinck, DeClerq, Savelsbergh, VanCoster, Oostra, Dewitte, & Lenoir, 2006b; Sudgen & Chambers, 2005; Wilmut, Du, & Barnett, 2016), which are more advantageous for maintaining balance compared with single support phases. The results of the time variables in percentages, including the load response and pre-swing phases, showed that the percentages from the whole gait cycle were higher in DCD_R children than in their TD peers. This is in contrast with the results of Deconinck et al. (2006b). However, in the study by Deconinck et al. (2006b), the children walked on a motor-driven treadmill. The different environment in which the walking task took place could change the walking pattern. In other words, various walking pathways may affect both groups of TD and DCD_R children in adapting the gait cycle under different conditions. Another possible explanation of the differences in gait pattern in DCD_R children is that the different gait pattern is an adaptive response to problems on the neuromuscular or postural control level, rather than an abnormal phenomenon (Deconinck et al., 2006b; Rosengren, et al., 2009).

The results of this study also showed that the performance of the children was different between FV, LV150, LV100 and NV conditions, regardless of the level of motor competence in both distance variables (scaled step length and stride length), the speed variable and some of the time variables including the stance phase (% and s), single support (% and s), load response (%) and pre-swing (%), showing that children walked faster and with longer steps in the FV condition than in LV150, LV100 and NV conditions (Table 2). These results support the view that visual information has an important influence on the spatial parameters of the gait cycle in children (Deconink et al., 2006a; Williams, Ashley, & Ullmann, 2010). With increased visual occlusion, children probably adopted a more cautious gait pattern. A similar pattern was observed also in adults and elderly persons (Saucedo & Yang, 2017). However, the swing phase (% and s), load response (s) and pre-swing (s) did not differ between the different visual conditions, supporting the hypothesis in which other information inputs such as proprioceptive ones could contribute more effectively for these parameters (Tremblay, 2010). Also, by decreasing walking speed, the children may increase time for sensory exploration (Hallemans et al., 2009) and utilization of the gained information.

In this line, the study highlights, when scaled to the total gait cycle duration, TD children in LV100 and NV obtained higher percentages from the gait cycle in the stance phase, single support, load response and pre-swing than DCD_R in the FV condition. These results suggest that the mechanisms of using proprioceptive feedback were better when TD children were walking under non-visual conditions in comparison with DCD_R children who received both normal visual information and proprioceptive feedback. To our knowledge, this study is the first to show that walking patterns for TD children in the absence of vision were more rhythmic than their DCD_R peers in the presence of vision.

Concerning the different visual conditions in the TD group (Table 2 and 3), the stance phase (%), single support (%), load response (%) and pre-swing (%) were significantly different in FV compared to LV100 and NV. However, FV and LV150 conditions were not different from each other. Furthermore, LV150 was also significantly different from LV100 and NV. The same results were found with the DCD_R children in all visual conditions (Table 2 and 3). Although Palomo et al. (2015) did not find any interaction results, most probably due to the smaller sample size, the current results suggest that 150ms is enough time to obtain and utilize visual information for walking with a normal gait pattern, while 100ms seems not to be enough, either for TD children or for DCD_R children. These results can support information-processing time theory, in which the minimum time of exposition of the stimulus to be detected is between 100ms and 150ms (Schmidt & Lee, 2011; Vickers, 2007).

Since there were significant differences in FV condition between the TD and DCD_R groups, it can be concluded that there is a general difference between these groups. Considering the differences in the two groups in the stance phase (%), single support (%), load response (%) and pre-swing (%), the TD and DCD_R groups were different only in the LV100 and NV conditions, when a significant difference was found only in the TD group (table 3). These results could be explained by the time that children need to process visual information. It has been suggested that DCD children in comparison with their TD peers have impairments in the processing of the visual information that is relevant to the performance of motor tasks (Miles, Wood, Vine, Vickers, & Wilson, 2015; Piek & Dyck, 2004; Sigmundsson, Hansen, & Talcott, 2003; Tsai, Wilson, & Wu, 2008). Therefore, it can be assumed that the lower level of motor competence affects the time which children need to process the visual information and their capability of gait adaption to the visual inputs. The current results show that TD children are more able to process visual information in less time than DCD_R children, suggesting that DCD_R children have more difficulties in adapting their gait to external inputs (Deconinck et al., 2006a). However, more studies focusing on the amount of time which DCD children need to perceive and process visual information are required. Such information would help us understand processing of visual information in DCD children while walking.

In conclusion, the results of the present study suggest that withdrawing and limiting vision affect the length, speed and time variables of the gait cycle in children, regardless of their motor competence. Although visual information has an influence on walking, it could not affect on all of the spatio-temporal parameters of the gait cycle, suggesting that the other information inputs such as proprioceptive ones could contribute more effectively for these parameters. Regarding the rhythm of the total gait cycle duration, TD children were able to use proprioceptive feedback under non-visual conditions in comparison with DCD_R children who received both normal visual information and proprioceptive feedback. This might show that not only vision but also proprioception information was not processed appropriately in DCD_R children. Such knowledge can be utilized in intervention for DCD children.

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