Effect of Embodied Training on the Balance-Scale Task:

Recurrence Quantification Analysis of Postural Fluctuations in Primary School Children

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Appendices

Relevant memories are in the language of the body (Smith & Thelen, 2003)

Tot nu toe is de opdracht om een scriptie te schrijven de moeilijkste taak in mijn leven geweest. Het confronteerde me met mijn angst om niet goed genoeg te zijn. Die angst heeft me te lang dwars gezeten en bezig gehouden. Hoewel ik veel geleerd heb, zowel inhoudelijk als over mezelf, ben ik blij dat het - eindelijk - klaar is. En ben ik best wel trots! Nu ga ik stoppen met roken, een leuke baan, fijne woning en dito man zoeken. Ik heb er zin in!

Bedankt lieve mensen voor alle gezelligheid, adviezen, aanmoediging, oppas en liefde!

Anna, Anne, Claudia, DJ, Els, Erik, Fleur, Irene, Jasmijn, Jasper, Joris, Lisette, Lodewijk, Marco, Mama, Margot, Mila, Oma, Ralf, Rogier, Sara, Sebastiaan, Senna♥, Simone, Sophie, Toon, Wilco, Yoeri

Amel.

Abstract

The aim of this study was to investigate an embodied account on the balance-scale task (Siegler, 1976) in children (*N* = 28) age 5 – 6 years (*M* = 5.9). Half of them received embodied training, by means of 15 min active balance training, half of them a non-embodied training, observing outcomes of balance-scale problems. Before and after training children were asked to solve 32 balance-scale problems. Results showed that the embodied training did not benefited performance whereas the non-embodied training did positively affect performance for the problem types conflict-distance, distance and weight. The rules Siegler defined did not accurately described performance. Furthermore, postural sway movement of the children was measured with a Nintendo Wii balance board as force platform (Shih, Shih, & Chu, 2010). Recurrence quantification Analysis (RQA), a relative new, non-linear method for examining the time evolution of data series (Webber & Zbilut, 2005) was applied to examine differences in temporal structure of postural sway between performance level, and between solving problems and standing quiet. RQA revealed changes in the dynamical properties of postural sway brought about by concurrent performance of the balance-scale task. Among the observed changes were differential effects on the AP and ML components of postural fluctuations. The results of RQA suggested that DET, MeanDL, MaxDL, ENT, and LAM were lower in the ML-direction during standing quiet than while solving balance-scale problems whereas no differences were found for RQA-measures in the AP-direction. Besides that, DET, MaxDL, ENT, and LAM were significant lower at pre-test in the High Performance Group in the ML-direction, and in the AP-direction DET, ENT, LAM, MaxVL were significant lower in the High Performance Group than in the Low Performance Group. These differences were gone at post-test. These findings suggest that postural sway movement supports problem solving in the balance-scale task. Further experimental investigations are needed to better understand this relation. It is thereby recommended to include all the six balance-scale problem types and to prolong the duration of the embodied training.

Keywords: balance-scale task, postural sway, embodied cognition

Almost 8% of the primary schools in the Netherlands do not offer education of basic quality (*De staat van het onderwijs,* 2010). In case of special primary schools this number is even higher, more than 22% of these schools do not meet the standards of basic quality as established by the Dutch government. These numbers have heightened the need to improve primary school education. For this reason the Dutch government started a research program to find out whether physical activity can improve school results in primary school children ("Effect bewegen," 2011). The study presented here follows the idea that physical activity can enhance learning abstract concepts in children within a domain not previously investigated; the balance-scale task (Siegler, 1976). This paper starts with a reflection on traditional cognitive science and will then outline the theory of embodied cognition. Next it proceeds with an example to illustrate how embodied cognition can in some cases explain cognitive processes better than standard cognitive science. The balance-scale task is then described, as this forms the basis of the research. After an explanation of postural sway and the way it reflects cognitive processes, it is explained why recurrence quantification analysis (RQA) is considered the best method for analyzing postural sway data. The introduction ends with three research questions and the corresponding hypotheses.

Western philosophers have for long regarded mind and body as two entirely different entities (Aristotle in de Anima; Descartes, 1641; Plato in Phaedo). Where the mind was everything, the body was merely seen as just a shell for the mind, or worse as Plato even stated: The mind is imprisoned in the body (Phaedo, 83a). This dualism and the supposed superiority of the mind over the body are still present in traditional theories of cognition. Human beings are there seen as information processing systems; they receive input from the environment, process that information in their brains, and act upon the decision reached (Dawson & Zimmerman, 2003). This is a solipsistic perspective; the focus is on the mind and the body plays a minor role. In this view the boundaries of cognition are set by the brain (e.g., Hurley, 1998) where neurons represent things in the world (Newell & Simon, 1961). Many psychologists share this sentiment. But as shown by research in cognitive development (e.g., Smith, 2005; Thelen, Schöner, Scheier, & Smith, 2001) artificial intelligence (e.g., Brooks, 1989, Clancey, 1997; Mataric, 1992) and grounded or embodied cognition (e.g., Barsalou, 2008; Clark, 1999) locating the source of complicated and adaptive behavior exclusively in the brain does not explain this behavior to a sufficient degree. So, luckily, a breath of fresh air is blowing as we will see in the following part.

In recent years there has been an increasing interest in the role of the body within cognitive processes (Evans, Davies, & Rich, 2009). Some illuminating findings about the body and its role in cognition are demonstrated in studies such as the one by Ping and Goldin-Meadow (2008) who showed that gesturing in instruction can help learning arithmetic in first graders and vice versa; requiring children to gesture can help to retain knowledge (Cook, Mitchell, & Goldin-Meadow, 2008). Another study found that children's gestures were an indicator of readiness to learn and of cognitive gains in a balance-scale task (Pine, Lufkin, & Messer, 2004). Thomas and Lleras (2009) showed that they could implicitly guide adults towards insight in problem solving by directing their actions. What all these studies have in common is that they are based, to a greater or lesser extent, on ideas of embodied cognition.

Embodied cognition is a rich and growing research program which emerges in diverse subfields of cognitive science. It can be seen as a direct response to the standard cognitivist view of the mind, which conceptualizes cognitive functions in terms of the so called computer metaphor (Shapiro, 2011). The field of embodied cognition is rapidly changing and embodied accounts have been formulated in different ways. But at the heart of all these approaches lies the embodiment hypothesis; the idea that intelligent behavior emerges in the interaction between brain, body and world, which are seen as equally important factors, and as a result of sensory-motor activity (Smith, 2005). Since the embodied cognition research program is in its early stages, the approach does not have hard and fast tenets that are agreed upon by all embodied cognition theorists (http://www.iep.utm.edu/embodcog). In his book *Embodied Cognition* Shapiro (2011) therefore aimed to introduce and summarize the central themes of embodied cognition. Shapiro distinguishes three themes, in no particular order of importance, which are prominent in the embodied cognition literature: Conceptualization, replacement, and constitution.

Conceptualization entails the idea that cognition depends upon the kind of experiences one has from having a body; sensorimotor capacities of an organism's body determine, limit or constrain our cognitive functions (that is, the way in which we can conceptualize and categorize; Barsalou, 2008; Thelen & Smith, 1994; Varela, Thompson, & Rosch, 1991). Thus, organisms that differ with respect to their bodies would differ as well in how they understand the world (Shapiro, 2011). In other words, the nature of the human mind is determined by the form of the human body and vice versa; our form of the body also partly determines the way the world appears to us. This is related to the next theme which is replacement.

Replacement deals with the belief that a body in constant real-time interaction with its environment replaces the need for computational and representational processes (Shapiro, 2011). Embodied cognition does not assume that we need internal representations in order to learn and understand the world (Smith, 2005). That is, cognition can be explained without mental processes proceeding algorithmically, operating on symbolic representations (Shapiro, 2011). Instead, cognition is constructive; humans actively construct a sensorimotor representation that is based on environmental features that are directly relevant to the goal-directed action it is currently performing (Shapiro, 2011). Because humans can sense their environment, it should be unnecessary for them to build an internal model of the world (Dawson & Zimmerman, 2003).

The last idea that Shapiro describes is *constitution*. This theme deals with the idea that cognitive processes extend beyond the brain; the body and world play a rather constitutive than merely a causal role in cognition (Shapiro, 2011). More radically one can say that cognition is a form of bodily activity. The mind, on this account, is not bounded by the brain, but extends into the environment of us (Clark & Chalmers, 1998). To illustrate the difference between embodied cognition and the classical cognitive science, and to show that it can help to understand processes difficult to grasp with traditional methods, an example of one of the best-studied tasks of infant cognition, the so-called A-not-B task will be described next.

A-not-B task

The A-not-B error was first described by Piaget (1954) who devised the A-not-B task to assess when infants acquire the concept of object permanence; the belief that an object is something that endures and exists in time and space independently of one’s own actions on it. The task has been performed in many variations, but all of them have the following general set up (Thelen et al., 2001); the infant sits in front of a table on which two identical boxes, A and B, are placed. The infant observes an experimenter hiding an attractive toy under a box at location A, within the infant’s reach. After a 3- to 5-second delay the infant is allowed to search. This ‘A-trial’ is repeated several times, with the infant typically finding the toy under A on each occasion. Then there is the critical switch in the task, the ‘B-trial’; now the experimenter hides the toy at a new location, B, also within easy reach of the baby. A delay is again imposed and then the infant is allowed to reach. Infants 12 months or younger make a peculiar “error”; they do not reach to B, where they saw the object disappear, but they persevere in reaching back to A, where they had found the toy previously (Piaget, 1954).

Traditionally, the explanation for this A-not-B error, and thus cognitive development, is attributed to infants’ lack of object concept. In this view the shift in cognitive development between 8 and 12 months of age is explained as a stage in which infants form the concept of object permanence (Piaget, 1954). Although there is contemporary agreement that Piaget’s account on the A-not-B task is not correct, more recent interpretations still include other static mental structures such as an maturing inhibitory mechanism (Ahmed & Ruffman, 1998) or maturing prefrontal structures (Baillargeon & Graber, 1988), and the not yet developed ability to act on one object in relation to another (Munakata, McClelland, Johnson, & Siegler, 1997).

Esther Thelen, pioneer in embodied cognition, calls such explanations problematic, since they only push the level of explanation back a step. Thelen et al. (2001) argue that in order to fully understand how change in cognitive development occurs, these theoretical mechanisms must also be explained. Moreover, these accounts do not explain why infants of 12 months or younger do not make the error when the A-not-B task is altered, for example by a shorter delay time between observing and reaching (Diamond, 1985). Furthermore, these “explanations” either underplay or completely overlook environmental factors; cognition is segregated from perceiving and acting.

To give a unified explanation for the A-not-B error, Smith, Thelen, Titzer, & McLin (1999) took an embodied account to try to understand infants’ behavior in the A-not-B task. They focused on what infants actually *do* and *have done* in the task instead of what infants *have* and *don’t have* as enduring concepts, representations, or deficits. The starting point here is what infants do in real time; they visually elicited reach repeatedly to one location and then return to the original location when the goal has changed. These researchers experimentally manipulated the A-not-B task on these factors to see if they could make 10-month-old infants perform like 12-month-old infants. In one of many experiments they shifted the infants’ posture (sitting or standing) between A trials and B trials. This manipulation did make 10-month-olds search correctly (Smith et al., 1999). The error in the A-not-B task, they argue, arises from interacting factors, including the infant’s history of reaching toward A, the salience of the hidden object, the duration of the pause between hiding and searching and the motions necessary to retrieve the object.

Thelen et al. (2001) and Smith et al. (1999) emphasize that the history of reaching is input for every new reach; in this way the past behavior is self-reinforcing. Switching body posture; standing instead of sitting, for the B-trial made the prior experience of searching in location less salient to the infant because for reaching from a standing position a new motor plan is necessary for reaching. Shapiro (2011) compared the behavior of the infant with a road map that is more likely to fold along its old crease lines than new ones. Instead of maturing brain matter, the shift between reaching correctly to B instead of A, appears to be tightly tied to self-locomotion, which also emerges in this same period; infants stop making the error when they begin to self-loco mote (Smith, 2005). Recall the theme conceptualization mentioned earlier, this A- not B-task shows that cognition indeed is bound to the world through the body, it depends upon the kind of experiences one had (Smith, 2005). Object concepts are irrelevant, no cognitive stage or whatsoever is necessary to explain the behavior in the task. The point: If a solipsistic assumption rests at the heart of cognitive development then the resulting explanations are inaccurate! Cognition is not passive retrieval; instead it is an active construction based upon human embodied goal-directed actions in real time (Smith, 2005).

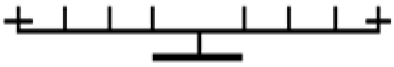
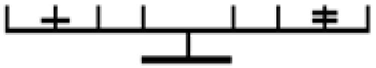
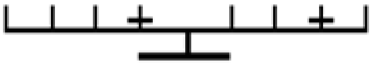
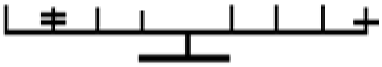
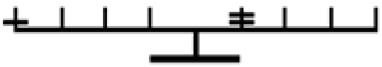
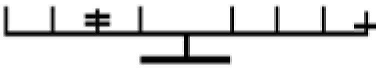
An objection to an embodied view of cognitive development is that it might be limited, it may only be able to account for low-level, goal-directed action that is, walking, reaching (etc.) and not for higher-level cognitive abilities (Lockman, 2001; Marcovitch & Zelazo, 2001; Markman, 2001; Sophian, 2001). To challenge this objection, an embodied account on another famous and often used task to study infant cognition, the balance-scale task (Siegler, 1976), will be investigated in the current study. So-called “higher-level cognitive abilities” are believed to be necessary in this task (e.g., Messer, Pine, & Butler, 2008). The balance-scale task is explained in the next paragraph.

Balance-scale task

The balance-scale task was originally introduced by Inhelder and Piaget (1958) as a method for assessing stages of cognitive development. Siegler (1976) developed the balance-scale task in its present form and since then balancing tasks have frequently been used as a reliable test bed for theories of cognitive development (e.g., Boom, Hoijtink, & Kunnen, 2001; Karmiloff-Smith, 1992; Maas & Jansen, 2003; Messer et al., 2008). In this task a child sees a simple balance scale and has to judge which way the balance arm will tip or if the scale will balance. Weights can be placed on the eight pegs, which are situated on equal distances from each other on both arms of the scale. Siegler (1976) described six different types of balance-scale problems, which are defined by the combination of weight and distance from the fulcrum, Table 1 shows these different problems. Balance problems (B) have equal weights at the same distance on both arms. For distance problems (D) weight is constant, but distance is different, so the side with the farther distance goes down. Weight problems (W) have different weights at the same distance on both sides, so that the side with the most weight goes down. Conflict problems have a different number of weights and distances on each side of the fulcrum and are therefore defined by their outcome: The side with more weight falls (conflict-weight, CW), the side with the greater distance falls (conflict-distance, CD), or the scale remains balance (conflict-balance, CB).

Table 1

Siegler's Rule Model with Predicted Response Pattern on Problem Types and Examples of Balance-scale problems

		Rule model			
Item types	Example	Rule I	Rule II	Rule III	Rule IV
Balance (B)		1.00	1.00	1.00	1.00
Weight (W)		1.00	1.00	1.00	1.00
Distance (D)		.00[a]	1.00	1.00	1.00
Conflict-weight (CW)		1.00	1.00	.33[c]	1.00
Conflict-distance (CD)		.00[b]	.00[b]	.33[c]	1.00
Conflict- balance (CB)		.00[b]	.00[b]	.33[c]	1.00

[a] Answers that the scale will remain in balance
[b] Answers that the scale will fall to the side with more weight
[c] Guesses the answer (chance level)

As with the A-not-B task, Piaget (1963) and Siegler (1976) hypothesized that children go, according through their ages, through a series of developmental stages. Here again the idea is that behavior is characterized by cognitive rules (Reber, 1993); to succeed in this task one has to identify the relevant task dimensions (weight and distance) and to understand their multiplicative relation. The responses to the balance-scale problems have been classified into a set of four rules which consists of step-like procedures that become more complex with development (Siegler, 1976). First, children between ages 5 and 7 compare only the amount of weights on each side. They predict that the scale will fall to the side with the largest number of weights if the numbers are unequal, and that the scale will remain in balance if the weights are equal (Rule I). Children 8 years or over employ Rule II, they also focus on weight and will consider distances but only in case where the weights are equal. At the next level, children age 10 years realize the importance of both weight and distance, but do not know how to combine them (Rule III) and so they guess. Finally, children are able to reason using proportions and can therefore discover the torque rule; multiplying distance by weight and compare the products of both sides (Rule IV) which results in the correct response to all types of balance-scale problems (Jansen & Maas, 2002). Determining rule use is assessed by testing the child on a set of balance-scale problems, a child is considered to use a particular rule based on her responses. Siegler and Chen (2002) gave a boundary of correct responses of 80%, and consistent with the predicted proportions concerning accuracy of each rule as summarized in Table 1.

The balance-scale task is undoubtedly the best-known task used to investigate proportional reasoning (Jansen, Raijmakers, & Maas, 2007). For solving this task higher cognitive processes are necessary, to fully succeed one has to able to apply the law of torque (e.g., Messer et al., 2008). However, as Smith et al. (1999) did with altering task constraints in the A-not-B task, and thereby making 10 months old infants perform like older infants, Ferretti and Butterfield (1992, 1985) altered constraints in the balance-scale task. They enlarged the differences between the products of weight and distance on each side of the balance, and in this way children who were classified as following Rule I, not only took the weight dimension but also the distance dimension in consideration when the torque differences were big enough, thereby following Rule II.

Following Ferretti and Butterfield (1992, 1985), in the present research a shift from Rule I to Rule II is tried to be accomplished in children of 5 – 6 years of age by means of learning in an embodied way about balance. Smith et al. (1999) stated that representations can be replaced for the kinds of experiences one has that come from having a body with particular perceptual and motor capacities. This falls within the domain of what Shapiro (2011) calls replacement. Thomas and Lleras (2009) already demonstrated that directed actions can positively influence problem solving of the Maier’s two-string problem, in adults. It is unknown however if replacement for problem solving in the balance-scale task, for which the higher cognitive function multiplying is needed, is possible with bodily activity. The first question this study therefore addresses:

1) Can an embodied experience of balance improve balance-scale task performance of primary school children?

Hypothesis (1): The experience of balance with one's own body can replace higher cognitive functions needed for solving the balance-scale task. Children who bodily experiences balance are expected to perform better on the balance-scale task than children who passively observe outcomes of balance-scale problems, especially regarding conflict-distance and distance problems. According to Siegler (1976) children in the age of five to six year are yet not able to solve those two types of problems correct.

Furthermore, in order to investigate an embodied account on the balance-scale task, the postural sway pattern of children will be measured while they solve balance-scale problems. For every second, our own body balance is regulated by the central nervous system (Balasubramaniam & Wing, 2002). The following section describes and elaborates on recent research on postural sway, and will explain why RQA is the best method to analyze postural sway.

Postural sway

When a person is standing quietly upright, very small internal (e.g., heartbeat) and external (e.g., gravitational force) forces are constantly acting on the body and cause unbalance. Our body adjusts with neuromuscular irregular, to maintain balance (e.g., Balasubramaniam & Wing, 2002) which results in, for the eye, imperceptible body sways (Duarte & Freitas, 2010). These constant low-amplitude responses are called postural sway and can be made visible, as shown in Figure 1, by the recording of the mean location of the gravitational force or pressure acting on the body, respectively center of gravity (COG), and center of pressure (COP), both measures for postural sway (Visser, Carpenter, Kooij, & Bloem, 2008).

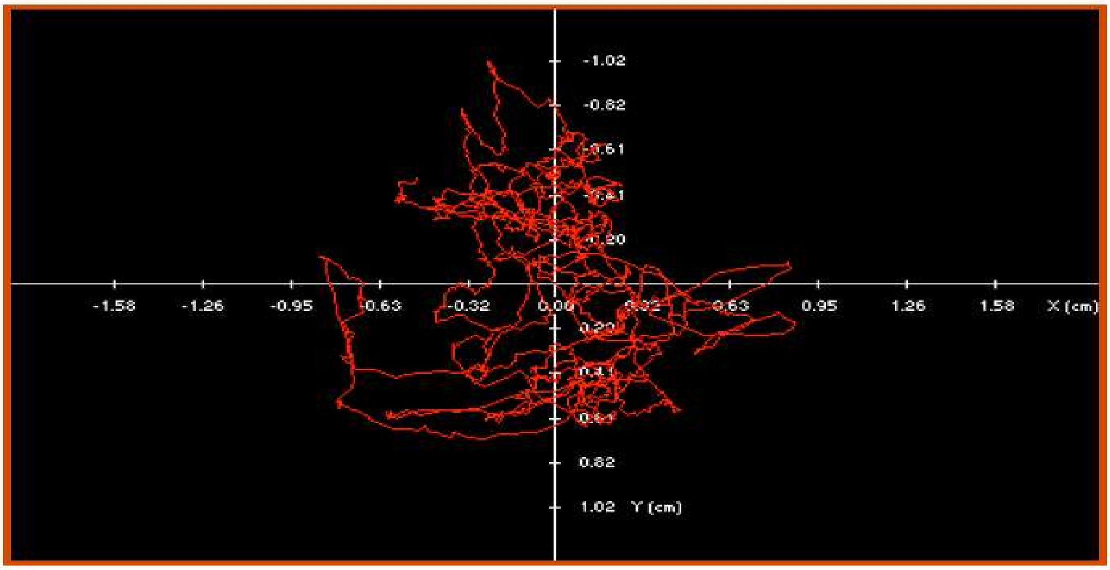


Figure 1. A sample of a map of the center of pressure (COP) in the AP direction (Y-axis) versus the ML direction (X-axis) (Pellecchia & Shockley, 2005, reprinted without permission). COP path is shown for an individual standing upright 30 s. To record postural sway it is common to use a force platform (Duarte & Freitas, 2010) where each change in COP affects the activation of the pressure or force sensors in the platform. Postural sway can be calculated from the output of the set of sensors, as a two-dimensional time-varying quantity. This results in two separate time series, one for movement in the anterior-posterior direction and one for the medio-lateral movement. The path traversed by the COP over time reveals the dynamic nature of postural control.

Development of the postural system begins in early infancy, around 9-months of age (Witherington et al. 2002). Between 4 and 6 years of age the postural system is in a sort of transition period and more adult-like postural responses begin to emerge (Woollacott & Shumway-Cook, 2002). The postural sway system is flexible; Zech et al. (2010) showed that postural stabilization can be improved by balance training.

Although postural sway seems a simple adjustment of our body, much information can be extracted from it as the following research shows. The postural sway pattern can assist in differential diagnosis between brain diseases; by comparing the postural sway pattern patients with cerebellar anterior lobe disease can be distinguished from patients with orthostatic tremor. Besides that, orthostatic tremor can be diagnosed using postural sway measures (Visser, Carpenter, Kooij, & Bloem, 2008; Yarrow, Brown, Gresty, & Bronstein, 2001). Another example is the prospective study of Swanenburg, Bruin, Uebelhart, and Mulder (2010), which showed that postural sway variables are of relevance in predicting fall risk in elderly individuals. Fournier et al. (2010) recently investigated postural control in children with Autism Spectrum Disorders (ASD). They came to the conclusion that children with ASD have a significantly greater normalized sway area compared to typically developing children.

It is yet unknown why these differences in postural sway pattern exists, but the above described research shows that postural sway behold more than just simple behavior and enabling upright standing. Furthermore, numerous research (Haddad, Emmerik, Wheat, & Hamill, 2008; Shockley, Santana, & Fowler, 2003) showed that it is ineffective for the success of a suprapostural task to maintain a constant postural configuration. This led to the conclusion that postural sway is not only an end goal in itself, but also a facilitator of the goals of suprapostural activity.

Only in the last decades, the analysis of the relationship between postural sway and cognition has gained attention in the literature. Various authors have tested the effect of different cognitive tasks on the execution of postural tests (Laufer, Ashkenazi, Josman, 2008; Pellecchia, 2003; Schmid, Conforto, Lopez, & D'Alessio, 2007; Stins, Michielsen, Roerdink, & Beek, 2009). The results obtained confirmed a significant interaction between cognitive processes and balance performance; COP path length and COP sway measures generally increased during a cognitive task in comparison when standing quiet (see review by Woollacott & Shumway-Cook, 2002). Because variability in postural sway pattern has for long been considered as random noise (Mazaheri, Negahban, Salavati, Sanjari, Parnianpour, 2010), in these studies postural sway was assessed by traditional linear statistics. However, postural sway exhibits characteristics of non-stationary; its properties change over time (Duarte & Zatsiorsky, 2001; Shockley et al., 2003). Non-stationarity violates the assumptions of many statistical analyses (Rossi, 2010; see also Campell & Molenaar, 2008). The embedding theorem (Takens, 1981) states that knowledge of the dynamics of a complex system may be obtained through the measurement of a single time series. In other words; through the interactive nature of dynamical variables it is possible, given one time series of a single variable, to recover the whole dynamical structure of the system. Based on this assumption a non-linear method of data analysis, named recurrence quantification analysis (RQA), was established by Zbilut and Webber in the early nineties (Marwan, 2008). This modern tool for the analysis of non-linear dynamical systems can be used to identify subtle patterns of recurrence in data series (Webber & Zbilut, 2005) and can give more insight in the mechanism of postural strategies (Nardone & Schieppati, 2010).

In short, a system's behavior (i.e. attractor state) is reconstructed by using time-delayed copies of a single time series as surrogate variables. This plot is called a higher dimensional phase space (for a detailed tutorial, see Webber & Zbilut, 2005). Points in a phase space are considered recurrent if they fall within some specified distance of one another. RQA examines these recurrent values and is in this way able to detect dynamics that are intrinsic, although not apparent, to the single, one-dimensional time series (Pellecchia & Shockley, 2005).

Although RQA seems a more suited analysis than traditional statistical methods, in the context of postural sway and cognition non-linear techniques have only recently been pursued (Pellecchia & Shockley, 2005; Riley, Baker, Schmit, & Weaver, 2005). Riley et al. found that mediolateral postural-sway variability decreased as the cognitive load increased. They suggested that cognitive activity draws away attention that interferes with postural control. That RQA is able to identify structures in postural sway which are not evident with linear methods, was also recently shown by Pellecchia and Shockley. They analyzed the same center of pressure data set with a conventional, linear method and with RQA and compared both outcomes. The results of the RQA suggested that the postural control system adapts in response to different attentional requirements. This conclusion could not have been reached with linear methods, where temporal patterns are ignored (Pellecchia & Shockley, 2005). So far, the issue whether cognitive activity during the balance-scale task is associated with changes in the profile of postural sway has not been examined in any existing studies. The next question this study addresses to further investigate an embodied account on problem solving in the balance-scale task:

2) How does the presence of the balance-scale task impacts the postural strategies in children?

Hypothesis (2): Based on the previously discussed research, a decrease in the temporal structure of the postural sway pattern, as defined in RQA measures, is expected for all children when solving balance-scale problems in comparison with standing quietly.

The interaction between cognition and postural sway is most often explained in terms of divided attention (e.g., Kahneman, 1973; Riley et al., 2005). However, as Smith et al. (1999) showed elegantly with the A-not B task, empirical investigations of cognition must begin with a consideration of the contribution of the body to our interactions with the world (Legrand, Grünbaum, & Krueger, 2009). Reasoning from an embodied perspective, it could be the case that we “use” our own body, which “knows” by experience all about balance, in the context of solving balance-scale problems without any higher cognitive functions needed. To make a first attempt to verify this hypothetical position, the last question this study addresses is therefore:

3) Is there a relation between the temporal structure in postural sway and the level of balance-scale task performance in children? If so, which direction does this relation have?

Hypothesis (3): A difference in the temporal structure in postural sway is expected between children who perform above average and children who perform below average on the balance-scale task. Children with a comparable postural-sway pattern are expected to perform roughly the same on the balance-scale task.

Method

Design

A matched-group design with pre-test, training and post-test, was used in this study. The Training Group had two between subject conditions; embodied (EM) and non-embodied (NE) and were matched over conditions based on sex, and mean and standard deviation of the score on pre-test. The training took place three days after the pre-test, directly followed by the post-test. The entire study was completed within a two weeks period. To compare the postural sway pattern between performance level, a median split based on performance on the balance-scale task was used to divide children into High Performance Group or Low Performance Group, separately for pre-test and post-test.

Participants

Twenty-eight children (19 girls, 9 boys *M* age = 5.9 years, age range: 4.9-7.0 years) were recruited at a Waldorf primary school in Nijmegen, the Netherlands (see Table 2, for Training Group characteristics). Parental authorization was requested through an informed consent form. All children completed the study. Due to a technical error part of the data (postural-sway data, see below) from 13 children was not registered during the post-test. All children were rewarded with a little present for their participation and a wooden balance scale was given to the entire class.

Table 2

Characteristics of Training Group

	embodied training (*n* = 14)	non-embodied training (*n* = 14)
Age	*M* = 6;0	*M* = 5;11
Sex		
Female	9	10
Male	5	4
Height	1.19 m	1.17 m
Body Mass	20.9 kg	20.3 kg
Preference hand	10 right-handed	13 right-handed

Materials

Balance scale. A plastic balance scale similar to that used by Siegler (1976) was used for demonstration and for making photographs. Figure 2 presents a picture of this scale. The arm of the balance scale was 71 cm long, with four equidistant pegs on each side of the fulcrum. The arm could swing from the point of attachment to the fulcrum 24 cm above the fulcrum's base. The pegs were spaced 6 cm apart, each peg was 8 cm high and could contain up to six weights. Equally heavy metal weights of ten different colors, to increase distinguish ability, were used. Each weight had a hole in its middle, weighed 78 g and measured 5 cm in diameter. Tipping of the balance scale was prevented by placing two removable blocks under the scale's arms as can be seen in Figure 2.

Figure 2. Photograph of the balance scale with a conflict-distance problem (on basis of Siegler, 1976). The scale is immobilized by two removable blocks.

Balance-scale problems. In the current study only four of the six original categories of balance-scale problems (Siegler, 1976) were used; (a) *balance problems*, which have equal weights at the same distance to the fulcrum; (b) *conflict-distance problems*, which have a different number of weights and distances on each side of the fulcrum and are therefore defined by their outcome; the side with the greater distance but with fewer weights goes down. Figure 2 provides an example of a conflict-distance problem; (c) *distance problems*, where the weight is held constant, so the side with the farther distance goes down and, d) *weight problems*, where distance is held constant, so that the side with the most weight goes down. These particular categories were chosen because for both problem types distance and conflict-distance a progress in performance between pre-test and post-test was possible according to the rule model of Siegler (1976). Balance and weight problems were included to give children sufficient success experience, to continue with the task (particularly in the pre-test).

For each category 16 problems were created (see Appendix A for all 64 balance-scale problems) based on the experiment by Siegler (1976). On one-half of the problems of each category there were weights on the fourth peg, the farthest one from the fulcrum, as well as on others closer to it. On the other one-half the weights were distributed only over the first three pegs. The number of weights for each problem was between two and ten. There were no substantial differences between the average numbers of weights in the four categories, as can be seen in appendix A. The balance-scale problems were split in two equal sets: 32 for the pre-test and 32 for the post-test, and were presented in random order, so in the end, each child saw all 64 problems. For the training in the NE condition an additional and similar set of 32 problems was created.

Balance board. In order to measure the children's Center of Gravity (COG) in a quantitative way a Nintendo Wii balance board (Nintendo of America Inc., Redmond, Washington) was used as a force platform (see Capello, Lenzi, & Chiari, 2004; Clark, Bryant, Pua, McCrory, Bennell, & Hunt, 2010; Shih, Shih, & Chu, 2010). The Nintendo Wii balance board (WBB) has a useable surface of 45.0 cm x 26.5 cm and contains four pressure sensors which are situated at each corner. These sensors measure the pressure and the moments of pressure acting on the WBB. The resulting time series were transmitted via Bluetooth to the laptop that was interfaced with the WBB using specifically written software IviewBalansExperiment (version 11, 2007, Voogd, H., the Netherlands). The WBB was positioned about one meter from the laptop on which the balance-scale problems were presented (Duarte & Freitas, 2010). Data was sampled at a rate of 100 Hz (Duarte & Freitas, 2010); a 12 s trial period therefore yielded 1200 data points. The WBB was concealed with a cover indexing foot position to establish standardization between children and to achieve a correct position for measuring pressure (Chiari, Rocchi, & Capello, 2002).

Remote control. Children answered balance-scale problems (see below) using a Nintendo Wii-remote control device (Nintendo of America Inc., Redmond, Washington). This device has multiple buttons, in this study only the A-button was used. An infrared camera in the tip of the Wii-remote control and an infrared LED emitter placed above the laptop monitor allowed the children to interact with items on the laptop monitor. The Wii-remote control was connected to laptop via Bluetooth using software library WiimoteLib version 1.7 (Peek, B. http://Wiimotelib.codeplex.com/releases/view/21997) in order to present stimuli and measure responses (Lee, 2008).

Procedure

Baseline measurement. Children were collected in pairs from their class and brought individually to two empty classrooms. There each child was instructed by an experimenter to stand quiet (Zok, Mazzà, & Cappozzo, 2008) in their socks on the WBB for a period of 12 s. During this period the baseline COG of each child was measured with the WBB while the child was fixating on a red dot on a white monitor (Figure 3) which was placed at the height of the children's eyes in upright position. Table 3 gives an overview of the study.

Table 3

Time Overview of this Study

Moment	Procedure
1 Fixation pre-test	Baseline measurement of postural sway, fixating on a red dot for 12s
Practice trial	Instruction and exercise with two simple balance-scale problems
Pre-test	32 balance-scale problems, each presented for 12s
2 Training	Embodied training / non-embodied training
Practice trial	Instruction and exercise with two simple balance-scale problems
Fixation post-test	Baseline measurement of postural sway, fixating on a red dot for 12s
Post-test	32 balance-scale problems (other than pre-test) each presented 12s

Note. There was a delay of three days between moment 1 and 2. The entire study was completed within a two weeks period.

Pre-test and post-test. Pre-test and post-test followed the same procedure. Once baseline COG was determined the experimenter showed the real balance scale to the child and she was told that she was going to see some photographs of this balance scale. The child's task was to predict whether the scale on the photograph would balance, tip to the left or tip to the right if the blocks underneath the scale would be removed (see Appendix B for the complete Dutch instruction).

Next, the child was asked to stand on the WBB, hanging one arm by her side and the preference arm bowed, in this way the remote control was directed to the laptop. Figure 3 shows the configuration of this study. A child received prompts to perform correct standing posture from the experimenter, after she showed incorrect standing position for more than 10 s during the session.

Prior to the actual data collection, the child performed two practice trials to make sure that she understood the task. After that the child was presented a photograph with a balance-scale problem on the monitor for 12 s. Next, three graphical response options (left, balance, right) appeared on the monitor (see Figure 3) and remained there until a response was recorded. Children answered by pointing the Wii-remote control to the possibility they thought was correct, and then pressed the A-button. After an inter-trial interval of 1 s, the next photograph was presented to the child. During the entire procedure COG was recorded by the WBB. Children did not receive feedback whether their answer was correct, but were encouraged to continue when necessary.

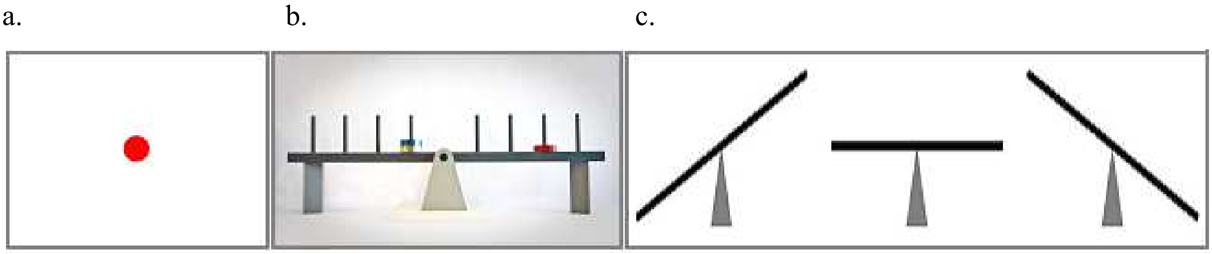


Figure 3. The configuration of this study with three screen snapshots (a, b, c). Children stood on the Nintendo Wii balance board (WBB) and a laptop was placed at the height of the child's eyes about one meter from the child. At fixation pre-test and fixation post-test COG was measured during the presentation of a red dot (a). 32 Different photographs with balance-scale problems (b) were presented for 12 s during pre-test and post-test. After each problem a screen with three answer options (c) appeared. Children answered by pointing the Wii-remote control to the answer they thought was correct, and then pressed the A-button. After an inter-trial interval of 1 s, the next photograph was presented. During the whole procedure COG was recorded by the WBB.

Training Group.

embodied training. In order to learn in an embodied way about balance, training was given to the children in the Embodied Training Group (EM). The main purpose of this training was to let children experience the concept of balance with their own bodies. In pairs, children received 15 min of training in a physical education room where they performed exercises. The exercises were based on the four types of balance-scale problems used in pre-, and post-test (see Appendix C for a complete overview of the exercises). Children were instructed to walk back and forth on a 30 cm high, 20 cm wide and 400 cm long wooden balance beam with weights in their hands. Bottles were used as weights and were either empty (28 g), filled with water (550 g) or with sand (800 g). Every time the child returned to the end of the beam she was directed to take a different arm position. There were three possibilities of arm position: (a) arm extended sideways, (b) arm in a 90° angle with the hand pointing upwards, and (c) arm extended with the hand resting on the shoulder (for two arms this gave six possibilities; aa, ab, ac, bb, bc and cc). Of the total of 32 exercises, 28 were performed in a static manner; arm position was instructed according to one of the six possibilities described above, and stayed that way during walking on the balance beam. In the other four exercises, children were constantly bending and extending their arms, while walking over the beam (e.g., a-c-a-c). Directly after this training the post-test was conducted.

non-embodied condition. In contrast to the EM condition, who experienced the concept of balance in an active bodily way, children in the NE had a passive 15-min training in which they observed the outcome of balance-scale problems. In pairs, children were presented 32 balance problems, eight from each balance-scale problem category. The problems were presented one by one, on the real balance scale, and were different than the balance-scale problems used for the pre-test and post-test. For each problem, the children were asked to predict whether the scale would balance, tip to the left, or tip to the right if the blocks were not there (see Appendix D for all problems in the trainings phase and the complete instruction in Dutch). After the two children made a prediction, blocks were removed by the researcher. In this way children observed the outcomes of balance-scale problems without getting any further explanation. Post-test was conducted directly after this training.

Data analysis

Scores on balance-scale problems. In order to test hypothesis 1 (EM performed better than NE after training) a first step was to examine performance on the balance-scale task. To do so, the number of correct answers for each participant for the pre-test and post-test separately was recorded (0 = *incorrect*, 1 = *correct*). The proportion scores for both the pre-test and post-test were subjected to repeated measures analysis to determine if there was a difference in performance between pre-test and pos-test for the EM and the NE condition after the trainings phase. A relative difference score was then calculated (x_{post} - x_{pre} / x_{post} + x_{pre}) and arcsine transformed, to meet the assumptions of parametric statistical tests (Rossi, 2010). With these transformed scores (reldiff1) another ANOVA was conducted to compare the progress between EM and NE. Data management and analysis was performed using SPSS Version 15.0.1.

Postural-sway data. Postural-sway data collection for each participant's trial began directly after the balance-scale problem was presented. Before entering the data in analysis, the first 50 samples for each response period were deleted, as well as the final 100 samples, leaving 1000 data points for the time-series analysis. In this study the center of gravity (COG) was chosen as a measure to quantify postural sway. Postural sway was calculated using the two time series of the two-dimensional projection of the COG on the floor, in the medial-lateral (ML; side-to-side) and anterior-posterior (AP; back-and-forth) directions. Because postural-sway data is non-stationary, irregular and non-periodic (Mazaheri, et al., 2010; Shockley et al., 2003) recurrence quantification analyses (RQA), was chosen to assess the time-dependent structure of postural fluctuations. RQA has the advantage that it requires no assumptions regarding the size, distribution or stationarity of the data (Webber & Zbilut, 2005). Since RQA is a relatively new analytical method in the behavioral sciences, the procedure and measures of RQA will be explained in more detail below.

The method of recurrence plots is a mathematical tool inherent to the dynamical system approach (Aβmann, Romano, Thiel, & Niemitz, 2007). A dynamic system is any system that undergoes change over time (Shapiro, 2011). In RQA, the system's behavior is reconstructed in phase space by using a certain number of time-delayed copies of a single time series as surrogate variables. The number of copies (or surrogate dimensions), determines the dimension of the phase space. A recurrence plot is a visualization of this phase space, in which the matrix elements correspond to those instances at which the state of the system recurs (Aβmann et al.).

To obtain a recurrence plot, the first step is to determine appropriate values for the input parameters; (time) delay, embedding dimensions, radius and minimum line length (Webber & Zbilut, 2005). Delay refers to the temporal separation between the copies of the two time series that are used as surrogate dimensions in reconstructed phase space. The delay and embedding dimension were determined from the time series using respectively mutual information and false nearest neighbors' techniques (see e.g., Webber & Zbilut, 2005). In this study, the delay was thirty data points. The number of embedding dimensions was set to seven. Next, a radius threshold that kept the total percent recurrent point at 5% was chosen (i.e. fixed recurrence rate; Webber & Zbilut, 2005). The radius determines the distance threshold over which two points are considered recurrent, so points that fall within this specified distance of one another are scored as being recurrent (Aβmann, et al., 2007). So in this study the radius varied between time series to generate a constant 5% recurrence. A number of three recurrent points in a row was used to determine the minimum length of a diagonal line in the recurrence plot (Pellecchia & Shockley, 2005). All RQA parameters (except radius) were kept fixed for the entire dataset, in order to make comparison between subjects and conditions possible. The RQA was then executed and resulted in a recurrence plot.

Recurrence plots exhibit typical small patterns as single black dots, diagonal structures and horizontal or vertical black lines, which are related to and indicative of the system's dynamical behavior. These lines all consist of recurrences points that fall within a specified distance of one another (Aβmann, et al., 2007; Webber & Zbilut, 2005). From these recurrences, several other dynamic measures can be obtained to quantify the temporal structure in the measured time serie (Webber & Zbilut, 2005). The average length of the diagonal lines in the recurrence plot is called Mean Diagonal Line (MeanDL). Trapping Time (TT) is the average length of the vertical lines and reflexes the rigidity of the system (Graag, Cox, Hasselman, Jansen & Weerth, in press). The longest diagonal line (MaxDL) is the longest pattern that is repeated and provides an index of the dynamical stability of the system (Pellecchia & Shockley, 2005). Furthermore, the recurrence variables determinism (DET) and entropy (ENT) were quantified from the recurrence matrix. DET is an index of the regularity of the COG (Hadad et al., 2008) and is quantified as the proportion of all the recurrent points that form diagonal lines in the recurrence plot (Aβmann, et al., 2007). ENT assesses how the diagonal lines are distributed and is an index of the complexity of the COG (Hadad, 2008). Laminarity (LAM) is analogous to DET, the percentage of points of all the recurrent points that form vertical lines (Aβmann, et al., 2007). All recurrence analyses on the postural sway data were performed using Matlab 2008-7 (Mathworks Inc.) software and Marwan's toolbox (http://www.agnld.uni-potsdam.de/~marwan/toolbox/ retrieved March 17, 2011) (Marwan, Romano, Thiel, & Kurths, 2007).

To examine if the postural strategies were impacted while solving balance-scale problems (hypothesis 2), as a first step correlations were executed between RQA measures and the overall proportion score, and between RQA measures and the proportion score on the four problem types separately. RQA measures for the fixation-pre-test and pre-test were then subjected to repeated measures analysis.

Finally, to see if a relation exists between the temporal structure in postural sway and the level of problem solving in balance-scale task in children (hypothesis 3), a median split based on balance-scale task performance was used to divide children into High Performance Group or Low Performance Group. ANOVAs were then conducted for fixation pre-test, and fixation post-test to compare RQA measures between the High, and Low Performance Group. Furthermore, RQA measures were subjected to multiple repeated-measures ANOVAs to determine if there was a distinction in the postural sway pattern between the High, and Low Performance Group between fixation-pre-test and pre-test. All differences in RQA measures were assessed in SPSS (15.0.1).

Results

Analysis of performance data: EM vs NE

Preliminary analysis. All children finished the experiment. Comparisons between the EM and NE Training Group were made for sex, height or weight, using unrelated t-tests. No significant differences were found between these two Training Groups ($F < 1$). Due to the matched group design there was no significant difference between the EM Training Group ($M = .48$) and the NE Training Group ($M = .47$) in the number of correct answers at pre-test ($t = .165$; $p = .869$) for all four categories of balance-scale problems. The proportion scores for the four problem types are given in Table 4.

Table 4

Proportion scores (SD) of Correct Answers for the Four Problem Types

	Pre-test					Post-test				
	B	CD	D	W	Total	B	CD	D	W	Total
Embodied	0.50 (0.07)	0.34 (0.11)	0.47 (0.09)	0.65 (0.08)	0.48 (0.21)	0.75 (0.10)	0.38 (0.14)	0.45 (0.13)	0.52 (0.12)	0.52 (0.16)
Non-embodied	0.54 (0.11)	0.31 (0.09)	0.47 (0.20)	0.56 (0.13)	0.47 (0.19)	0.67 (0.10)	0.60 (0.11)	0.66 (0.15)	0.66 (0.19)	0.65 (0.20)

Note. N =14 in both Training Groups.

Main analysis.

A repeated-measures ANOVA with two within-subjects (Test [pre-test, post-test], Problem type [B, CD, D, W]) and one between-subject factor (Training Group [NE, EM]) was conducted to assess the proportion scores on the balance-scale problems. Repeated-measures ANOVA revealed a main effect of Test, $F(1,26) = 10.00$, $p = .004$, eta^2 = .28. Both Trainings Groups together answered significantly more problems correctly at post-test ($M = .91$) than they did at pre-test ($M = .78$). Although there was no significant effect of Training Group ($F < 1$), indicating that the mean proportion scores in the NE and EM Training Group were the same, an interaction effect between Test and Training Group that approached significance was found, $F(1,26) = 3.98$, $p = .057$, eta^2 = .13. This interaction effect suggests that the two Training Groups performed differently at post-test. At post-test the NE Training Group tended to answer more balance-scale problems correctly ($M = .99$) compared with the EM Training Group ($M = .84$) as can be seen in Figure 4. So a clear benefit of the embodied training for improving performance on solving balance-scale problems could not be identified by this analysis, which leads to the rejection of hypothesis 1.

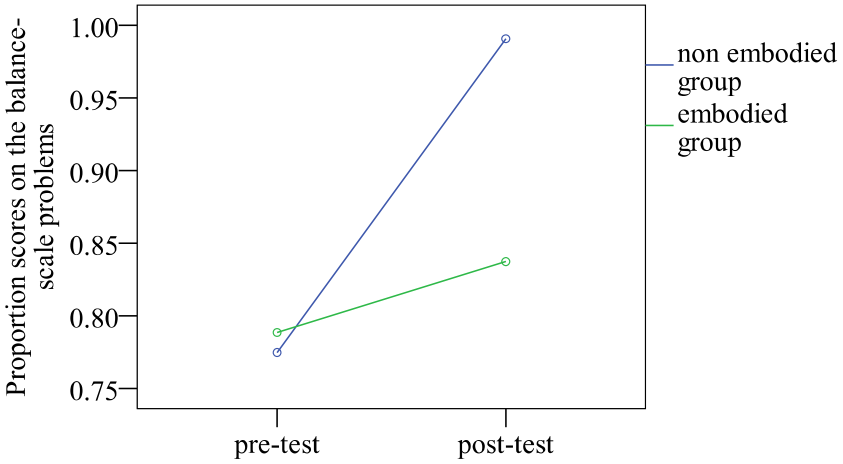


Figure 4. The proportion scores of the EM and NE Training Group at pre-test, and at post-test. During post-test the NE Training Group answered significantly more correct than the EM Training Group.

Furthermore, a significant main effect for Problem type was found, *F*(3,24) = 4.25, *p* = .015, eta² = .35, which means that there was a significant difference in the amount of correct answers between one or more problem categories for both Training Groups together. Another ANOVA was conducted with one between-subject factor (Training Group [NE, EM]) to analyze the relative difference scores of the four problem types. A significant effect for Training Group was found, *F*(4,21) = 3.25, *p* = .032, eta² = .38. This indicates that the NE Training Group and the EM Training Group differ on their relative difference scores over all four problem types together. Overall, the EM Training Group did not made any progress between pre-test and post-test (*M* = .01) in solving the four types of balance-scale problems, in contrast to the NE Training Group that made some overall progress (*M* = .18).

For the four problem types separate, the relative difference scores differed significantly between the EM Training Group and the NE Training Group for weight problems, *F*(1,24) = 5.94, *p* = .023, eta² = .20; distance problems, *F*(1,24) = 4.96, *p* = .036, eta² = .17 and conflict-distance problems, *F*(1,24) = 4.85, *p* = .037, eta² = .17. The relative difference score for balance problems did not differ significantly between the EM and the NE Training Group. As shown in Figure 5, the NE Training Group made progress between pre-test and post-test in solving conflict-distance problems (*M* = .29), distance problems (*M* = .20) and weight problems (*M* = .13) in comparison to the EM Training Group, whose amount of correct answers decreased between pre-test and post-test for conflict-distance problems (*M* = -.10), distance problems (*M* = -.09) and weight problems (*M* = -.16).

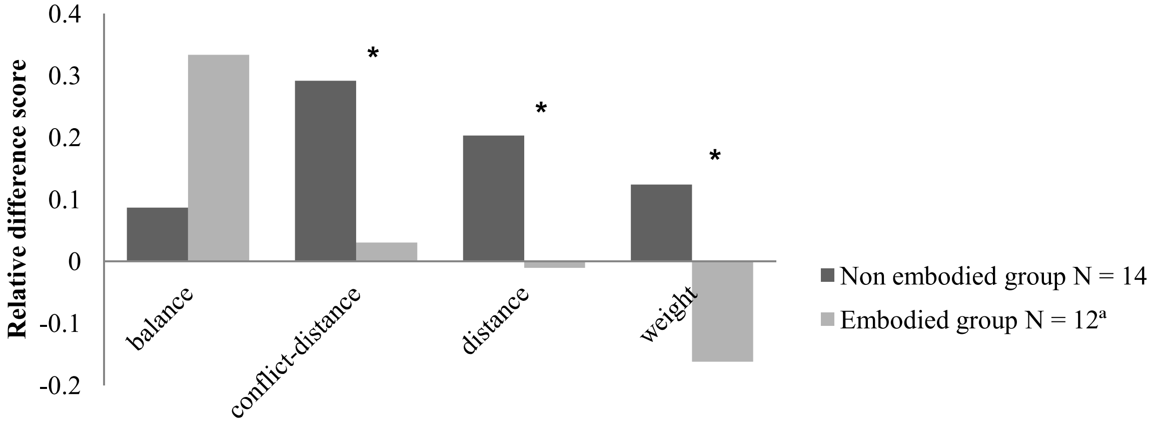


Figure 5. Relative difference scores in the EM and NE Training Group.
[a] A relative difference score could not be obtained for two children due to the fact that they did not answer any balance-scale problem correctly for one type of problem.
* $p < .05$.

Analysis of postural sway data

Preliminary analysis. At pre-test, postural sway data of six children and at post-test postural-sway data of 13 children could not be obtained due to a technical error. At fixation pre-test there was no significant relationship between any of the seven RQA measures (DET, MeanDL, MaxDL, ENT, LAM, TT, MaxVL) and sex, height, weight, or age of the children ($N = 22$) in the ML- or the AP-direction ($F < 1$). After this it was explored whether any of the seven RQA measures correlated with the overall proportion score or with the four problem types separately. At pre-test no significant correlations were found in the ML-direction. In the AP-direction a negative correlation which approached but did not reach significance was found between the overall score and MaxVL $r(20)= -.42$, $p = .053$, at pre-test a higher overall proportion score tended to correlate with a lower MaxVL. This was specifically true for conflict-distance problems $r(20) = -.45$, $p = .037$ and weight problems $r(20)= -.43$, $p = .047$. Also, there was a positive correlation between weight problems and MaxDL $r(20)= .51$, $p = .014$, which indicated that at pre-test the higher the proportion score on weight problems, the larger the MaxDL was in the AP-direction. A negative correlation which approached significance was found between the proportion score on distance problems and MaxVL, children who had higher proportion scores on distance problems tended to have a lower MaxVL in the AP-direction $r(20)= -.42$, $p = .051$.

At post-test there was no relationship between any of the RQA measures and the overall proportion scores on balance-scale problems in the ML-direction. However, when the

RQA measures were split according to problem type, MaxVL was found to be negatively related to the proportion score on balance problems *r*(13) = -.55 *p* = .034, and a negative correlation which approached significance was also found between LAM and the proportion score on balance problems *r*(13)= -.50, *p* = .056, in the ML-direction. At post-test, children who had higher proportion scores on balance problems tended to have a lower MaxVL and LAM in the ML-direction.

In the AP-direction, a negative correlation was found between the overall proportion scores and MaxDL *r*(13)= -.58, *p* = .02, which indicates that at post-test MaxDL was found to be lower when the overall score was higher. As for the four balance-scale problem types separately, there was only a significant correlation between the problem type weight and the RQA measure MaxDL *r*(13)= -.52, *p* = .045, a higher score on weight problems was related to a lower MaxDL in the AP-direction at post-test.

Main analysis.

Performance analysis: High versus low performers. A median split based on balance-scale task performance was used to divide children into the High Performance Group or the Low Performance Group. At pre-test 13 children were labeled as High, and 9 children were labeled as Low (*Mdn* = .43). At post-test 6 children were divided in the High Performance Group, and 9 in the Low Performance Group (*Mdn* = .56) (see Table 5). Considering the children of whom the RQA data was available for both pre-test and post-test, 50% of the children that were categorized as High at pre-test were also in the High Performance Group at post-test, for the Low Performance Group this percentage was 83% (see Table 6 for the proportion scores).

Table 5

Number of Children in Performance Group (High vs Low) and Trainings Group (Embodied vs Non-embodied)

	Pre-test			Post-test		
	High*	Low*	Total	High*	Low*	Total
Embodied	7	4	11	3	2	5
Non-embodied	6	5	11	3	7	10
Total	13	9	22	6	9	15

* Performance Groups are uneven due to the fact that data is missing.

Table 6

Proportion scores (SD) of Correct Answers for the Four Problem Types for High Performance, and Low Performance Group

	Pre-test					Post-test				
	B	CD	D	W	Total	B	CD	D	W	Total
High Performance[a]	.58	.37	.63	.84	.60	.63	.60	.65	.75	.66
	(.39)	(.20)	(.29)	(.17)	(.15)	(.44)	(.35)	(.29)	(.25)	(.14)
Low Performance[b]	.44	.26	.26	.41	.35	.61	.29	.35	.43	.42
	(.27)	(.23)	(.18)	(.19)	(.08)	(.22)	(.11)	(.17)	(.21)	(.09)

[a] *N* =13
[b] *N* =9

To examine if the presence of the balance-scale task impacted the postural strategies (hypothesis 2) a repeated measures ANOVA with one between-subject factor (Performance [High, Low]) and one within-subject factor (Test [fixation pre-test, pre-test]) was conducted first. The High and Low Performance Group together had significantly lower RQA measures as is shown in Table 7, at fixation pre-test than at pre-test for DET, MeanDL, MaxDL, ENT, and LAM in the ML-direction (respectively: F(1,20)= 6.01, *p* = .024, eta^2 = .23; *F*(1,20)= 6.52, *p* = .019, eta^2 = .25; *F*(1,20)= 8.76, *p* = .008, eta^2 = .31; *F*(1,20)= 4.67, *p* = .043, eta^2 = .19; *F*(1,20)= 6.12, *p* = .022, eta^2 = .23). No differences were found between fixation pre-test and pre-test for TT, and MaxVL, and no interaction effects were found. In the AP-direction no significant differences or interactions were found in RQA measures between fixation pre-test and pre-test for the High and Low Performance Group together.

Table 7

Mean RQA Measures at Fixation Pre-test and at Pre-test for Performance Group in the ML-direction

	DET*	MeanDL*	MaxDL*	ENT*	LAM*
Fixation pre-test	.68	9.16	363.82	2.27	.90
Pre-test	.78	12.47	558.85	2.56	.94

*p < .05.

One of the fundamental issues of the present study was to examine if children who differed on performance had a distinct postural sway pattern (hypothesis 3). To do so, and to further answer hypothesis 2, ANOVAs were conducted with one between-subject factor (Performance [High, Low]) to assess the seven RQA measures (DET, MeanDL, MaxDL, ENT, LAM, TT, MaxVL) at fixation pre-test, and fixation post-test in the ML-direction, and the AP-direction. Before pre-test the High and Low Performance Group did not significantly differ in RQA measures in both the ML-, and the AP-direction ($F < 1$), and neither were differences found between the High and Low Performance Group at fixation post-test in the ML-, or AP-direction ($F < 1$). Furthermore, pair-wise comparisons of the RQA measures revealed no differences between fixation pre-test and fixation post-test in the ML- and AP-directions.

Multiple repeated-measures ANOVAs, with one within-subject (Problem type [B, CD, D, W]) and one between-subject factor (Performance [High, Low]), each to assess one of the seven RQA measures at pre-test (DET, MeanDL, MaxDL, ENT, LAM, TT, MaxVL) were then conducted. From the data in Table 8a it can be seen that at pre-test the High Performance Group had lower RQA measures than the Low Performance Group in both the ML-, and the AP-direction. Data analysis revealed a significant main effect for Performance on RQA measures DET, MaxDL, ENT, and LAM (DET, $F(1,20) = 5.07$, $p = .036$, eta^2 = .20; MaxDL, $F(1,20) = 5.49$, $p = .030$, eta^2 = .22; ENT, $F(1,20) = 4.72$, $p = .042$, eta^2 = .19; LAM, $F(1,20) = 5.03$, $p = .036$, eta^2 = .20) in the ML-direction (see Figure 6), thereby supporting hypothesis 3. There was a difference which approached but did not reach significance between the Low and High Performance Group for TT, where the High Performance Group appeared to have a lower TT than the Low Performance Group in the ML-direction, $F(1,20) = 4.12$, $p = .056$, eta^2 = .17. ANOVAs concerning the RQA measures MeanDL, and MaxVL did not indicate a difference between the High and Low Performance Group in the ML-direction at pre-test.

Table 8a

Mean RQA Measures for the High, and Low Performance Group at Pre-test in the ML-, and AP-direction

	DET		MeanDL		MaxDL		ENT		LAM		TT		MaxVL	
	ML*	AP*	ML	AP	ML*	AP	ML*	AP*	ML*	AP*	ML	AP	ML	AP*
High[a]	.73	.89	11.04	17.99	489.68	776.10	2.41	2.86	.92	.98	7.58	11.13	56.35	57.47
Low[b]	.85	.93	14.53	19.67	658.75	780.05	2.78	3.01	.97	.99	9.87	12.50	68.19	62.04
Mean	.78	.91	12.78	18.68	574.22	777.72	2.60	2.92	.95	.98	8.52	11.69	62.27	59.34

* $p < .05$.
[a] $N = 13$
[b] $N = 9$

Table 8b

Mean RQA Measures for the High, and Low Performance Group at Post-test in the ML-, and AP-direction

	DET		MeanDL		MaxDL		ENT		LAM		TT		MaxVL	
	ML	AP	ML	AP	ML	AP	ML	AP	ML	AP	ML	AP	ML	AP
High[a]	.86	.92	14.41	19.78	646.89	774.76	2.78	2.99	.97	.99	9.95	12.35	71.98	63.09
Low[b]	.85	.93	14.40	20.35	657.75	782.44	2.78	3.03	.97	.99	9.88	12.61	70.17	62.56
Mean	.86	.92	14.40	20.07	652.32	779.37	2.78	3.01	.97	.99	9.91	12.51	70.89	62.77

[a] $N = 6$
[b] $N = 9$

In the AP-direction ANOVAs revealed a main effect of Performance; DET, ENT, LAM, and MaxVL were significantly greater for the Low Performance Group than the High Performance Group (DET, $F(1,20)= 7.36$, $p = .013$, eta²= .27; ENT, $F(1,20)= 4.92$, $p = .038$, eta²= .20; LAM, $F(1,20)= 7.20$, $p = .014$, eta²= .27; MaxVL, $F(1,20)= 4,99$, $p = .037$, eta²= .20), which is shown in Figure 6. There was a difference which approached significance with regard to TT, the High Performance Group appeared to have a lower TT than the Low Performance Group, $F(1,20)= 4.27$, $p = .052$, eta²= .18. No significant differences between the High and Low Performance Group were found concerning MeanDL, and on MaxDL in the AP-direction. At post-test, ANOVAs on the RQA measures did not reveal any difference between the High and Low Performance Group for both the AP- and ML-directions (see Table 8b).

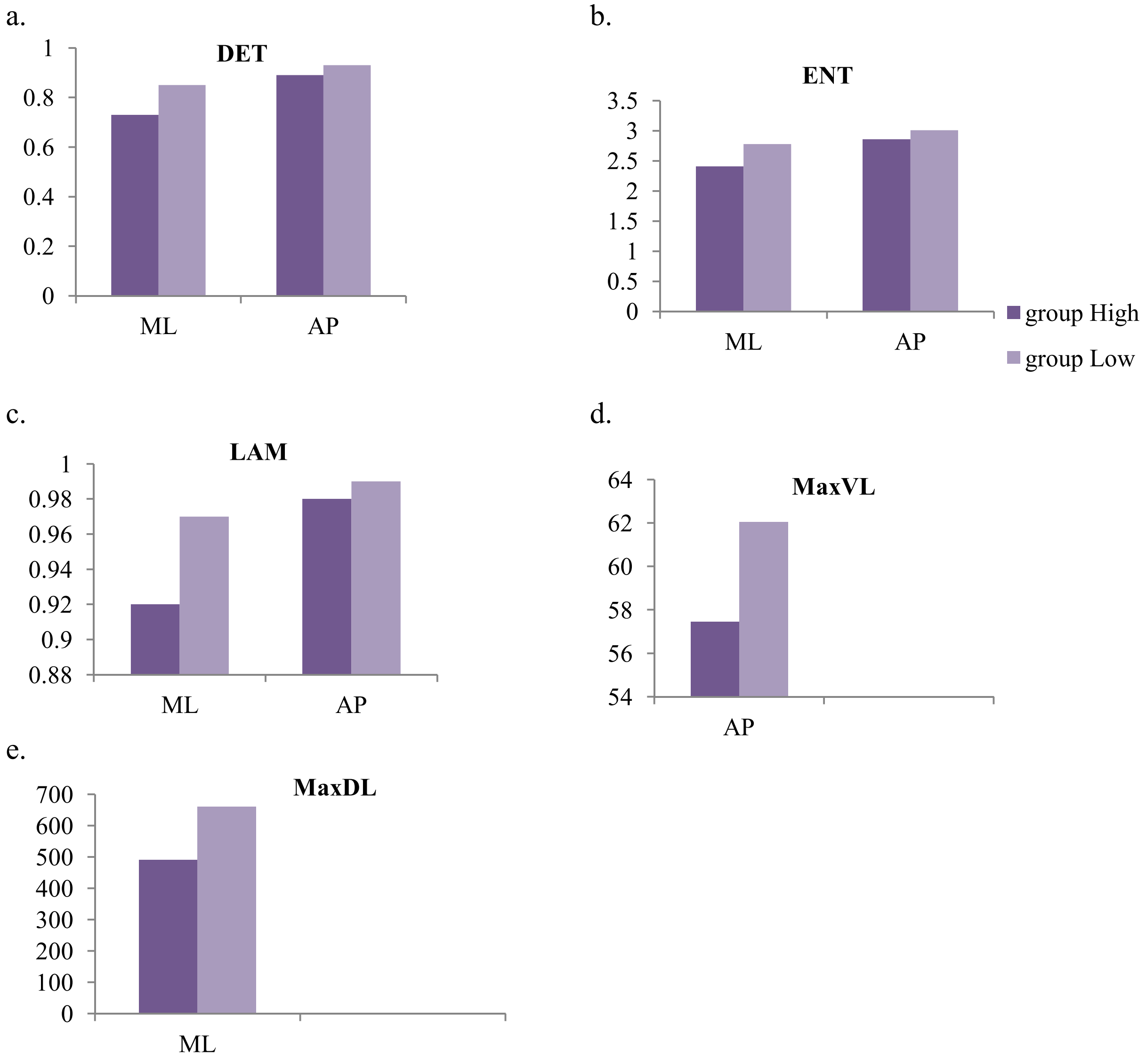


Figure 6. Differences ($p > .05$) between the High and Low Performance Group in the RQA measures DET (a), ENT (b), LAM (c), MaxVL (d), and MaxDL (e) at pre-test in the ML- and AP direction.

Furthermore, at pre-test a significant effect of Problem type was found on the RQA measures MeanDL, ENT, and TT in the ML-direction, respectively MeanDL $F(3,18) = 6.19$, $p = .004$, eta² = .51; ENT $F(3,18) = 3.40$, $p = .040$, eta² = .36, and TT, $F(3,18) = 3.27$, $p = .045$, eta² = .35 (see Table 6 and Figure 7). Paired-sample T tests indicated that MeanDL was significantly higher for weight problems ($M = 13.41$) than for distance problems ($M = 11.99$), $t(21) = -3.31$, $p = .003$; that ENT was significantly higher for weight problems ($M = 2.62$) than for distance problems ($M = 2.52$), $t(21) = -2.73$, $p = .012$; and that TT was significant higher for weight problems ($M = 8.92$) than for distance problems ($M = 8.30$), $t(21) = -2.47$, $p = .022$.

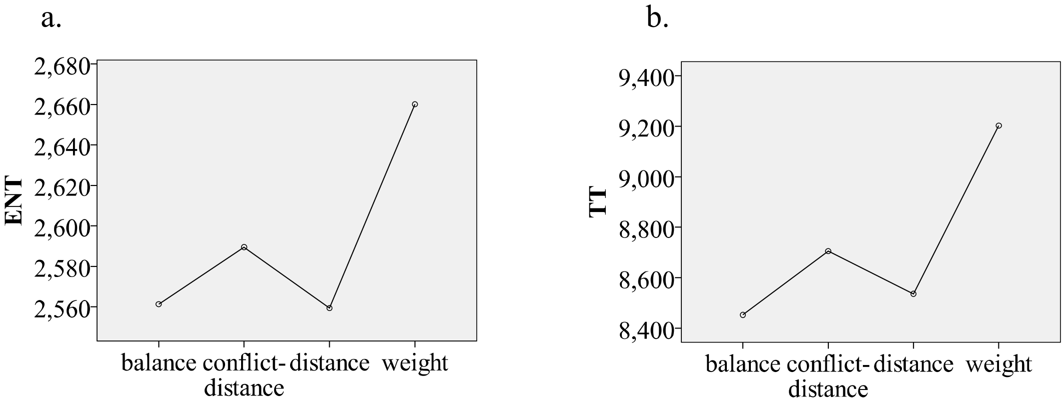


Figure 7. Significant effects of Problem type on the RQA measures ENT (a) and TT (b). Further analysis revealed that only between weight and distance problems the RQA measures ENT and TT differed significantly.

The interaction between Problem type and Performance on the RQA measure MeanDL at pre-test was significant, $F(3,18) = 4.35$, $p = .018$, eta² = .42, there was a tendency for MeanDL to increase in weight problems for the Low Performance Group ($M = 16.89$) but not for the High Performance Group ($M = 11.01$) in comparison to the other three balance-scale problems in the ML-direction (linear contrast $F(1,20) = 53.42$, $p = .006$, eta² = .33) as can be seen in Figure 8.

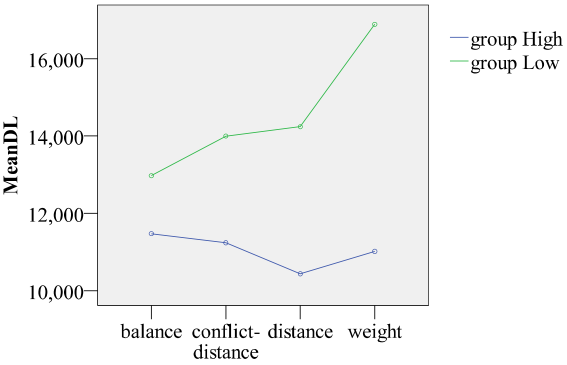


Figure 8. Interaction effect ($p < .05.$) between Problem type and Performance Group on MeanDL at pre-test in the ML-direction. MeanDL increased in weight problems in the Low Performance Group, but not in the High Performance Group.

An interaction which approached significance between Problem type and Performance on the RQA measure TT revealed the same tendency, *F*(3,18) = 3.00, *p* = .058, eta² = .33. Here again TT tended to increase in weight problems for the Low Performance Group (*M* = 10.74) but not for the High Performance Group (*M* = 7.67) in comparison with the TT on the other three balance-scale problems in the ML-direction, linear contrast, *F*(1,20) = 9.57, *p* = .006, eta² = .32. ANOVAs concerning the RQA measures DET, MaxDL, LAM, and MaxVL did not indicate a difference between Problem type or an interaction between Performance and Problem type in the ML-direction at pre-test.

In the AP-direction a significant difference was found for Problem type on the RQA measure DET, *F*(3,18)= 4.01, *p* = .024, eta² = .40; (linear) *F*(1,20)= 7.81, *p*= .011, eta² = .28 at pre-test (see Figure 9). A paired-samples T test indicated that DET was significantly higher for weight problems (*M* = 9.15) than for balance problems (*M* = 9.07), and than for conflict distance problems (*M* = 9.05), respectively *t*(21)= -2.29, *p* = .033, and *t*(21) = -3.10, *p* = .005. ANOVAs did not reveal any effect for Problem type on the seven RQA measures in the ML-, or in the AP-direction at post-test.

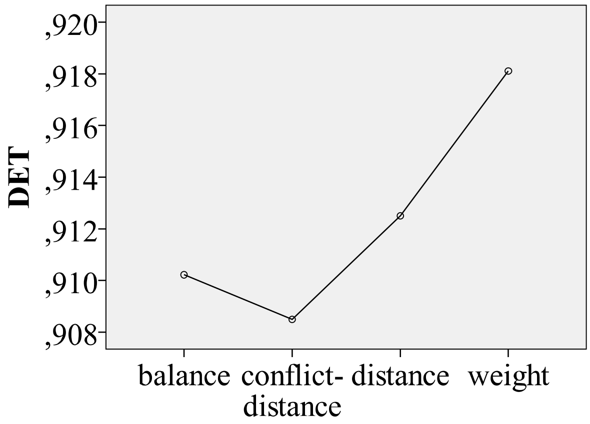


Figure 9. Significant effect for Problem type on the RQA measure DET at pre-test in the AP-direction.Further analysis revealed that DET differed significantly between the problem types balance and weight, and between the problem types conflict distance and weight.

Embodied / Non-embodied. ANOVAs were conducted with one between-subject factor (Training Group [EM, NE]) to assess the seven RQA measures at fixation pre-test, and fixation post-test in the ML-direction, and the AP-direction. A difference that approached significance between the Training Groups EM (*N* = 10) and NE (*N* = 12) was found for DET, *F*(1,20)= 4.07, *p* = .057, eta² = .17, and for LAM, *F*(1,20)= 4.32, *p* = .051, eta² = .18 at fixation pre-test in the ML-direction. The RQA measures DET and LAM tended to be higher in the EM Training Group respectively (*M* = .77) and (*M* = .94) than in the NE Training Group, respectively (*M* = .58) and (*M* = .86).

In the AP-direction a significant effect for Training Group was found on DET, *F*(1,20)= 7.88, *p* = .011, eta² = .28; on MeanDL, *F*(1,20)= 9.97, *p* = .005, eta² = .33; on ENT, *F*(1,20)= 6.89, *p* = .016, eta² = .26; on LAM, *F*(1,20)= 6.77, *p* = .017, eta² = .26; and on TT, *F*(1,20)= 10.31, *p* = .004, eta² = .34. The RQA measures DET, MeanDL. ENT, LAM, and TT were significantly higher in the EM Training Group, respectively (*M* = .93; *M* = 20.45; *M* = 3.04; *M* = .99; *M* = 13.13) than in the NE Training Group, respectively (*M* = .86; *M* = 14.66; *M* = 2.71; *M* = .97; *M* = 9.93) at fixation pre-test in the AP-direction.

The Training Groups EM (*N* = 10) and NE (*N* = 6) did not differ significantly on RQA measures at fixation post-test, in the ML-direction, or in the AP-direction.

To further compare the RQA measures between the EM and NE Training Group multiple repeated-measures ANOVAs, with one within-subject (Problem type [B, CD, D, W]) and one between-subject factor (Training Group [EM, NE]), each to assess one of the seven RQA measures at pre-test and at post-test separately (DET, MeanDL, MaxDL, ENT, LAM, TT, MaxVL) were conducted for the ML-direction and for the AP-direction separately. Results showed no significant effect for Training Group and neither a significant interaction between Training Group and Problem type in the ML-direction at pre-test. In the AP-direction at pre-test a significant effect for Training Group was found on MaxDL, *F*(1,20)= 4.83, *p* = .04, eta² = .20; MaxDL was greater for the NE Training Group (*M* = 788.90) than for the EM Training Group (*M* = 764.29).

At post-test an effect that approached significance was found for Training Group on MeanDL, *F*(1,13)= 4.50, *p* = .054, eta²= .26 in the ML-direction; the EM Training Group tended to have a higher MeanDL (*M* = 16.51) than the NE Training Group (*M* = 13.00). No significant effect of Training Group was found for the other six RQA measures in the ML-direction at post-test, neither was there a significant effect for Training Group in the AP-direction at post-test. No interactions were found in the ML- or the AP-direction at post-test.

DISCUSSION

This study set out with the aim of improving performance on the balance-scale task in children by an embodied experience of balance (Siegler, 1976). The results suggest that there was no positive effect of embodied training, in which children experienced balance with their own body, on balance-scale task performance. This is in contrast with the findings of Thomas and Lleras (2009) who showed that directed actions can influence higher order cognitive processing. Although the task differed between the studies, Maiers' two string problem versus the balance-scale task, and the participants variated, adults versus children, these differences do not explain why the embodied training in this study was not helpful. The embodied training might not have been long, or equivalent to the balance-scale task, enough to influence performance on the balance-scale task. Although not significant, performance on the problem type balance seemed to improve in the EM Training Group (see Figure 5). In a future study it is therefore recommended to alter the embodied training by a longer duration or by more repetitions.

Contrary to expectations, and in contrast to Sieglers' study, children in the NE Training Group, who observed outcomes of balance-scale problems, seemed to benefit from this observation. In this Training Group performance was affected by non-embodied training in a positive way for the problem types conflict-distance, distance and weight (modest effect). The conclusion that can be draw here is that observing outcomes of balance-scale problems affects performance, but raises at the same time the question why it was helpful. Of the original six problem types (Siegler, 1976) four problem types were used in this study of which only the problem type conflict-distance differed on both the weight and distance dimension. The NE Training Group observed eight outcomes of this problem type during training. It could be the case that, without understanding or applying the torque rule (weight x distance), this Training Group might have implicitly learned (Reber, 1993), namely "in cases of a difference in both the weight and distance dimension, the side with the least weight will always go down". Further research must be done to determine if adding the problem type conflict-weight (because the outcome there is the opposite of the problem type conflict-distance) would lead to different results.

Although the balance-scale problems used in this study were based on the study of Siegler (1976), the findings of the current study did not support the rule-system model as is described in Table 1. Siegler predicted a virtually perfect performance on balance and weight problems for 5-6 years and a less than 10% correctly outcome in distance and conflict-distance problems (Siegler & Chen, 2002). These numbers do not match the scores in the current study, as can be seen in Table 4. Except for the average score on the problem type conflict-distance (only at pre-test), all other average scores were above chance level, but below the 80% boundary Siegler and Chen defined. The evidence from the current study suggests that Siegler's rule-system model seems not sufficiently complex enough to deal with the range of predictions made by children. This is in agreement with a number of criticisms leveled against rule assessment (see Boom, Hoijtink & Kunnen, 2001; Ferretti & Butterfield, 1986; Jansen & van der Maas, 2002; Messer et al., 2008).

The second question this research addressed was wether the presence of the balance-scale task impacted postural sway in children age 5-6 years. To answer this question RQA-measures between fixation pre-test and pre-test were compared. Examination of the temporal structure of postural fluctuations revealed that indeed the RQA-measures Determinism (DET), Mean diagonal line (MeanDL), Maximal diagonal line (MaxDL), Entropy (ENT), and Laminarity (LAM) were lower in the ML-direction when standing quiet than when solving balance-scale problems (modest effects). In the AP-direction no difference in temporal structure of postural fluctuations between standing quiet and solving balance scale problems was found.

To explain these differences one could focus on the difference in attentional demands between standing quiet and solving balance-scale problems; it requires more ability to concentrate to solve a balance-scale problem than to stand quiet (e.g. Kahneman, 1973). Reasoning this way, the results corroborate the findings of a great deal of previous work in this field. Pellecchia and Shockley (2005), and Riley et al. (2005) already demonstrated that the attractor of the complex dynamic system is found to be less stable and less complex, when the cognitive task costs high attentional demand, as showed by the RQA measures ENT and MaxDL. However, the difference in DET is not in line with this reasoning; in the current study DET showed less regularity of the attractor when solving balance-scale problems, than when standing quiet, whereas Pellecchia and Shockley found that the attractor becomes more regular, as showed by DET, when the attentional demands of a cognitive task increase. So the level of ability to concentrate cannot explain all the differences found in this study.

Not only differences in postural sway pattern between standing quiet and solving balance-scale problems were found, the results also showed that the High, and Low Performance Group (as established by balance-scale task performance) had a distinct postural sway pattern while solving balance-scale problems at pre-test (hypothesis 3). More specifically, at pre-test DET was higher in the Low Performance Group (modest effect), which suggests that the temporal structure of ML-, and AP postural fluctuations were more regular in the Low Performance Group than in the High Performance Group during the balance-scale task (Aβmann, et al., 2007; Hadad et al., 2008; Pellecchia & Shockley, 2005). MaxDL, which provides an index of the dynamical stability of the system and the temporal structure in COG (Pellecchia & Shockley, 2005), was at pre-test lower in the High Performance Group than in the Low Performance Group in the ML-direction (modest effect).

This indicates that the temporal structure of the ML COG was less mathematically stable in the High Performance Group (Pellecchia & Shockley). Furthermore was Entropy (ENT) at pre-test lower in the High Performance Group than in the Low Performance Group in both the ML-, and AP- direction (modest effect) which suggests that the deterministic structure of the ML- and AP COG was less complex in the High Performance Group than in the Low Performance Group (Aβmann, et al., 2007; Hadad, 2008; Pellecchia & Shockley, 2005). LAM was at pre-test also lower in the High Performance Group than in the Low Performance Group in the ML-direction.

These results are remarkable because no differences in RQA measures between the High, and Low Performance Group where found at fixation pre-test (standing quietly and fixating on a red dot). This leads to the conclusion that the differences in postural sway pattern between the High, and Low Performance Group must be related to solving balance-scale problems.

As stated before, ability to concentrate does not explain to a sufficient degree the differences in RQA measures, or one should say that it costs more attentional demand to solve correctly than incorrectly. What else might explain these observed differences in recurrence patterns between the two conditions? Smith (2005) stated; “Taking a dynamic systems approach to cognition requires thinking about cognition in entirely new ways.” (p 279). Taking an embodied account here, solving balance-scale problems might not be something one does only in the head, but with one’s own entire body. In this way the postural sway movement seems to facilitate higher cognitive process, or even more radically, is equal to cognition! In other words, a child “uses” her whole body (in this case by the means of postural sway) to solve balance-scale problems. The body knows by its nature all about balance (Balasubramaniam & Wing, 2002). This idea also accords with the observations that differences in RQA measures are mostly in the ML-direction, the same direction as in which the problems were presented.

Apart for results already described, at pre-test differences in dynamic profile between the four problem types in the ML-direction were found for the RQA measures MeanDL, ENT, and TT. In the AP-direction a significant difference was found between problem types for DET. These differences in the organization of the postural sway between the four types of problems further support the idea of a postural system “facilitating” cognition. Specifically the postural organization for the problem type Weight differed as can be seen in Figure 7 and 8. Recall the constitution theme Shapiro (2011) distinguished; cognition is a form of bodily activity, and the found results are indicating that this might be true in the case of postural sway and the balance-scale task!

Further research

The present study is new that it combined postural sway, the balance-scale task, and RQA. Reviewing the literature, no data were found on this association. Embodied cognition has fewer uniform methodological practices compared to the standard cognitive science (Shapiro, 2011) and it is here demonstrated that it is worthwhile to investigate cognition and postural sway of young children by means of recurrence quantification analysis (RQA). The main advantage of RQA is that it can provide information about the organization of non-stationary data where other conventional methods fail. As Pellecchia and Shockley (2005) said; “The analytic tools available through RQA promise insight into the mechanism and processes underlying postural control not accessible with a conventional approach to the study of postural sway” (p 136).

In addition, the present study offers evidence that postural stabilization should not only be regarded as an end goal. RQA revealed and quantified temporal patterns within the postural sway time series. Children who performed above average on the balance-scale task differed in RQA measures from children who performed below average, and RQA measures differed between problem types. In addition this study showed that ML COG and AP COG can be affected differentially. Although it is here suggested that postural sway facilitates, or is equal to, cognitive processes, further research regarding the role of postural sway and cognition would be of great help in understanding the relation between both.

In the current study a 12 s period was used for postural sway acquisition and this appeared to be long enough. This finding has important implications for investigation postural sway data, for it is common to use a period of 30s (Le Clair & Riach, 1996; Pellecchia & Shockley, 2005). The use of a WBB as force platform was also demonstrated in this study. Force platforms are expensive instruments and cost about $ 20.000. The WBB is a commercial product and has the advantage of low cost, accessibility and is easily updated with the newest technology.

A limitation of the present study is the small sample size, also due to technical problems. For a few RQA measures, specifically TT, the *p*-value approached but did not reach significance. Besides that, observed differences in RQA measures at pre-test between the High, and Low Performance Group were not significant at post-test, overall, the postural sway pattern became more regular at post-test (but not for fixated). It is not sure why these differences in RQA measures disappeared. Performance Group was smaller at post-test due to technical problems, and also had received a different training which might have influenced the postural sway pattern (Zech, 2010). In a subsequent study it would be good to enlarge the number of children to understand these different findings. Besides that, a follow up could give more insight into the adaptive nature of postural sway. Taken all together; the issue of postural sway and cognition is an intriguing one which could be usefully explored in further research.

Referentielijst

Aßmann, B., Romano, M. C., Thiel, M., & Niemitz, C. (2007). Hierarchical organization of a reference system in newborn spontaneous movements. *Infant Behavior & Development, 30*, 568–586.

Ahmed, A., & Ruffman, T. (1998). Why do infants make A not B errors in a search task, yet show memory for the location of hidden objects in a nonsearch task? *Developmental Psychology, 34*, 441-453.

Baillargeon, R., & Graber, M. (1988). Evidence of location memory in 8-month-old infants in a nonsearch AB task. *Developmental Psychology, 24*, 502-511.

Balasubramaniam, R., & Wing, A. M. (2002). The dynamics of standing balance. *Trends in Cognitive Sciences, 6*, 531 – 536.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617-645.

Boom, J., Hoijtink, H., & Kunnen, S. (2001). Rules in the balance classes, strategies, or rules for the balance scale task? *Cognitive Development, 16*, 717–735.

Brooks, R. (1989). A robot that walks; Emergent behaviors from a carefully evolved network. *Neural Computation, 1*, 253-262.

Capello, A., Lenzi, D., & Chiari, L. (2004). Periodical in-situ re-calibration of force platforms: A new method for the robust estimation of the calibration matrix. *Medical & Biological Engineering & Computing, 42*, 350-355.

Chiari, L., Rocchi, L., & Cappello, A. (2002). Stabilometric parameters are affected by anthropometry and foot placement. *Clinical Biomechanics, 17*, 666–677.

Clancey, W. (1997). *Situated cognition: On human knowledge and computer representations.* Cambridge, MA: Cambridge University Press.

Clark, A. (1999). An embodied cognitive science? Embodiment in cognitive science. *Trends in Cognitive Sciences, 3*, 345-351.

Clark, A. R., Bryant, A. L., Pua, Y., McCrory, P., Bennell, K., & Hunt, M. (2010). Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. *Gait & Posture, 31*, 307–310.

Clark, A., & Chalmers, D. J. (1998). The Extended Mind. *Analysis, 58*, 7-19.

Cook, S. W., Mitchell, Z., & Goldin-Meadow, S. (2008). Gesturing makes learning last. *Cognition, 106*, 1047–1058.

Dawson, M. R. W., & Zimmerman, C. (2003). Interpreting the internal structure of a connectionist model of the balance scale task. *Brain and Mind, 4*, 129–149.

De Graag, J. A., Cox, R. F. A., Hasselman, F., Jansen, J., & Weerth, de, C. (2010).

Functioning within a relationship: Mother-infant synchrony and infant sleep. "Manuscript submitted for publication".

Descartes, R. (1996). Meditations on first philosophy: With selections from the objections and replies (J. Cottingham, Trans.). Cambridge, England: Cambridge University Press. (Original work published 1641).

Diamond, A. (1985). Development of the ability to use recall to guide action, as indicated by infants' performance on A-not-B. *Child Development, 56*, 868–883.

Duarte, M., & Freitas, S. M. S. F. (2010). Revision of posturography based on force plate for balance evaluation. *Revista Brasileira de Fisioterapia, 14*, 183-92.

Duarte, M., & Zatsiorsky, V. M. (2001). Long-range correlations in human standing. *Physics Letters A, 283*, 124–128.

Effect bewegen op reken- en taalvaardigheid onderzocht. (2011, January). *Persberichten UMCG.* Retrieved from http://www.umcg.nl/NL/UMCG/Nieuws/Persberichten/Pages /Effectbewegenoprekenentaalvaardigheidonderzocht.aspx

Evans, J., Davies, B., & Rich, E. (2009).The body made flesh: Embodied learning and the corporeal device. *British Journal of Sociology of Education, 30*, 391-406.

Ferretti, R. P., & Butterfield, E. C. (1986). Are children’s rule-assessment classifications invariant across instances of problem types? *Child Development, 57*, 1419–1428.

Ferretti, R. P., & Butterfield, E. C. (1992). Intelligence-related differences in the learning, maintenance, and transfer of problem-solving strategies. *Intelligence, 16*, 207-223.

Fournier, K. A., Kimberg, C. I., Radonovich, K. J., Tillman, M. D., Chowd, J. W., Lewis, M. H., Bodfish, J. W., & Hass, C. J. (2010). Decreased static and dynamic postural control in children with autism spectrum disorders. *Gait & Posture, 32*, 6–9.

Haddad, J. M., Van Emmerik, R. E. A., Wheat, J. S., & Hamill, J. (2008). Developmental changes in the dynamical structure of posturalsway during a precision fitting task. *Experimental Brain Research, 190*, 431–441.

Hurley, S. L. (1998). *Consciousness in action*. London, England: Harvard University Press.

Inhelder, B. and J. Piaget (1958). *The growth of logical thinking from childhood to adolescence.* New York: Basic Books.

Jansen, B. R. J., & van der Maas, H. L. J. (2002). The development of children’s rule use on the balance scale task. *Journal of Experimental Child Psychology, 81*, 383–416.

Jansen, B. R. J., Raijmakers, M. E. J., & Visser, I. (2007). Rule transition on the balance scale task: A case study in belief change. *Synthese, 155*, 211–236.

Kahneman (1973). *Attention and Effort.* Englewood Cliffs, New Jersey: Prentice-Hall.

Karmiloff-Smith, A. (1992). *Beyond modularity: A developmental perspective on cognitive science.* Cambridge, MA: MIT Press.

Laufer, Y., Ashkenazi, T., & Josman, N. (2008). The effects of a concurrent cognitive task on the postural control of young children with and without developmental coordination disorder. *Gait & Posture, 27*, 347–351.

Lee, J. C. (2008). Hacking the Nintendo Wii Remote. *Pervasive Computing, 7*, 39-45.

Legrand, D., Grünbaum, T., & Krueger, J. (2009). Dimensions of bodily subjectivity. *Phenomenology and the Cognitive Sciences, 8*, 279–283.

Lockman, J. J. (2001). *An embodied theory of cognitive deveopment: Within reach?* [Peer commentary on the paper "The dynamics of embodiment: A field theory of infant perseverative reaching" by E. Thelen, G. Schöner, C. Scheier, & L. B. Smith].

Maas, H. L. J. van der, & Jansen, B. R. J. (2003). What response times tell of children's behavior on the balance scale task. *Journal of Experimental Child Psychology, 85*, 141–177.

Markman, A. B. (2001). *Are dynamical systems the answer?* [Peer commentary on the paper "The dynamics of embodiment: A field theory of infant perseverative reaching" by E. Thelen, G. Schöner, C. Scheier, & L. B. Smith].

Marcovitch, S. & Zelazo, P. (2001). *On the need for conscious control and conceptual understanding* [Peer commentary on the paper "The dynamics of embodiment: A field theory of infant perseverative reaching" by E. Thelen, G. Schöner, C. Scheier, & L. B. Smith].

Marwan, N. (2011). Marwan's Toolbox (Version 5.16) [Computer software]. Potsdam, Germany. Retrieved March 17, 2011, from **Error! Hyperlink reference not valid.**/~marwan/toolbox

Marwan, N. (2008). A historical review of recurrence plots, *The European Physical Journal, 164*, 3–12.

Marwan, N., Romano, M. C., Thiel, M., & Kurths, J. (2007). Recurrence plots for the analysis of complex systems. *Physics Reports, 438*, 237-329.

Mataric, M. J. (1992). Integration of representation into goal-driven behavior based robots. *IEEE Transactions on Robotics and Automation, 8*, 304-312.

Mazaheria, M., Negahban, H., Salavati, M., Sanjari, M. A., & Parnianpour, M. (2010). Reliability of recurrence quantification analysis measures of the center of pressure during standing in individuals with musculoskeletal disorders. *Medical Engineering & Physics, 32*, 808–812.

Messer, D. J., Pine K. J., & Butler, C. (2008). Children’s behaviour and cognitions across different balance tasks. *Learning and Instruction, 18*, 42-53.

Molenaar, P.C.M., & Campbell, C.G. (2008). Discussion of the special issue on growth models for longitudinal data in educational research. *Educational Research and Evaluation, 14*, 377-390.

Munakata, Y., McClelland, J. L., Johnson, M. H., & Siegler, R. S. (1997). Rethinking Infant Knowledge: Toward an Adaptive Process Account of Successes and Failures in Object Permanence Tasks. *Psychological Review, 104*, 686-713.

Nardone, A., & Schieppati, M. (2010). The role of instrumental assessment of balance in clinical decision making. *European Journal of Physical and Rehabilitation Medicine, 46*, 221-237.

Newell, A., & Simon, H.A. (1961). Simulation of human thought. In D. Wayne (Ed.), Current trends in psychological theory (pp. 152-179). Pittsburgh, PA: University of Pittsburgh Press.

Nintendo Wii balance board [Apparatus and software]. (2007). Redmond, Washington: Nintendo of America Inc.

Peek, B. WiimoteLib (Version 1.7) [Software library]. Retrieved March 3, 2010, from http://wiimotelib.codeplex.com

Pellecchia, G. L., & Shockley, K. (2005). Application of recurrence quantification analysis: Influence of cognitive activity on postural Fluctuations. In M. A. Riley & G. C. Van Orden (Eds.), Tutorials in contemporary nonlinear methods for the behavioral sciences (pp. 95-141). Retrieved December 2, 2010, from http://www.nsf.gov/sbe/bcs /pac/nmbs/nmbs.jsp

Pellecchia, G. L. (2003). Postural sway increases with attentional demands of concurrent cognitive task. *Gait and Posture, 18*, 29-34.

Piaget, J. (1963). *The origins of intelligence in children,* W.W. Norton.

Piaget, J. (1954) *The construction of reality in the child*. Basic Books.

Pine, K. J., Lufkin, N., & Messer, D. (2004). More gestures than answers: Children learning about balance. *Developmental Psychology, 40*, 1059–1067.

Ping, R. M., & Goldin-Meadow, S. (2008). Hands in the air: Using ungrounded iconic gestures to teach children conservation of quantity. *Developmental Psychology, 44*, 1277–1287.

Reber, A. S. (1993). Implicit learning and tacit knowledge: An essay on the cognitive unconscious. Oxford, UK: Oxford University Press.

Rijksoverheid, Inspectie van het Onderwijs. (2010). *De staat van het onderwijs: Onderwijsverslag 2008/2009* (Publicatie No. 22DW2010B204). Retrieved from http://www.rijksoverheid.nl/documenten-en-publicaties/publicatiespb51 /onderwijsverslag-2008-2009.html

Riley, M. A., Baker, A. A., Schmit, J. M., & Weaver, E. (2005). Effects of visual and auditory short-term memory tasks on the spatiotemporal dynamics and variability of postural sway. *Journal of Motor Behavior, 37*, 311-324.

Riley, M. A., Balasubramaniam, R., & Turvey, M. T. (1999). Recurrence quantification analysis of postural fluctuations. *Gait and Posture, 9*, 65–78.

Rossi, J. S. (2010). Parametric Statistical Tests. In I. B. Weiner & W. E. Craighead (Eds.), *The Corsini Encyclopedia of Psychology* (pp 1151-1152). New York: Wiley.

Schapiro, A. C., & McClelland, J. L. (2009). A connectionist model of a continuous developmental transition in the balance scale task. *Cognition, 110*, 395–411.

Shapiro, L. (2011). Embodied Cognition. Abingdon, Oxon: Routledge.

Schmid, M., Conforto, S., Lopez, L., & D'Alessio, T. (2007). Cognitive load affects postural control in children. *Experimental Brain Research,* 179, 375–385.

Shih, C. H., Shih, C. T., & Chu, C. L. (2010). Assisting people with multiple disabilities actively correct abnormal standing posture with a Nintendo Wii Balance Board through controlling environmental stimulation. *Research in Developmental Disabilities, 31*, 936–942.

Shockley, K., Santana, M., & Fowler, C. A. (2003). Mutual interpersonal postural constraints are involved in cooperative conversation. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 326–332.

Siegler, R. S. (1976). Three Aspects of Cognitive Development. *Cognitive Psychology, 8*, 481-520.

Smith, L. B. (2005). Cognition as a dynamic system: Principles from embodiment. *Developmental Review,* 25, 278–298.

Smith, L. B., & Thelen, E. (2003). Development as a dynamic system. *Trends in Cognitive Sciences,* 7, 343-34.

Smith, L. B., Thelen, E., Titzer, R., & McLin, D. (1999). Knowing in the context of acting: The task dynamics of the A-Not-B error. *Psychological Review, 106*, 235-260.

Sophian, C. (2001). *Does cognitive development move beyond sensorimotor intelligence?* [Peer commentary on the paper "The dynamics of embodiment: A field theory of infant perseverative reaching" by E. Thelen, G. Schöner, C. Scheier, & L. B. Smith].

Swanenburg, J., de Bruin, E. D., Uebelhart, D., & Mulder, T. (2010). Falls prediction in elderly people: A 1-year prospective study. *Gait & Posture, 31*, 317–321.

Thelen, E., Schöner, G. Scheier, C. & Smith, L. B. (2001). The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioral and Brain Sciences, 24*, 1-86.

Thelen, E., & Smith, L. B. (1994). A Dynamic System s Approach to the development of Cognition and Action (Cambridge: MIT Press).

Takens, F. (1981). Detecting strange attractors in turbulence. *Lecture Notes in Mathematics, 898*, 366–381.

Thomas L. E., & Lleras, A. (2009). Swinging into thought: Directed movement guides insight in problem solving. *Psychonomic Bulletin & Review, 16*, 719-723.

Varela, F., Thompson, E., & Rosch, E. (1991). The Embodied Mind: Cognitive Science and Human Experience (Cambridge: MIT Press).

Visser, J. E., Carpenter, M. G., Kooij, H. van der, Bloem, B. R. (2008). The clinical utility of posturography. *Clinical Neurophysiology, 119*, 2424–2436.

Voogd, H. (2007). IviewBalansExperiment (Version 11) [Computer software]. Nijmegen, the Netherlands.

Webber, C. L., & Zbilut, J. P. (2005). Recurrence Quantification Analysis of Nonlinear Dynamical Systems. In M. A. Riley & G. C. Van Orden (eds.), Tutorials in Contemporary Nonlinear Methods for the Behavioral Sciences Web Book (pp. 353-400). Retrieved February 5, 2011, from http://www.nsf.gov/sbe/bcs/pac/nmbs /nmbs.jsp

Witherington, D. C., von Hofsten, C., Rosander, K., Robinette, A., Woollacott, M. H., & Bertenthal, B. I. (2002). The development of anticipatory postural adjustments in infancy. *Infancy, 3*, 495-517.

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait and Posture, 13*, 1–14

Yarrow, K., Brown, P., Gresty, M. A., & Bronstein, A. M. (2001). Force platform recordings in the diagnosis of primary orthostatic Tremor. *Gait and Posture, 13*, 27–34.

Zech, A., Hubscher, M., Vogt, L., Banzer, W., Hänsel, F., & Pfeifer, K. (2010). Balance training for neuromuscular control and performance enhancement: A systematic review. *Journal of Athletic Training, 45*, 392–403.

Zok, M., Mazzà, C., & Cappozzo, A. (2008). Should the instructions issued to the subject in traditional static posturography be standardised? *Medical Engineering & Physics, 30*, 913–916.

Appendix A

Table A1 provides the two balance scale problems used in the practice trials. The distance problems used in pre-test and post-test are presented in Table A2, conflict-distance problems are given in Table A3, Table A4 shows all balance problems, and weight problems are presented in Table A5.

Table A1
Type of Balance Scale Problem and Distribution of the Weights for the Practice Trial

	Left				Right			
	Peg 1	Peg 2	Peg 3	Peg 4	Peg 5	Peg 6	Peg 7	Peg 8
Distance			1	1			1	1
Weight	1							2

Table A2
Distance Problems with Equal Amounts of Weight at Different Distances from the Fulcrum

Left				Right			
Peg 1	Peg 2	Peg 3	Peg 4	Peg 5	Peg 6	Peg 7	Peg 8
5					5		
3						3	
			2				2
4	1				1	4	
		3	2			2	3
2	2				2	2	
		2	1			1	2
1	3			3	1		
	2			2			
			4			4	
	2				2		
		5				5	
	1	1		1	1		
		3	1		1	3	
	3	2		3	2		
		2	2		2	2	

Note. Total weights used = 119 (*M* = 2.36).

Table A3

Conflict-Distance Problems with More Weight on One Side, but the Weight on the Other Side is Farther from the Fulcrum; the Side with the Weight Farther would go Down

Left				Right			
Peg 1	Peg 2	Peg 3	Peg 4	Peg 5	Peg 6	Peg 7	Peg 8
	5						4
3					4		
			3				2
4					2	3	
		3	1				3
1				1	1		
			5			1	2
3	1				5		
			2			1	
	3			4			
			4		1	1	
	3	1			5		
			5		2	1	
		3		4			
		2	1			2	
	3			2	2		

Note. Total weights used = 109 ($M = 2.59$).

Table A4

Balance Problems with Equal Amounts of Weight Equidistant from the Fulcrum

Left				Right			
Peg 1	Peg 2	Peg 3	Peg 4	Peg 5	Peg 6	Peg 7	Peg 8
2	1					1	2
1	3					3	1
4	1					1	4
3	2					2	3
1	4					4	1
3							3
5							5
		1	3	3	1		
	2	1			1	2	
		4	1	1	4		
	1	4			4	1	
		3	2	2	3		
			3	3			
		1			1		
	2					2	
		4			4		

Note. Total weights used = 124 ($M = 2.38$)

Table A5

Weight Problems with Unequal Amounts of Weight Equidistant from the Fulcrum

Left				Right			
Peg 1	Peg 2	Peg 3	Peg 4	Peg 5	Peg 6	Peg 7	Peg 8
2							3
5							4
2							4
3	2					1	2
3	1					4	1
3	1					2	1
2	2					4	1
1	1					2	1
			3	4			
	4					2	
		4			5		
	2	3			1	3	
	2	1			4	1	
	1	3			1	1	
	1	2			2	3	
	3	1			1	2	

Note. Total weights used = 118 (*M* = 2.56).

Appendix B

Dit is een weegschaal. Deze twee blokken (proefleider wijst blokken aan) zorgen ervoor dat de weegschaal niet kan bewegen. Als ik de blokken zou weghalen kan de weegschaal naar deze kant vallen (proefleider wijst naar links), deze kant opgaan (proefleider wijst naar rechts) of in evenwicht blijven (proefleider wijst aan). Zo meteen zal je een aantal foto's van deze weegschaal op een computerscherm zien. Op de foto zullen de blokken onder de armen van de weegschaal staan, net zoals hier. Jij moet goed kijken naar de weegschaal en bedenken wat er gaat gebeuren als de blokken weg worden gehaald. Na elke foto zie je een plaatje met drie antwoordmogelijkheden. Door te wijzen en op deze knop te drukken (proefleider wijst knop op Wii remote control aan) kan je antwoord geven. We gaan nu eerst samen oefenen. Zie je deze foto? Wat denk je dat er met de weegschaal gebeurt als de blokken worden weggehaald, blijft de weegschaal in evenwicht, gaat hij naar links of naar rechts? Nu mag jij klikken op het antwoord wat je denkt dat het beste is. Goed zo (altijd). We oefenen er nog een en dan gaan we echt beginnen.

Appendix C

Children in the EM Training Group were instructed to walk back and forth on a balance beam with weights in their hands. Every time the child returned on the end of the beam she was instructed to take a different arm position. Of the total of 32 exercises, 28 were performed in a static manner (see Table A6). In the other four exercises, children were constantly bending and extending their arms while walking (see Table A7).

Table A6

Static Exercises of Training for the Embodied Training Group

Problem Type	Left arm extended sideways	Left arm in a 90° angle, hand pointing upwards	Left arm extended, hand resting on shoulder	Right arm extended, hand resting on shoulder	Right arm in a 90° angle, hand pointing upwards	Right arm extended sideways
B	sand					sand
D			water			water
W	sand					empty
CD			sand			empty
B			sand	sand		
D			water		water	
W			sand	empty		
CD			water			empty
B			water	water		
D	water			water		
W	empty					water
CD		water				empty
B	water					water
D		empty				empty
W	sand					water
CD		empty		sand		
B		water			water	
D	empty				empty	
W	water					sand
CD		empty		water		
B	empty					empty
D		sand		sand		
W			water	sand		
CD	empty				sand	
B		empty			empty	
D	sand			sand		
W		empty			water	
CD	empty				water	

Table A7

Dynamic Exercises of Training for the Embodied Training Group

Left arm extended sideways	Left arm in a 90° angle, hand pointing upwards	Left arm extended, hand resting on shoulder	Right arm extended, hand resting on shoulder	Right arm in a 90° angle, hand pointing upwards	Right arm extended sideways
sand	sand			empty	empty
sand		sand	sand		sand
water		water	empty		empty
	empty	empty	water	water	

Appendix D

The NE Training Group observed outcomes of 28 balance scale problems (see Table A8) in training and were given the following instruction: Zo meteen zal ik op verschillende manieren wat gewichten op de pinnen van de weegschaal plaatsen. Jullie mogen dan voorspellen of de weegschaal naar deze kant (links aanwijzen), deze kant (rechts aanwijzen) gaat, of dat hij in evenwicht blijft (aanwijzen). Als jullie antwoord hebben gegeven zal ik de blokken weghalen en dan kan je zien wat er gebeurt.

Table A8

Balance Scale Problems as Observed in the Trainings Phase in the Non-embodied Training Group

	Left				Right			
Problem Type	Peg 1	Peg 2	Peg 3	Peg 4	Peg 5	Peg 6	Peg 7	Peg 8
D	1						1	
CD	2	1				2	2	
B				4	4			
CD			2	3			4	
W	3	1					1	2
W	1	1					1	2
D				2		2		
B			2	3	3	2		
CD		3			2	3		
B			3			3		
D	4						4	
CD			1	3				2
W		4	1			2	2	
CD		4			3	2		
W			2			1		
D		1	3		3	1		
D		1	3				1	3
B			2	1	1	2		
CD		3	1		5			
W	2							5
D	2	2			2	2		
CD			2	3			2	1
B			2	3	3	2		
W				4	1			
B	2	3					3	2
W		4	1			2	2	
D			5				5	
D			1	4		4	1	
B		5					5	
CD	2	1			4			
W		1					2	
B	1	2					2	1