Article 25fa pilot End User Agreement

This publication is distributed under the terms of Article 25fa of the Dutch Copyright Act (Auteurswet) with explicit consent by the author. Dutch law entitles the maker of a short scientific work funded either wholly or partially by Dutch public funds to make that work publicly available for no consideration following a reasonable period of time after the work was first published, provided that clear reference is made to the source of the first publication of the work.

This publication is distributed under The Association of Universities in the Netherlands (VSNU)'Article 25fa implementation' pilot project. In this pilot research outputs of researchers employed by Dutch Universities that comply with the legal requirements of Article 25fa of the Dutch Copyright Act are distributed online and free of cost or other barriers in institutional repositories. Research outputs are distributed six months after their first online publication in the original published version and with proper attribution to the source of the original publication.

You are permitted to download and use the publication for personal purposes. Please note that you are not allowed to share this article on other platforms, but can link to it. All rights remain with the author(s) and/or copyrights owner(s) of this work. Any use of the publication or parts of it other than authorised under this licence or copyright law is prohibited. Neither Radboud University nor the authors of this publication are liable for any damage resulting from your (re)use of this publication.

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please contact the Library through email: copyright@ubn.ru.nl, or send a letter to:

University Library
Radboud University
Copyright Information Point
PO Box 9100
6500 HA Nijmegen

You will be contacted as soon as possible.

Full Length Article

Motor learning and movement automatization in typically developing children: The role of instructions with an external or internal focus of attention

Hilde Krajenbrink^{a,*}, Femke van Abswoude^a, Sanne Vermeulen^a,
Sandra van Cappellen^{a,1}, Bert Steenbergen^{a,b}

^a Behavioural Science Institute, Radboud University Nijmegen, Montessorilaan 3, PO Box 9104, 6500 HE Nijmegen, The Netherlands

^b Centre for Disability and Development Research, Australian Catholic University, Melbourne, Australia

ARTICLE INFO

Keywords:

Motor learning

Focus of attention

Constrained action hypothesis

Working memory

ABSTRACT

The aim of the current study was to examine the effects of an external focus of attention (i.e., on the movement outcome) versus an internal focus of attention (i.e., on the movement itself) on motor learning in typically developing children. We examined both immediate motor performance (i.e., *practice effect*, when focus instructions are given) as well as motor performance after one week (i.e., *learning effect*). In addition, we examined if an external and an internal focus of attention differently affected movement automatization, as measured using a dual-task paradigm. Finally, we explored whether the effect of attentional focus instructions on motor learning was influenced by children's working memory capacity. Participants were 8–12 year old ($N = 162$) typically developing children. Participants practiced a new motor task (i.e., 'Slingerball throwing task'). Results showed that an external focus of attention led to higher throwing accuracy during practice, but this beneficial effect did not extend to the retention test one week later. Furthermore, movement automatization did not differ after external or internal focus of attention instructions, and working memory capacity did not predict motor learning in children in either of the instruction conditions. This is the first study to show that the beneficial effects of an external focus of attention on discrete motor tasks found in previous studies with a child population seem to be short lived and decline after a one-week interval.

1. Introduction

The use of instructions is one of the most important variables in the process of motor skill learning (Schmidt & Lee, 2005). With regards to the content of the instructions, minor differences in wording of instructions can already influence the performer's focus of attention. This, in turn, has a significant impact on motor performance and learning (Wulf, Hoss, & Prinz, 1998). In this respect, an external focus of attention (i.e., focus on the outcome of a movement) was shown to result in enhanced motor performance and learning compared to an internal focus of attention (i.e., focus on movements of the body; for a review, Wulf, 2013). Instructions promoting an external focus of attention facilitate both immediate changes in motor performance (i.e., during practice when focus instructions are given) and later motor learning (i.e., after a certain interval) across a wide variety of tasks (e.g., Chiviacowsky, Wulf, & Wally, 2010; Ong, Bowcock, & Hodges, 2010; Totsika & Wulf, 2003). Wulf, McNevin, and Shea (2001) formulated the constrained

* Corresponding author at: Montessorilaan 3, 6525 HR Nijmegen, The Netherlands.

E-mail address: h.krajenbrink@pwo.ru.nl (H. Krajenbrink).

¹ Present address: Center of Research on Psychological and Somatic disorders, Tilburg University, PO Box 90153, 5000 LE Tilburg, The Netherlands.

action hypothesis to explain the differential effects of attentional focus on motor skill performance and learning. According to this hypothesis, an external focus of attention allows automatic control processes to naturally self-organize. In contrast, an internal focus of attention induces a conscious type of control. The theory implies that this type of control involves working memory and interferes with automatic control mechanisms. This may lead to less effective and less efficient motor performance and motor learning.

To test the constrained action hypothesis, studies have used a dual-task paradigm to assess to what extent the level of movement automatization differs as a function of attentional focus (Kal, van der Kamp, & Houdijk, 2013; Poolton, Maxwell, Masters, & Raab, 2006; Wulf et al., 2001). In the dual-task paradigm, a secondary cognitively demanding task has to be performed in parallel with the primary motor task. The rationale behind this paradigm is that the attentional resources needed to perform the primary motor task are higher for consciously controlled movements as compared to automatized movements. As such, the performance of a cognitive task is expected to interfere with performance on a consciously controlled motor task, but should not, or to a lesser extent, affect performance on an automatized motor task (Abernethy, 1988). Wulf et al. (2001), using a dual-task paradigm, showed that adopting an external focus of attention as compared to an internal focus of attention, led to better performance on the primary balancing task, and also to shorter reaction times in response to auditory stimuli during balancing. The finding that an external focus of attention yields superior dual-task performance as compared to an internal focus of attention has been replicated twice with different motor tasks and using varying dual-task manipulations (Kal et al., 2013; Poolton et al., 2006). Thus, movements performed and learned under an external focus of attention demand less attention than movements performed and learned under an internal focus of attention. This implies that cognitive resources, like working memory, are less involved in motor performance and motor learning with an external focus of attention as compared to an internal focus of attention.

Research examining the effects of attentional focus instructions is predominantly performed in the adult population. Surprisingly however, only a few studies have examined attentional focus effects in children, despite the fact that childhood represents an important motor learning period. The handful of studies that were performed in typically developing children have led to equivocal results. Chow, Koh, Davids, Button, and Rein (2014), Emanuel, Jarus, and Bart (2008), Perreault and French (2016), and van Abswoude, Nuijen, van der Kamp, and Steenbergen (2018) did not find significant differences between performance after external or internal focus of attention instructions measured both during practice (Emanuel et al., 2008; van Abswoude et al., 2018) and during retention test assessed 24–48 h after the last practice session (Chow et al., 2014; Emanuel et al., 2008; Perreault & French, 2016; van Abswoude et al., 2018). On the other hand, many studies replicated the beneficial effects of adopting an external focus of attention as measured during practice (Abdollahipour, Wulf, Psotta, & Nieto, 2015) or following retention test 24–48 h after practice (Brocken, Kal, & van der Kamp, 2016; Flores, Schild, & Chiviacowsky, 2015; Hadler, Chiviacowsky, Wulf, & Schild, 2014; Thorn, 2006). Notably, all studies examined the effects of attentional focus instruction either immediately, during practice, or following a short-term retention test 24–48 h after practice. Changes in motor performance that are generally reported during practice are promising, however, they may only be temporary and do not necessarily reflect learning (Emanuel et al., 2008).

Given these equivocal results, it is crucial to examine the underlying mechanisms of attentional focus instructions in children, which may differ from those in adults. Yet, only two of these studies did address the possible mechanisms underlying attentional focus effects in children (Brocken et al., 2016; van Abswoude et al., 2018). Both studies examined the effects of external focus instructions (i.e., “to move the golf club like a pendulum”) and internal focus instructions (i.e., “to move the arms like a pendulum”) on motor learning of a golf-putting task in children. Additionally, they included a measure of working memory to explore the relationship between motor learning and working memory capacity. Contrary to their expectations, however, both studies found that working memory capacity did not affect motor learning in a different way for the internal focus group compared to the external focus group. That is, working memory capacity of the children could not explain the differential effect of attentional focus instructions on motor learning.

The first aim of the present study is to examine the effects of attentional focus instructions in typically developing children. To this end, we examined the effect of instructions with an external versus instructions with an internal focus of attention on both immediate motor performance (i.e., *practice effect*, when focus instructions are given) and motor performance after one week (i.e., *learning effect*) of a novel movement task. In line with the constrained action hypothesis and previous research, we expected that adopting an external focus of attention as compared to an internal focus of attention is more beneficial for both *practice and learning effects* in children. Second, we examined the effect of external versus internal focus of attention on movement automatization. We used a dual-task paradigm to assess movement automatization. We expected that performing a dual-task interferes less with performance on the primary motor task after external focus instructions as compared to internal focus instructions. Third, and finally, we explored the role of verbal and spatial working memory capacity with regard to motor learning after both focus of attention instructions.

2. Methods

2.1. Participants

A total of 169 children participated. Seven participants who were diagnosed with ADHD (2), ADD (3), Autism (1) or ADHD and PDD-NOS (1) were excluded from further statistical analyses. The remaining sample consisted of 86 boys and 76 girls with ages varying from 8.27 to 12.80 ($M = 10.64$, $SD = 1.19$). Written informed consent was obtained from the parents/guardians, the schools, and the participants themselves if they were twelve years old. The study was approved by the university's ethics committee (EC2013-1811-147a1). The participants were unaware of the purpose of the experiment and the experimental task was novel to all of them and, hence, devoid of pre-established automaticity.

Fig. 1. The task setting. The figure displays the line from which the participant swings the 'slingerball', the flight trajectory of the 'slingerball', and the horizontal target.

2.2. Experimental tasks

The motor task was the Slingerball throwing task which involved swinging a 'slingerball' to a horizontal target. To perform the task, the participant had to hold the end of a ribbon that was connected to the 'slingerball' with the dominant hand. The participants had to swing the 'slingerball' backwards two to three times before releasing it. As shown in Fig. 1, the horizontal target area was a circle with a diameter of 2 m that consisted of eight concentric circles with a width of 12.5 cm each. This served as a measure of throwing accuracy. If the participant hit one of the zones points were assigned, 1 (= bull's eye), 2, 3, 4, 5, 6, 7, 8, 9 (= outside the circles), respectively. Thus, a lower score was an indication of a higher throwing accuracy. Distance of the participant to the target area was set at 5 m.

During the dual-task paradigm, the primary motor task was performed together with a cognitive task that consisted of counting tones. To determine baseline performance, the participant had to count the number of tones as accurately as possible for a total duration of two minutes. Pitches of 1000 Hz were produced from a computer at random intervals between 5 and 10 s. The duration of each tone was 350 ms. The percentage concordance between the number of tones reported and the actual number of tones was used as the outcome variable.

To assess working memory capacity, two subtests of the standardized Automated Working Memory Assessment (AWMA; Alloway, 2007) were used. The listening recall task was used to measure verbal working memory. In this task, the participant was presented with a series of short sentences. After each sentence, the participant had to indicate whether the sentence was true or false. At the end of the series, the participant had to recall the first word of each sentence in the sequence. The spatial recall task was used to measure spatial working memory. In this task, the participant was presented with a series of paired shapes. One shape featured a red dot and could be rotated. After each pair of shapes, the participant had to indicate whether the shape with the dot was the same or a mirror image of the other shape. At the end of the series, the participant had to recall the location of each dot in the sequence. Both tests started with one item to recall. After four successful responses, one item was added and the test continued, until the participant did not succeed in reporting four out of six sequences correctly. For both subtests, the memory score reflecting the recalling part of the task was used. Test-retest reliability of the listening recall test and the spatial recall tests are 0.88 and 0.79, respectively (Alloway, 2007).

2.3. Procedure

The experiment took place at the participant's school and was conducted across three sessions of half an hour each, with the third session one week after the second session (see Fig. 2). Each participant performed the test sessions individually. Participants were assigned to either the external or the internal focus group using a minimization strategy to ensure age and gender balance between

Day 1	Day 2	Day 3 (one week later)
<ul style="list-style-type: none"> • General explanation of the research • Motor skills (MABC-2) 	<ul style="list-style-type: none"> • Pretest (20 trials) • Practice phase (80 trials) • Manipulation check 	<ul style="list-style-type: none"> • Working memory (AWMA) • Retention test (20 trials) • Manipulation check • Single-task of tone counting • Dual-task (20 trials)

Fig. 2. The experimental set-up.

both groups. Instructions for the external focus group were directed at the movements of the ‘slingerball’ and instructions for the internal focus group were directed at the movements of the arm (see Table 1). The amount and timing of the different focus instructions were similar among the two conditions.

The first session started with a general explanation of the study in which participants were also informed of their rights as experimental participants. Afterwards, motor skills were assessed using the Movement Assessment Battery for Children – second edition (MABC-2; Henderson, Sugden, & Barnett, 2007), to verify whether motor skills were equal among the external and the internal focus group. At the beginning of the second session, all participants received the same general instruction regarding the task goal (i.e., to aim at the target) and the basic technique of swinging a ‘slingerball’, which was directly followed by a demonstration from the experimenter. Subsequently, participants performed 20 trials as a baseline measurement. After this pretest, participants received specified instructions to ensure either an external or an internal focus of attention. During the practice phase, participants swung the ball 80 times. Participants received swinging and throwing instructions every 20 trials and a short reminder of the instructed focus after every ten swings (see Table 1). At the end of the practice phase, a manipulation check was performed by asking participants what they were focusing on during the task. At the beginning of the third session, one week after the practice phase, working memory was assessed using the Automated Working Memory Assessment (AWMA; Alloway, 2007). After this, both the retention test and dual-task were conducted. During the retention test, participants swung the ball 20 times. Next, another manipulation check was performed which was followed by a single-task of tone counting. Several minutes later, the dual-task was conducted, in which participants concurrently swung 20 balls while attending to the secondary task of tone counting. No further instruction was given during both retention test and dual-task. Finally, participants were thanked for their cooperation and received a bouncing ball for their contribution.

2.4. Data analysis

All analyses were performed using SPSS version 22. Alpha level was set at 0.05. When the assumption of sphericity was violated, Greenhouse-Geisser corrections were performed. For the partial eta squared effect sizes, 0.01 was considered a small effect, 0.06 was considered a medium effect, and 0.14 was considered a large effect (Cohen, 1988). Independent samples *t*-tests were performed to compare MABC-2 scores and performance on the Slingerball throwing task during pretest between the external and the internal focus of attention group.

2.4.1. The effect of attentional focus instructions on practice and learning

In order to assess the *practice effect* of attentional focus instructions, accuracy scores during practice phase were averaged across blocks of 10 trials and analyzed in a 2 (focus group) $\times$ 8 (blocks) analysis of variance (ANOVA) with repeated measures on the last factor. Furthermore, to analyze the *learning effect*, accuracy scores were averaged across the 20 trials for both the pretest and retention test and analyzed in a 2 (focus group) $\times$ 2 (test: pretest, retention test) ANOVA with repeated measures on the last factor.

2.4.2. The effect of attentional focus instructions on movement automatization

To examine if the effect of a dual-task on performance of the throwing task differed between the attentional focus groups, a 2 (focus group) $\times$ 2 (test: retention test, dual-task) ANOVA was conducted with the accuracy scores on the throwing task as the dependent variable. Furthermore, to examine whether the difference in accuracy scores between the single- and dual-task of tone counting differed between the attentional focus groups, a 2 (focus group) $\times$ 2 (test: single-task, dual-task) ANOVA was conducted,

Table 1
Instructions for external and internal focus of attention groups.

	External	Internal
Swinging	Ensure the ball has a backspin while swinging	Ensure your arm turns backwards while swinging
Throwing	Ensure you let the ball go when it is directed towards the target	Ensure you let loose when your arm is right in front of you
Reminder	Pay attention to the ball	Pay attention to your arm

Table 2

Coding scheme for the fragments reported in the manipulation check.

Code	Definition	Example
External	Directed at an external element of the task	“The ball”
Internal	Directed at an internal element of the task	“My arm”
Movement	Directed at elements of the movement without a clear external or internal focus	“Swinging and throwing”
Aiming	Directed at specific aiming elements without a clear external or internal focus	“The direction”
Goal	Directed at the end-goal of the task	“The circle in the middle”
Other	Other	“Keep concentrated”

with the accuracy scores on the tone counting task as the dependent variable.

2.4.3. The role of working memory

To investigate whether working memory influenced motor learning in a different manner for the external and the internal focus group, a hierarchical regression analysis was performed. Prior to the analysis, the variables verbal working memory and spatial working memory were standardized by subtracting the mean of each variable and dividing the results by the standard deviation. In the basic model, the main effects of attentional focus, verbal working memory, and spatial working memory were the predictors. Next, the two-way interactions between attentional focus and verbal working memory and attentional focus and spatial working memory were added to the model. The difference score between pretest and retention test served as the dependent variable.

2.4.4. Manipulation check

Finally, verbal answers on the manipulation check were explored following the procedure of [Perreault and French \(2016\)](#) and [van Abswoude et al. \(2018\)](#). The answers of the participants were divided into multiple fragments that were coded separately using the coding scheme that is displayed in [Table 2](#).

3. Results

The level of motor skills as assessed by the MABC-2 was similar among the external focus group ($M = 8.56$, $SD = 2.62$) and the internal focus group ($M = 8.76$, $SD = 2.72$); $t(160) = -0.48$, $p = .632$. Moreover, the external focus group ($M = 7.06$, $SD = 0.94$) and internal focus group ($M = 7.07$, $SD = 0.91$) did not differ on the average score among the first 20 trials of the Slingerball throwing task, $t(160) = -0.03$, $p = .977$.

3.1. The effect of attentional focus instructions on practice and learning

[Fig. 3](#) shows the average scores on the throwing task over time. Analysis of the *practice effect* showed a significant main effect for block, $F(7, 1120) = 9.87$, $p < .001$, $\eta_p^2 = 0.06$, indicating that performance on the throwing task improved with practice. Bonferroni post hoc analyses showed participants improved significantly from block 1 to block 4, and from blocks 1, 2, and 3 to blocks 6, 7, and 8. Furthermore, there was a significant main effect of condition, $F(1, 160) = 4.88$, $p = .029$, $\eta_p^2 = 0.03$, indicating that, overall, the external focus group ($M = 6.23$, $SD = 0.09$) performed better during practice than the internal focus group ($M = 6.52$, $SD = 0.09$). The interaction between block and condition was not significant, $F(7, 1120) = 1.31$, $p = .242$, $\eta_p^2 < 0.01$, indicating that the change in performance over blocks was similar for both focus groups.

Analysis of the *learning effect* showed a significant main effect for test, $F(1, 157) = 129.47$, $p < .001$, $\eta_p^2 = 0.45$, indicating that participants performed significantly better during the retention test ($M = 6.30$, $SD = 0.97$) than during the pretest ($M = 7.08$, $SD = 0.92$). However, neither the main effect of condition, $F(1, 157) = 0.05$, $p = .825$, $\eta_p^2 < 0.01$, nor the interaction between test

Fig. 3. The accuracy scores on the Slingerball throwing task during pretest, practice phase, retention test, and dual-task for the external and internal focus group separately.

and condition, $F(1, 157) < 0.01$, $p = .972$, $\eta_p^2 < 0.01$, was statistically significant. This indicates that the extent to which learning had occurred did not differ between the external and the internal focus group.

3.2. The effect of attentional focus instructions on movement automatization

For the throwing task, analysis of the dual-task showed a significant main effect for test, $F(1, 156) = 16.45$, $p < .001$, $\eta_p^2 = 0.10$. Unexpectedly, performance on the throwing task during dual-task ($M = 6.08$, $SD = 1.01$) was superior to that on the retention test ($M = 6.30$, $SD = 0.97$). However, neither the main effect of focus group, $F(1, 156) = 0.65$, $p = .423$, $\eta_p^2 < 0.01$, nor the interaction between test and focus group, $F(1, 156) = 2.44$, $p = .120$, $\eta_p^2 = 0.02$, was statistically significant. This indicates that the increase in performance accuracy on the throwing task from single-task to dual-task was similar for both attentional focus groups. For the tone counting task, there was again a significant main effect for test, $F(1, 156) = 47.34$, $p < .001$, $\eta_p^2 = 0.23$, performance accuracy of tone counting was higher during single-task ($M = 97.51\%$, $SD = 4.52\%$) compared to dual-task ($M = 93.23\%$, $SD = 7.81\%$). However, neither the main effect of focus group, $F(1, 156) = 0.59$, $p = .442$, $\eta_p^2 < 0.01$, nor the interaction between test and focus group, $F(1, 156) = 0.29$, $p = .592$, $\eta_p^2 < 0.01$, was statistically significant. This indicates that the decline in performance accuracy on the tone counting task from single-task to dual-task was similar for both attentional focus groups.

3.3. The role of working memory

For the role of working memory, we found that attentional focus and working memory did not affect children's motor learning, $F(3, 154) = 0.24$, $p = .867$ ($R^2 = 0.005$). Furthermore, the interaction between attentional focus and verbal working memory ($\beta = 0.07$, $p = .554$) and attentional focus and spatial working memory ($\beta = -0.03$, $p = .797$) did not significantly affect motor learning, nor did its inclusion improve model fit ($\Delta R^2 = 0.002$, $p = .955$). This indicates that verbal working memory and spatial working memory did not (differently) affect motor learning on the throwing task for the external and the internal focus group.

3.4. Manipulation check

Finally, the responses on the manipulation check are displayed in Table 3. Percentages of each coding category across the external and internal focus of attention group are presented for the first and second manipulation check separately. As expected, the external focus of attention group reported more external cues compared to the internal focus of attention group, and the internal focus of attention group reported more internal focus cues compared to the external focus of attention group.

4. Discussion

The main purpose of the current study was to examine both the *practice effect* (i.e., on immediate motor performance during practice) and *learning effect* (i.e., on motor performance after one week during retention) of attentional focus instructions. A large number of children ($N = 162$) participated in the study. This is the first study to examine attentional focus for motor learning and to distinguish *practice effect* from long-term *learning effect*. We found that the attentional focus only affected *practice*, but not *learning*. Children who received an external focus of attention demonstrated a higher throwing accuracy than children with an internal focus of attention. However, these beneficial effects of an external focus of attention were only present during practice and did not extend to the retention test one week later. This is in line with previous studies that found external focus benefits either during practice (Abdollahipour et al., 2015) or following a very short retention of 24–48 h after practice (Brocken et al., 2016; Flores et al., 2015; Hadler et al., 2014; Thorn, 2006). Our results, combined with those of previous studies (Abdollahipour et al., 2015; Brocken et al., 2016; Flores et al., 2015; Hadler et al., 2014; Thorn, 2006) therefore suggest that the benefits of an external focus are short lived and decline after a one-week interval.

Our findings on the differential effects of attentional focus instructions on *practice* and *learning* in children, are novel and extend previous results. Moreover, they provide new insight into the mechanisms for motor learning in children. According to traditional motor learning theories, motor learning processes are characterized by initial effortful and conscious stages that become more and more autonomous with further practice (Masters, 1992). During the early stages of motor learning, knowledge is rule-based and instructions are highly effective (Schmidt & Lee, 2005). Indeed, we showed that instructions related to an external focus of attention are particularly beneficial during *practice*. As Dreyfus (2004) argues, ultimately, it is the repeated practice and experience induced by

Table 3
Results of the manipulation check.

	Condition	External	Internal	Movement	Aiming	Goal	Other
M1	External	25%	13%	20%	20%	18%	4%
	Internal	8%	47%	13%	13%	14%	5%
M2	External	23%	12%	20%	16%	24%	6%
	Internal	7%	40%	23%	11%	14%	4%

M1, manipulation check 1; M2, manipulation check 2.

instructions, rather than the instructions itself, that allow motor learning to occur. This could explain why attentional focus instructions did not affect *learning*. Both attentional focus groups increased in throwing accuracy due to the repeated practice (Bernstein, 1996; Dreyfus, 2004). An alternative explanation could be that one day of practice may have been too short. Children may need an extended amount of practice before the beneficial effects of an external focus of attention will endure after practice.

The second aim of our study was to examine to what extent the automaticity of the Slingerball throwing task differed following practice with an external or internal attentional focus. Again, there were no differences between the external and the internal focus of attention groups, which is in line with the results on the *learning effect*. Unexpectedly, our results demonstrated that one week after practice, both attentional focus groups performed better on the throwing task in the dual-task condition as compared to the single-task condition. This is in contrast to previous studies that compared motor performance between single-task conditions and dual-task conditions. In a review study it was demonstrated that in general, interference effects are present when the primary motor task is combined with a secondary task (Huang & Mercer, 2001). These contrasting findings hint at the fact that the mechanisms of motor learning and attention differ between children and adults. It seems that children more strongly prioritize motor tasks in a dual-task situation than adults do (Schaefer, Krampe, Lindenberger, & Baltes, 2008). Schaefer et al. (2008) investigated dual-task performance in both children and adults. As expected, adults showed performance decrements in both the motor task and the cognitive task under dual-task conditions. In contrast, similar to our results, children improved their performance on the motor task. The authors argue that, since children have less developed motor skills compared to adults, children tend to invest more resources into the motor task than adults, to avoid putting their performance at risk. This prioritization does come at a cost for the cognitive task, which is performed worse in the dual-task condition, compared to the single-task condition. In addition, during data collection, we observed that the increased complexity caused by the additional tone counting task, made the children in the present study more alert such that they put more effort into the task. Empirical support for this speculation was found more than one century ago. Yerkes and Dodson (1908) demonstrated that the relation between physiological arousal and performance follows an inverted-U shape. An optimal level of physiological arousal exists, with under- or over-arousal adversely affecting task performance. Based on this inverted U-shape we speculate that the increased task demands caused by the additional tone counting task, may have caused an increase in physiological arousal, which may have ultimately led to improvement in performance as well. These findings in children warrant further investigation, as it may have important implications. An optimal level of arousal, and with that an optimal level of attention, is relevant for many settings in which children learn new skills, including education and sports. Finally, it should be acknowledged that the unexpected result could be due to a simple sequence effect, as all children performed the dual-task after the retention test (i.e., single task). However, this is unlikely considering the amount of practice participants already had.

The final aim of our study was to explore the role of working memory capacity for motor learning. Our results demonstrated that working memory did not predict the extent to which motor learning had occurred, neither after internal focus instructions, nor after external focus instructions. These results are consistent with previous research showing a lack of effect of working memory on motor learning of a golf putting task in general (Brocken et al., 2016; van Abswoude et al., 2018). Together these results question the role of working memory capacity for motor learning in general and more specifically for motor learning with an external versus an internal focus of attention. Possibly, the AWMA is not the most optimal way to measure working memory capacity in this study. The AWMA may have been too broad to reflect the specific aspects of working memory that are related to motor learning on the Slingerball throwing task. The AWMA is relatively complex and may therefore tap multiple executive functions. Furthermore, performance on the test may depend on a range of other cognitive abilities and general IQ as well. Further research should include a relatively simple, motor related test to measure the concept of working memory.

Finally, a limitation and one note of caution of the current study should be mentioned. Although the use of a manipulation check is a step forward in research on focus of attention effects in children, we believe that the way in which we performed the manipulation check might have a few shortcomings. First, the answers depend to a large extent on the verbal skills of the participants. Some children may not have been able to verbally report what they focused on during the task. Second, there is a risk for socially desirable answers, as indicated by children repeating the exact instructions or answering with “I focused on what you said”. Third, even though we used a straightforward coding scheme, the answers were sometimes susceptible for multiple interpretations. Finally, we would like to point out one note of caution on the manipulation of focus of attention. When manipulating focus of attention, minor differences in the wording can result in varying outcomes, which highlight the sensitivity of instructional nuances (Lewthwaite & Wulf, 2017). This may be related to the modest effect sizes in the current study and warrants further inquiry when studying the effects of attentional focus instructions. Nevertheless, the results question the beneficial effects of an external focus of attention for long-term motor learning in children. Further research is therefore warranted to examine the long-term effects of attentional focus instructions by including multiple measurements over a longer period of time. Furthermore, movement automatization should be examined at every measurement point, for example using a dual-task paradigm, to get more insight into the mechanisms underlying attentional focus instructions.

5. Conclusion

The current study adds to the limited research focusing on the effects of attentional focus instructions in children by including a large sample size, a baseline measurement of motor skills and task performance, and longer-term retention test and dual-task. The results of our study demonstrated that an external focus of attention is only beneficial during *practice*, but not for *learning* on the Slingerball throwing task. Furthermore, movement automatization as measured using a dual-task paradigm, and working memory involvement did not differ after external or internal focus of attention instructions. This is the first study demonstrating that the differential effect of attentional focus instructions on discrete motor tasks in children seems to be short lived and declines after a one-

week interval.

Declarations of interest

None.

Funding

This work was supported by the Behavioural Science Institute, Radboud University, The Netherlands.

Acknowledgements

The authors wish to thank the children and their parents, as well as the schools who participated in this research. Furthermore, the authors would like to thank Nienke Nuijen for her assistance in data collection, Roy Krajenbrink for his help with designing the figure that displays the task setting, and Gerrie Bulten for her help sewing the 'slingerballs'.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.humov.2018.06.010>.

References

- Abdollahipour, R., Wulf, G., Psotta, R., & Nieto, M. P. (2015). Performance of gymnastics skill benefits from an external focus of attention. *Journal of Sports Sciences*, 33(17), 1807–1813. <http://dx.doi.org/10.1080/02640414.2015.1012102>.
- Abernethy, B. (1988). Dual-task methodology and motor-skills research: Some applications and methodological constraints. *Journal of Human Movement Studies*, 14(3), 101–132.
- Alloway, T. P. (2007). *Manual automatized working memory assessment*. Oxford: Pearson.
- Bernstein, N. A. (1996). On dexterity and its development. In M. Latash, & M. T. Turvey (Eds.), *Dexterity and its development* (pp. 3–244). Mahwah, NJ: Lawrence Erlbaum.
- Brocken, J. E. A., Kal, E. C., & van der Kamp, J. (2016). Focus of attention in children's motor learning: Examining the role of age and working memory. *Journal of Motor Behavior*, 48(6), 527–534. <http://dx.doi.org/10.1080/00222895.2016.1152224>.
- Chiviacowsky, S., Wulf, G., & Wally, R. (2010). An external focus of attention enhances balance learning in older adults. *Gait & Posture*, 32(4), 572–575. <http://dx.doi.org/10.1016/j.gaitpost.2010.08.004>.
- Chow, J. Y., Koh, M., Davids, K., Button, C., & Rein, R. (2014). Effects of different instructional constraints on task performance and emergence of coordination in children. *European Journal of Sport Science*, 14(3), 224–232. <http://dx.doi.org/10.1080/17461391.2013.780097>.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Dreyfus, S. E. (2004). The five-stage model of adult skill acquisition. *Bulletin of Science Technology & Society*, 24(3), 177–181. <http://dx.doi.org/10.1177/0270467604264992>.
- Emanuel, M., Jarus, T., & Bart, O. (2008). Effect of focus of attention and age on motor acquisition, retention, and transfer: A randomized trial. *Physical Therapy*, 88(2), 251–260. <http://dx.doi.org/10.2522/ptj.20060174>.
- Flores, F. S., Schild, J. F. G., & Chiviacowsky, S. (2015). Benefits of external focus instructions on the learning of a balance task in children of different ages. *International Journal of Sport Psychology*, 46(4), 311–320. <http://dx.doi.org/10.7352/ijsp2015.46.311>.
- Hadler, R., Chiviacowsky, S., Wulf, G., & Schild, J. F. G. (2014). Children's learning of tennis skills is facilitated by external focus instructions. *Motriz: Revista de Educação Física*, 20, 418–422. <http://dx.doi.org/10.1590/S1980-65742014000400008>.
- Henderson, S. E., Sugden, D. A., & Barnett, A. (2007). *Movement assessment battery for children* (Second edition). London: Pearson (movement ABC-2).
- Huang, H.-J., & Mercer, V. S. (2001). Dual-task methodology: Applications in studies of cognitive and motor performance in adults and children. *Pediatric Physical Therapy*, 13(3), 133–140. <http://dx.doi.org/10.1097/00001577-200110000-00005>.
- Kal, E. C., van der Kamp, J., & Houdijk, H. (2013). External attentional focus enhances movement automatization: A comprehensive test of the constrained action hypothesis. *Human Movement Science*, 32(4), 527–539. <http://dx.doi.org/10.1016/j.humov.2013.04.001>.
- Lewthwaite, R., & Wulf, G. (2017). Optimizing motivation and attention for motor performance and learning. *Current Opinion in Psychology*, 16, 38–42. <http://dx.doi.org/10.1016/j.copsyc.2017.04.005>.
- Masters, R. S. W. (1992). Knowledge, knerves, and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology*, 83, 343–358. <http://dx.doi.org/10.1111/j.2044-8295.1992.tb02446.x>.
- Ong, N. T., Bowcock, A., & Hodges, N. J. (2010). Manipulations to the timing and type of instructions to examine motor skill performance under pressure. *Frontiers in Psychology*, 1. <http://dx.doi.org/10.3389/fpsyg.2010.00196>.
- Perreault, M. E., & French, K. E. (2016). Differences in children's thinking and learning during attentional focus instruction. *Human Movement Science*, 45(Suppl. C), 154–160. <http://dx.doi.org/10.1016/j.humov.2015.11.013>.
- Poolton, J. M., Maxwell, J. P., Masters, R. S. W., & Raab, M. (2006). Benefits of an external focus of attention: Common coding or conscious processing? *Journal of Sports Sciences*, 24(1), 89–99. <http://dx.doi.org/10.1080/02640410500130854>.
- Schaefer, S., Krampe, R. T., Lindenberger, U., & Baltes, P. B. (2008). Age differences between children and young adults in the dynamics of dual-task prioritization: Body (balance) versus mind (memory). *Developmental Psychology*, 44(3), 747–757. <http://dx.doi.org/10.1037/0012-1649.44.3.747>.
- Schmidt, R. A., & Lee, T. D. (2005). *Motor control and learning: A behavioral emphasis* (4th ed.). Human Kinetics Champaign, IL.
- Thorn, J. E. (2006). *Using attentional strategies for balance performance and learning in nine through 12 year olds*. Tallahassee: Florida State University [Doctoral dissertation].
- Totsika, V., & Wulf, G. (2003). The influence of external and internal foci of attention on transfer to novel situations and skills. *Research Quarterly for Exercise and Sport*, 74(2), 220–225. <http://dx.doi.org/10.1080/02701367.2003.10609084>.
- van Abswoude, F., Nuijen, N. B., van der Kamp, J., & Steenbergen, B. (2018). Individual differences influencing immediate effects of internal and external focus instructions on children's motor performance. *Research Quarterly for Exercise and Sport*, 1–10. <http://dx.doi.org/10.1080/02701367.2018.1442915>.
- Wulf, G. (2013). Attentional focus and motor learning: A review of 15 years. *International Review of Sport and Exercise Psychology*, 6(1), 77–104. <http://dx.doi.org/10.1080/1750984x.2012.723728>.
- Wulf, G., Hoss, M., & Prinz, W. (1998). Instructions for motor learning: Differential effects of internal versus external focus of attention. *Journal of Motor Behavior*, 30(2), 169–179. <http://dx.doi.org/10.1080/00222899809601334>.
- Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology*, 54(4), 1143–1154. <http://dx.doi.org/10.1080/02724980143000118>.
- Yerkes, R. M., & Dodson, J. D. (1908). The relationship of strength of stimulus to rapidity of habit formation. *Journal of Comparative Neurology*, 18, 459–482. <http://dx.doi.org/10.1002/cne.920180503>.