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Children's age modulates the effect of part and whole practice in motor learning

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A B S T R A C T

Motor skills can be learned by practicing the whole or part of a movement. In whole practice (WP), a skill is acquired by practicing the movement in its entirety, whereas in part practice (PP), a task is learned by practicing its components before combining them. However, the effectiveness of WP and PP in children is unclear. We, therefore, examined the effects of WP and PP on the learning of juggling among first-, third-, and fifth-graders. Children of each grade were pseudo-randomly assigned to the WP or PP group to learn cascade juggling in 6 days. After baseline assessments, the WP learners practiced three-beanbag juggling. The PP learners practiced one-beanbag juggling on the first 2 days, two-beanbag juggling on the following 2 days, and three-beanbag juggling on the last 2 days. Practice consisted of 40 trials each day. Skill retention and transfer trials (juggling in the opposite direction) were measured 24 h after training (number of catches). There was no significant difference between WP and PP in skill retention (WP: 1.28 ± 0.73; PP: 1.42 ± 046, $p = .40$) and transfer (WP: 1.31 ± 0.78; PP: 1.37 ± 0.55, $p = .49$). However, a time $\times$ grade $\times$ group interaction ($p < .001$) was observed in retention. Children of different grades received differential benefits from the WP and PP regimens. The fifth-graders learned better using WP, whereas the first- and third-graders showed better learning with PP. We discuss the three possible explanations for the results (neural maturity, explicit learning, and coordination capabilities).

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Research into practice modes for skill learning has important developmental and pedagogical implications (Yan, Thomas, & Thomas, 1998). Specifically, motor skills can be learned in parts or as a whole. Part practice (PP) refers to the learning of separate components of a skill, one part at a time, before combining them all. Whole practice (WP), on the other hand, is learning a skill in its entirety, all at once (Magill & Anderson, 2013). Conceivably, by breaking down a skill into smaller parts, the physical and cognitive demands placed on a learner can be reduced for more effective learning. However, learning is a complex process. The optimal learning effect can be obtained only when the type of practice specifically fits the characteristics of the learner and the skill to be learned (Newell, 1991). In addition, childhood is a period of remarkable changes in cognitive and motor competence. It is important to consider the dynamics of age, motor experience, and task characteristics before deciding on the optimal learning strategy (Yan et al., 1998). Therefore, questions remain about the best practice mode for skill learning in children. Depending on skill characteristics, PP and WP can yield different learning benefits for particular motor skills.

According to the Cognitive Load Theory (CLT; Wickens, Hutchins, Carolan, & Cumming, 2013), there are three sources of cognitive load during learning. The intrinsic load is the information processing demand of the target task to learn, the extraneous load is the distraction, and the germane load is the investment of effort by the learner. CLT posits that these loads rely heavily on learners' working memory (Wickens et al., 2013). Naylor and Briggs (1963) suggested that task complexity and skill organization are the key factors to consider for planning and implementing a practice mode. The complexity and skill organization of Naylor and Briggs's proposal (1963) should correspond to the intrinsic load of CLT (Wickens et al., 2013). The task complexity describes the cognitive and motor demands placed on a performer (Kuriyama, Stickgold, & Walker, 2004; Meister et al., 2005; Wulf & Shea, 2002), with more complex tasks placing more demands on the information processing speed and capacity. For instance, driving is more complex than finger tapping. Skill organization describes the inter-dependence between the components of a skill (Fontana, Mazzardo, Furtado, & Gallagher, 2009), with greater organization minimizing the demands on information processing because of greater predictability about how the components will interact with each other. For example, juggling requires greater inter-limb coordination between the hands than throwing does. Magill and Anderson (2013), Naylor and Briggs (1963) suggested that PP would be optimal for learning skills of high complexity and low organization, whereas WP may yield superior results in learning skills of low complexity and high organization. College-age adults learn juggling better with WP than with PP (Knapp & Dixon, 1952). In acquiring a bimanual coordination task, training both hands simultaneously (WP) shows less spatial interference (as observed in drawing lines of different orientations with two hands) than training one hand at a time (PP) (Wenderoth, Puttemans, Vangheluwe, & Swinnen, 2003). Furthermore, in older adults, WP results in more time-efficient, forceful and smoother movements than PP for the acquisition of a three-step signature task (to reach for a pen, bring a pen to a paper, and sign the name; Ma & Trombly, 2001). The findings show WP superiority for learning motor skills that are relatively low in complexity and relatively high in organization.

In adults' motor learning, the differential benefits of WP and PP are associated with skill characteristics (Naylor & Briggs, 1963). Although both WP and PP enhance the learning of certain motor skills, it does not necessarily mean that *children* of different ages benefit similarly from WP and PP. Children normally have lower cognitive or motor capabilities than adults (Gathercole, Pickering, Ambridge, & Wearing, 2004; Hale, Bronik, & Fry, 1997). Consequently, children may show unique developmental characteristics in motor learning (Thomas, Yan, & Stelmach, 2000; Yan, Thomas, & Payne, 2002; Yan, Thomas, Stelmach, & Thomas, 2000). A better understanding of the relative effects of WP and PP in children of different ages results in optimal and specific teaching approaches. This was the purpose of the present experiment.

Motor learning poses varying cognitive demands on children of different ages. Younger children have lower information processing ability (Hale et al., 1997). Based on CLT (Wickens et al., 2013), due to younger children's information processing limitations, they may experience greater intrinsic loads than older children in learning the same motor skill. Therefore, the learning outcomes of children in response to WP or PP may differ. Examining the learning outcomes of PP and WP in children may provide teachers and coaches with valuable pedagogical information. The results may help understand the role of child development in training strategies so that we can design rehabilitation for children with motor impairments. In this study, elementary school children practiced a beanbag juggling task using either PP or WP. Performance in a 24-h retention test can effectively predict relatively permanent changes in motor proficiency (Kantak & Winstein, 2012). We examined whether learning juggling skills by PP or WP led to differential outcomes in children of various ages. Considering the increasing capability of children to learn complex skills as they become older, we expected a significant interaction between the grade level and practice type on the average number of catches. Young children would benefit more from PP whereas older children would benefit more from WP.

1. Methods

1.1. Participants

A hundred and six first-, third-, and fifth-graders voluntarily participated in the study (Table 1). These children had no prior juggling experience, no known visual, neurological or motor deficits (based on parent-report). All children were right-handed, confirmed by the Edinburgh Handedness Inventory (Oldfield, 1971). Informed consent, approved by the Institutional Review Board of Beijing Normal University, was obtained from the parents prior to the experiment. Each child received a small gift at the end of the experiment.

1.2. Materials

The cascade juggling task is usually performed with professional stage balls, which are too big to fit into the hands of children. Beanbags are a suitable alternative to stage balls for young jugglers to catch and toss, increasing their confidence and maintaining practice motivation (Hautala, 1988). Thus, white beanbags ($4 \times 4 \times 4$ cm^3, approximately 50 g) were used for skill learning in this experiment.

1.3. Procedures

Data were collected in the gymnasium of a local primary school. Children from the same class (first-, third- or fifth-grade) were pseudo-randomly assigned to the WP or the PP group. The two sub-groups had equal numbers of males and females. The children started the cascade juggling by using their dominant hand in a baseline test and in an acquisition phase. Fig. 1A shows the procedures: on day 1, the baseline skill of three-beanbag juggling was assessed. Each child performed the three-beanbag juggling task 10 times. The number of catches before dropping a beanbag was recorded for each of the 10 trials.

From day 2 to day 7, the learners were given verbal instructions and demonstrations by the same well-trained experimenter before practicing the same juggling task. They practiced the skill simultaneously in the school playground for 4 blocks of 10 trials per day. On days 2 and 3, the PP learners practiced one-beanbag juggling; a trial ended after 10 tosses (back and forth between two hands) or when the beanbag dropped; the number of catches in each trial was recorded. The PP groups

Table 1
Demographics of participants.

Grade	Group[a]	Mean age (SD)	Sex (M/F)
First-graders	WP	6.82 (0.64)	11/6
	PP	6.53 (0.64)	8/8
Third-graders	WP	8.73 (0.77)	10/7
	PP	9.18 (0.73)	10/7
Fifth-graders	WP	10.94 (0.75)	11/8
	PP	10.95 (0.78)	13/7

[a] WP and PP refer to the whole practice and part practice groups, respectively.

A

	Baseline	Acquisition			Retention and Transfer
	Day 1	**Day 2, 3**	**Day 4, 5**	**Day 6, 7**	**Day 8**
Whole Practice (n = 53)	10 trials 3-beanbag juggling	**3-beanbag** 4 blocks of 10 trials, trial ends when beanbag drops	**3-beanbag** 4 blocks of 10 trials, trial ends when beanbag drops	**3-beanbag** 4 blocks of 10 trials, trial ends when beanbag drops	**Retention** 10 trials 3-beanbag juggling **Transfer** 10 trials 3-beanbag reverse juggling
Part Practice (n = 53)	10 trials 3-beanbag juggling	**1-beanbag** 4 blocks of 10 trials, 10 tosses each	**2-beanbag** 4 blocks of 10 trials, trial ends when beanbag drops	**3-beanbag** 4 blocks of 10 trials, trial ends when beanbag drops	**Retention** 10 trials 3-beanbag juggling **Transfer** 10 trials 3-beanbag reverse juggling

B

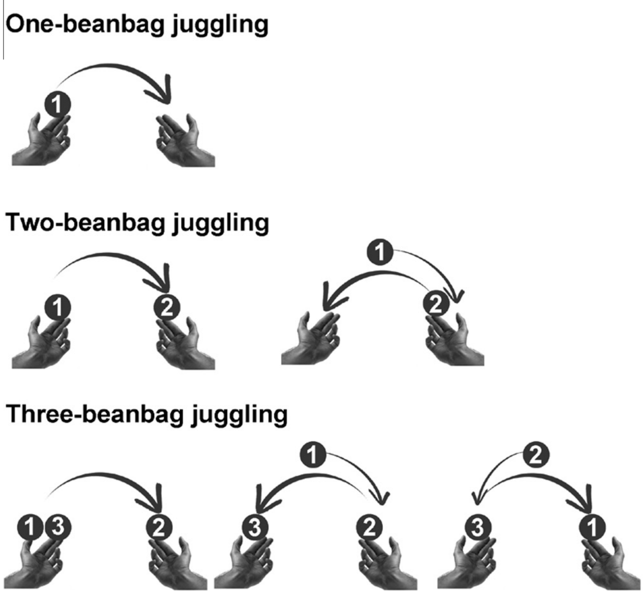

Fig. 1. Experimental procedures. (A) Baseline assessment was performed on day 1. Acquisition phase was from day 2 to day 7. Retention and transfer tests were conducted on day 8. (B) Steps to perform one-, two- and three-beanbag cascade juggling in the study.

practiced two-beanbag juggling on days 4 and 5, and three-beanbag juggling on days 6 and 7 (a trial ended when a beanbag was dropped). In two-beanbag juggling, the learners started tossing a beanbag from their dominant hand to their non-dominant hand. When the beanbag was at its apex, each child tossed another beanbag from the non-dominant hand to the dominant hand, and so on.

At the beginning of three-beanbag juggling, the children held two beanbags in their dominant hand and one beanbag in their non-dominant hand. They started tossing one of the beanbags in their dominant hand to their non-dominant hand. When the beanbag was at its apex, they tossed the beanbag from their non-dominant hand to their dominant hand. When the beanbag from the non-dominant hand reached its apex, they tossed another beanbag from the dominant hand to the non-dominant hand, and so on. In both two- and three-beanbag juggling, the number of catches before the first drop in each trial was recorded.

For all practice sessions, the WP learners practiced the skill in its entirety (three beanbags). A trial ended when a beanbag was dropped. To reduce fatigue, the children were given 3-min breaks between blocks. No juggling trials were allowed outside the experimental practice, and this was monitored by parents. Fig. 1B shows the steps required to perform cascade beanbag juggling. On day 8, a retention test (24-h retention test) was administered where the children performed three-beanbag cascade juggling 10 times without any feedback. In addition, a 10-trial transfer test was also included which required the children to do three-beanbag cascade juggling in the opposite direction.

1.4. Statistical analysis

The number of catches before dropping a beanbag was counted in every trial. Mean acquisition performance on each training day was computed as the dependent variable. A two-way mixed ANOVA was conducted for the WP group on the dependent variable with training day (training days 1–6) and grade level (first- *vs* third- *vs* fifth-grade) as within-subject and between-subject factors, respectively. The same two-way mixed ANOVAs were conducted for PP groups, separately for each beanbag condition (1, 2, or 3).

For baseline, retention and transfer analyses, grade level and practice type (WP *vs* PP) were independent variables. The maximum number of catches before dropping a beanbag was counted in every trial in the baseline, retention and transfer tests. The average number of catches was computed for each test as a dependent variable. A two-way between-subject ANOVA was conducted on the dependent variable at baseline with practice type and grade level as between-subject factors. A three-way mixed ANOVA was conducted on the dependent variable with practice type and grade level as between-subject factors, and time (baseline *vs* retention) as a within-subject factor. We also conducted a two-way between-subject ANOVA with grade level and practice type as between-subject factors on percentage of performance improvement (100 * (retention – baseline)/baseline) to see if the behavioral enhancement was comparable in WP and PP. Finally, analysis of transfer data was conducted with a two-way ANOVA with practice type and grade level as between-subject factors. Effect sizes were computed using the partial eta squared statistic. Post-hoc simple effects analyses were conducted with Bonferroni adjustments.

2. Results

2.1. Skill acquisition

The acquisition performance of WP and PP across training days is shown in Fig. 2. For WP groups, a significant training day × grade level interaction was observed, $F(10, 250) = 3.23$, $p < .01$, $\eta_p^2 = .11$. Relative to the first day of training, the first-graders and third-graders attained significant performance improvement on the fourth training day whereas significant improvement was observed on the third training day in the fifth-graders. Starting from the fourth training day, the third-graders performed better than the first-graders. The main effect of grade level was significant, $F(2, 50) = 14.49$, $p < .01$, $\eta_p^2 = .37$. The first- and third-graders had similar levels of performance whereas the fifth-graders had the highest performance. There was a significant main effect of training day on the acquisition performance, $F(5, 250) = 15.10$, $p < .01$, $\eta_p^2 = .23$. The performance started to improve on the third training day.

For the PP group, there was a significant main effect of training day in one-beanbag trials, $F(1, 50) = 13.84$, $p < .001$, $\eta_p^2 = .22$. Performance on training day 2 was better than that on training day 1. The main effect of grade level was significant, $F(2, 50) = 59.77$, $p < .001$, $\eta_p^2 = .71$. The first-graders did not perform as well as the third- and fifth-graders. The third- and fifth-graders showed no difference in performance. In two-beanbag practice, the main effect of training day was significant, $F(1, 50) = 18.06$, $p < .001$, $\eta_p^2 = .27$. Performance on training day 4 was better than that on training day 3. The main effect of grade level was also significant, $F(2, 50) = 49.85$, $p < .001$, $\eta_p^2 = .67$. The first-graders did not perform as well as the third- and fifth-graders. The third- and fifth-graders showed no difference in performance. In three-beanbag practice, there was significant

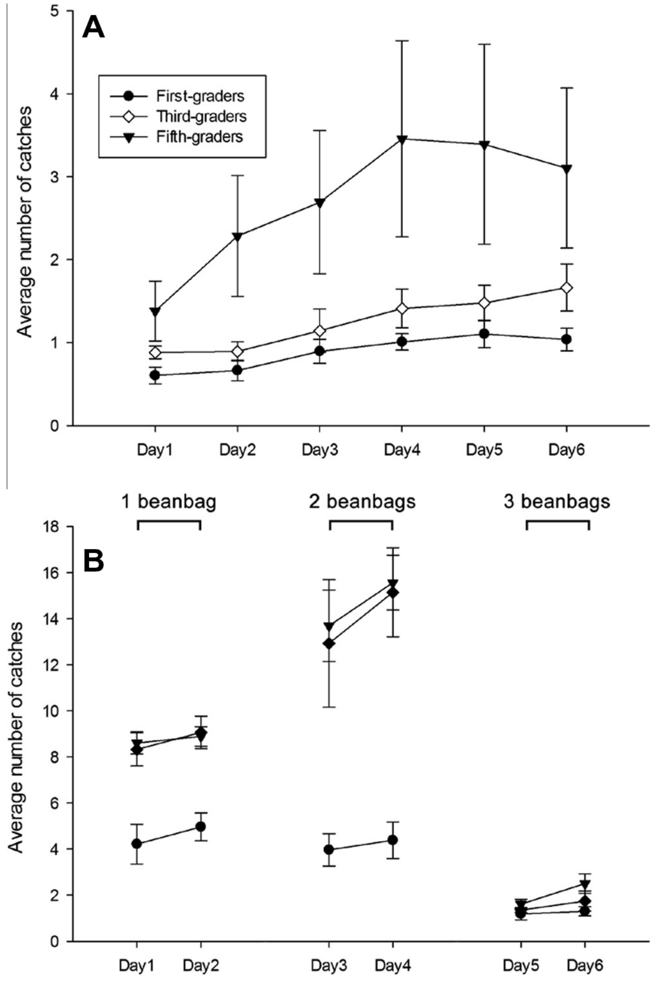

Fig. 2. Acquisition performance for children in the whole practice condition (A) and in the part practice condition (B). Error bars represent 95% CI.

training day × grade level interaction, $F(2, 50) = 3.47$, $p < .05$, $\eta_p^2 = .12$. On both training days 5 and 6, performance of the first-graders was poorer than that of the fifth-graders while there was no performance difference between the third- and fifth-graders on both days. Improvement was only observed in the fifth-graders from training day 5 to training day 6. Moreover, there were significant main effects of training day ($F(1, 50) = 13.92$, $p < .001$, $\eta_p^2 = .22$) and grade level ($F(2, 50) = 12.13$, $p < .001$, $\eta_p^2 = .33$) on juggling performance. Performance was greater on training day 6 than on training day 5. There was no performance difference between the first- and third-graders while the fifth-graders had the highest performance.

2.2. Skill retention

The time × grade × practice type interaction was significant, $F(2, 100) = 10.07$, $p < .001$, $\eta_p^2 = .17$. The first- and third-graders had better performance in the retention test than in the baseline in the PP condition only; whereas the fifth-graders benefitted from both PP and WP. In the baseline test in both PP and WP conditions, the first- and third-graders did not differ from each other while the fifth-graders had the highest performance. This was also true for the retention performance in the WP condition. However, there was no retention performance difference between the 3 grade levels in the PP condition. Baseline performance was similar for WP and PP in all grade levels. Thus, results should not be attributed to baseline performance differences. In retention test, PP first- and third-graders performed better than their WP counterparts, and the reverse was observed in the fifth-graders. Performance after WP in the fifth graders was superior to all other situations. Furthermore, the main effects of time ($F(1, 100) = 87.65$, $p < .001$, $\eta_p^2 = .47$) and grade level ($F(2, 100) = 21.58$, $p < .001$, $\eta_p^2 = .30$) were significant. Performance was greater in the retention test than at baseline. The level of skill in the juggling performance was not different between the first- and third-graders, and was the highest in the fifth-graders.

Further analyses showed that there was a significant interaction of practice type and grade level on performance improvement, $F(2, 100) = 7.78$, $p < .001$, $\eta_p^2 = .14$. The PP first- and third-graders showed greater improvement than their WP counterparts (first-graders: 106.1% *vs* 31.6%; third-graders: 103.5% *vs* 31.0%). The PP and WP fifth-graders did not show any significant difference in their level of improvement (71.1% *vs* 103.82%). In the WP condition, there was no difference between the first- (31.6%) and third-graders (31.0%) while the improvement was the highest in the fifth-graders (103.82%). In the PP condition, there was no difference in the level of improvement between the 3 grade levels. The main effect of practice type was also significant, $F(2, 100) = 8.56$, $p < .01$, $\eta_p^2 = .08$. Children showed greater improvement in the PP than in the WP condition. This is likely due to greater improvements in PP in first- and third-graders. Fig. 3A shows comparisons of baseline and retention tests of different practice type and grades.

2.3. Skill transfer

The grade $\times$ practice type interaction was significant, $F(2, 100) = 8.37$, $p < .001$, $\eta_p^2 = .14$. In WP, there was no difference between the first- and third-graders while the skill level of the performance was the best in the fifth-graders. In PP, there was no difference between the third-graders and the other grade levels while the first-graders' performance was poorer than the fifth-graders'. There was no transfer performance difference between WP and PP first-graders. PP third-graders had better transfer performance than their WP counterparts, whereas WP fifth-graders showed superior transfer performance to their PP counterparts. The main effect of grade level was also significant, $F(2, 100) = 22.84$, $p < .001$, $\eta_p^2 = .31$. Transfer performance was not different between the first- and third-graders, and was the best in the fifth-graders. Fig. 3B shows the skill transfer of groups with different practice types and grades.

3. Discussion

Our results support the hypothesis that children in different grade levels benefit differently from PP and WP. Grade level can be a proxy for age to interact with practice type for producing differential learning outcomes. The fifth-graders benefitted more from WP while the first- and third-graders learned better with PP. In fact, the number of catches was still low in retention and should not be regarded as skill mastery. However, the increase in the number of catches from baseline to retention represents an increased chance of successful execution of the skill and may indicate improved inter-limb and visuomotor coordination in the course of different juggling practices. We discuss the results from three perspectives which are potentially interrelated. In particular, neural maturation may be associated with both explicit learning and motor coordination.

3.1. Neural maturation

Neural maturation is associated with improvements in cognitive and motor performance (Casey, Giedd, & Thomas, 2000; Gogtay et al., 2004; Sowell, Delis, Stiles, & Jernigan, 2001; Sowell et al., 2003, 2004; Spear, 2000). Learning is an indirect behavioral measure of neuroplasticity (Dayan & Cohen, 2011). Our findings show the potential role of brain maturation in skill acquisition. Our results

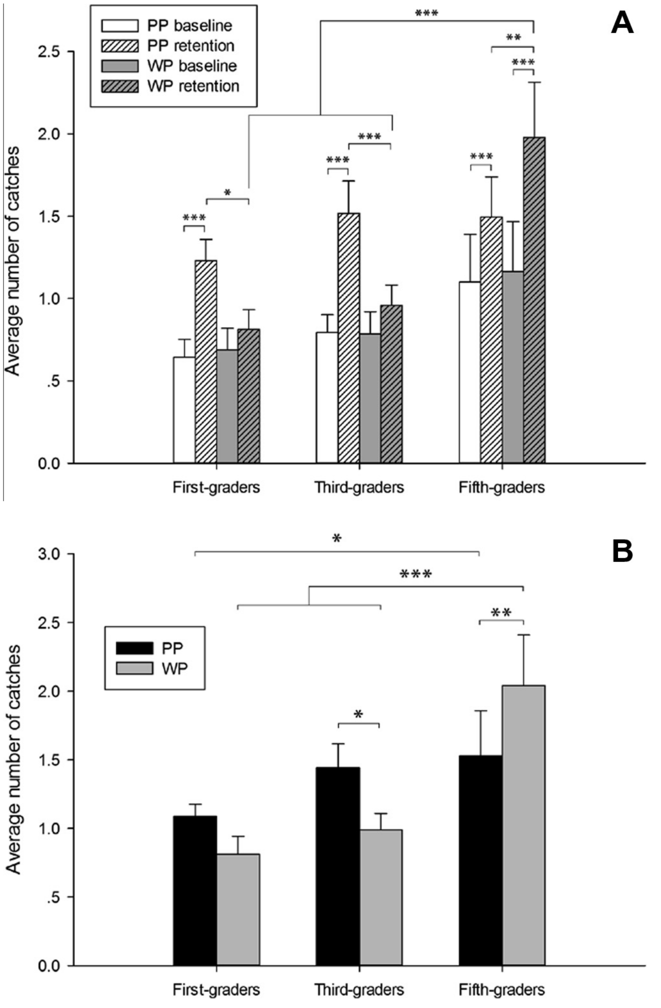

Fig. 3. Differential benefits of whole and part practices in students of different grade levels (WP = whole practice, PP = part practice, error bars represent 95% CI). (A) Baseline and retention performance. (B) Transfer performance. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

show that children of different ages benefit differently from PP and WP, suggesting that their learning potential may depend on neural maturity to support certain learning modes.

Optimal learning can be fully realized only when the neural areas supporting certain modes of learning are mature enough. These structures may include the frontal lobe, the cerebellum and the corpus callosum, all of which are indispensable for bimanual coordination. The frontal lobe supports the programming of sequential movement (Hernandez et al., 2002; Lepage et al., 1999), which is still maturing in late childhood (Giedd et al., 1999). The prefrontal cortex is associated with working memory, an ability to maintain and manipulate information in the mind (Luciana & Nelson, 1998). Working memory is crucial for motor learning, particularly for those with limited information processing ability (Maxwell, Masters, & Eves, 2003). In addition, the cerebellum is associated with the learning of complex bimanual coordination skills, and reaches its optimal volume at the ages of 11.8 years for females and 15.6 years for males (Diamond, 2000; Tiemeier et al., 2010).

Furthermore, serving as a bridge between the left and the right hemispheres, the corpus callosum does not complete its myelination before 10 years of age. Prior to this time, the functional efficiency of bimanual skills is sub-optimal (Jeeves, Silver, & Milne, 1988). The corpus callosum enables both excitatory and inhibitory activity between the 2 hemispheres of the brain (Bloom & Hynd, 2005). Behavioral results show that inter-hemispheric communication increases from 5 to 10 years of age in the bimanual coordination of a line-drawing task, which is in line with neuroimaging results (Fagard, Hardy-Leger, Kervella, & Marks, 2001). Additional evidence has suggested that maturation of the corpus callosum continues after adolescence (Giedd et al., 1996; Rajapakse et al., 1996; Thompson et al., 2000) and integrity of the corpus callosum can be related to one's working memory (Zahr, Rohlfing, Pfefferbaum, & Sullivan, 2009).

Both first- and third-graders learned better with PP. This suggests that the functions supported by the frontal lobe, the cerebellum, and/or the corpus callosum, are still undergoing development, and are not mature enough to support the learning of juggling skill in its entirety. From a neurobiological perspective, developmental constraints in the brain affect children's information processing ability and sensitivity to different training methods.

3.2. Explicit learning

Children of different ages have varying capabilities of learning when they are aware of what to learn (*e.g.*, explicitly learning a motor sequence). In implicit learning, however, such awareness or acknowledgment is absent. Motor learning of a juggling skill can be regarded as an explicit form of learning as this skill is complex, requiring a great deal of cognitive resources and conscious information processing from the learners in the early learning phase.

Previous studies have shown that implicit learning of task regularities is age-invariant (Amso & Davidow, 2012). Children of different ages differ from each other mainly in their explicit knowledge of a procedural skill (Thomas & Nelson, 2001; Vinter & Perruchet, 2000). CLT assumes that PP has a less intrinsic load than WP (Wickens et al., 2013). From this perspective, young children in this study did not have enough information processing capability to keep up with the requirements to learn explicitly with WP; this was not the case in PP where the requirements for explicit learning were relatively lower. In this view, the first- and third-graders might not have sufficient information processing ability and/or working memory for explicit procedural learning, whereas their older counterparts could readily succeed at 3-beanbag juggling.

3.3. Motor coordination

Motor coordination in children improves with age. This endows older children with a greater capability to acquire a new motor skill that requires more complex bimanual coordination. Movement sequencing ability in children improves with age. Learning of a temporal pattern of sequential movements improves with age in children aged 6–13 years and the improvements in executive functions and response speed predict learning outcomes (Shin, 2011). In addition, children show substantial improvements in eye–hand coordination while growing up. In a multi-limb coordination task, skill consistency in children increases with age (Getchell, 2006; Getchell & Whitall, 2003) and rhythmic movement stability increases from the age of 6 years to adulthood (James, Hong, & Newell, 2009).

Moreover, 7- to 10-year-olds have better bimanual coordination than 4- to 6-year-olds (Mason, Bruyn, & Lazarus, 2010). Stability of bimanual coordination also increases with age in childhood (Robertson, 2001). From 6 to 15 years of age, age is correlated with performance both in symmetric and asymmetric bimanual coordination (Marion, Kilian, Naramor, & Brown, 2003). With increasing age, from 6 years to young adulthood, temporal stability in bimanual line–circle drawing improves: particularly after 14/15 years of age (de Boer, Peper, & Beek, 2012). The higher coordination capability in older children may be a prerequisite for learning new coordination skills. Newell, Carlton, Fisher, and Rutter (1989) suggested that training with natural coordinated movements can facilitate motor skill acquisition. As the fifth-graders had greater ability to coordinate, getting used to the required coordination pattern was better for their skill learning. In contrast, the younger students (first- and third-graders) were less able to coordinate limbs to take advantage of practicing the required coordination pattern. Thus, their skill learning was thwarted in WP. By breaking down the skill into smaller and more manageable parts, they can master the skill more effectively, although they cannot assimilate the required coordination pattern to the same extent as the WP group.

3.4. Limitations

Several limitations were noted. First, the training program was relatively short. It is possible that younger children might show accelerated improvement later in a long practice period (Fig. 2). Secondly, WP and PP differ from each other not only in practice mode, but also in difficulty. This study cannot differentiate the effects of practice mode and difficulty on motor learning. Motor skills other than juggling may be used in future studies to examine the individual contributions of these two factors. Thirdly, retention performance was assessed 24 h after training. Assessing the maintenance of the skill improvement for a longer period would have been an interesting and worthwhile undertaking. Fourthly, a relatively small sample size was used. Future studies should use a larger sample to verify the present results. Fifthly, the length of practice trial varied as WP learners might drop the ball earlier in a trial. This may be controlled for by recording the average number of successful catches per trial after a fixed number of catches is reached. Lastly, interpretation of the one-beanbag acquisition should be treated with caution. The raw data showed that the one-beanbag juggling performance was nearly perfect in the fifth- and third-graders. Although children of the three grade levels showed similar performance increments in one-beanbag practice, a ceiling effect might have precluded us from drawing the conclusion that students from the three grade levels were equally responsive to one-beanbag practice.

4. Conclusions

WP and PP have differential benefits for motor learning in children of different grade levels. This may be attributed to developmental differences in neural maturity, information processing capability to support explicit learning, and motor coordination capabilities. It adds to Naylor and Briggs's theory (1963) that in addition to skill characteristics, a learner's maturational status is also critical in predicting motor learning with different practice types. This study bears pedagogical implications for motor skill learning in children.

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