

Examining motor learning in older adults using analogy instruction

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ABSTRACT

Objective: Previous studies have reported that analogy promotes stable motor performance under cognitively demanding situations such as stress and fatigue. However, it is unclear whether analogy is useful for motor learning among older adults, or whether the benefits of motor learning by analogy can be generalized to older adults. The present study examined these questions.

Methods and design: Groups of young and older table tennis novices learnt to perform a forehand topspin stroke in table tennis, receiving either analogy instruction or a set of explicit instructions. Afterwards, participants were asked to perform a motor task in three testing situations: dual-task, immediate retention and skill consolidation. Motor performance was assessed using a validated scoring system.

Results: Motor performance induced by analogy instruction was comparable to that induced by explicit instruction in both young and older adults. In addition, similar to young adults, the older analogy-instructed participants demonstrated more robust motor performance than their explicitly instructed counterparts in dual-task, immediate retention and skill consolidation testing situations.

Conclusions: Analogy instruction aided older adults in acquiring new motor skills, and the benefits of analogy to reduce the cognitive demand of motor learning can be generalized to the older population.

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1. Introduction

Motor learning, a process by which relatively permanent changes are made in the capability for movement (Schmidt, 1988), is an essential process throughout the lifespan. While children typically acquire fundamental motor skills to develop the competency to perform a range of functional motor tasks (Sullivan, Katak, & Burtner, 2008), older adults commonly learn new motor skills or relearn known motor skills to improve their psychological wellbeing, or to support their autonomy. Unfortunately, declining motor learning abilities with aging, manifesting as a slower rate of learning and reduced performance, are well documented (Bo, Borza, & Seidler, 2009; Fraser, Li, & Penhune, 2009;

McNay & Willingham, 1998; Serbruyns et al., 2015; Voelcker-Rehage, 2008). Although the acquisition of simple motor tasks appears not to be affected by aging, owing to sensory adaptation (Seidler, 2007a) and learning strategies (Rabbitt, 1997), a decline in motor learning in complex tasks has been shown with aging (Bo et al., 2009; Curran, 1997; Shea, Park, & Braden, 2006). For example, Curran et al. (1997) found that older adults (age range: 60–79) improved more slowly than young adults in a serial reaction time (SRT) task. Shea et al. (2006) reported that the ability to organize individual elements of movement sequences into sub-sequences was less efficient in older adults (age range: 65–68) compared with young adults. Converging evidence from various fields (e.g., cognitive science and neuroscience) suggests that this age-related decline in motor learning might be associated with impairments in sensorimotor and cognitive functioning, including working memory (Anguera, Reuter-Lorenz, Willingham, & Seidler, 2010; Bo et al., 2009; Colcombe & Kramer, 2003; Craik & Grady, 2002; Reuter-Lorenz et al., 2000; Voelcker-Rehage, 2008).

Working memory is a cognitive system that holds and manipulates information while performing cognitive operations (Baddeley, 1986), and is essential in motor learning. During motor

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learning tasks, instructions are often given by teachers or coaches to convey relevant information to learners (Hodges & Franks, 2002). Learners then use cognitive resources from working memory to process and manipulate the instructional information. Given a declining capacity for working memory with age (Balota, Dolan, & Duchek, 2000; Verhaeghen & Salthouse, 1997), older adults may encounter difficulty comprehending instructions. Moreover, if the amount of information conveyed by instructions exceeds the cognitive capacity of learners, learning may be less effective (Wulf & Weigelt, 1997). Therefore, instructions involving less cognitive demand are preferable for older populations to acquire motor skills. In this context, analogy may provide an appropriate method.

Analogy is a form of instruction that aids the learning of a new concept by relating it to a fundamentally similar concept (Gentner, 1983; Gentner, Anggoro, & Klibanoff, 2011; Schustack & Anderson, 1979). This technique is commonly used by sport coaches to convey motor skill information to learners. For example, swimming coaches may teach their students to 'kick like a dolphin' when they learn the butterfly swimming stroke, or rope skipping instructors may ask learners to 'jump like a rabbit' when they skip the rope. Using analogy instruction can help recipients to easily understand the techniques required to perform the skill effectively. In addition to facilitating understanding of instructions, previous studies have also shown that performance induced by analogy instruction is more robust than when induced by explicit instructions in cognitively demanding situations, such as psychological stress or dual-task conditions (Komar, Chow, Chollet, & Seifert, 2014; Lam, Maxwell, & Masters, 2009; Law, Masters, Bray, Eves, & Bardswell, 2003; Poolton, Masters, & Maxwell, 2007). For instance, in a motor learning study of table tennis, Liao and Masters (2001) taught a group of table tennis novices to perform a forehand topspin stroke with either analogy instructions or explicit instructions. The results showed that analogy instructed learners maintained stable table tennis skill, even under stressful experimental conditions, compared with explicitly instructed learners (Liao & Masters, 2001).

One recent study examined the use of analogy in motor skill acquisition among an older population (Kleynen et al., 2014). Kleynen et al. (2014) reported that older stroke survivors exhibited improvements in walking speed following analogy instruction. However, the study involved a small sample size and only two of three participants showed a significant improvement (Kleynen et al., 2014). As such, it remains unclear whether analogy-based methods are applicable for motor learning by older adults. Importantly, it is currently not clear whether the motor learning benefits induced by analogy instruction shown in previous studies (i.e., robust performance under cognitive demanding situations, Lam et al., 2009; Liao & Masters, 2001) can be generalized to older adults. The present study sought to clarify this question.

We examined the motor learning involved in performing a forehand topspin stroke in table tennis, based on the method used in Liao and Masters' (2001) study. Both young and older adults were instructed to perform the motor skill with two sets of instructions (explicit or analogy) in the learning phase. Following the learning phase, participants were required to perform the motor task under three testing conditions: the dual-task (DT), immediate retention (IR) and skill consolidation (SC) tests. We predicted that older participants would exhibit a slower learning rate than young adults, and that the analogy instruction groups of all ages would benefit more than the explicit instruction groups, showing more robust performance under dual-task test conditions and sustained performance in both immediate and long-term retention tests.

2. Methods

2.1. Participants

Thirty-six young adults (mean age = 21.9, SD = 2.3 years, range: 18–26) and 34 older adults (mean age = 66.9, SD = 4.6 years, range: 60–76) participated in the present study. All participants reported that they were right-handed, had no neurological diseases, no back pain, no chronic pain of the right forearm, shoulder or hand, and reported that they did not have any prior experience in table tennis. All participants also scored 24 or above in the Cantonese version of the Mini-Mental State Examination (Chiu, Lee, Chung, & Kwong, 1994), attained 20/20 vision in the visual acuity test (Ferris, Kassoff, Bresnick, & Bailey, 1982) with either corrective glasses or no glasses and scored 12 or above in the Digit-Span Memory Test (both forward and backward spans, Wechsler, Coalson, & Raiford, 2008). Participants received a full debrief and small financial reward upon the completion of the study. Human Research Ethics Committee of the Education University of Hong Kong approved the present study.

2.2. Apparatus

Two cameras (Model: G15, Canon) were positioned to record motor skill performance throughout the study. As in Liao and Masters' (2001) study, a table tennis ball machine (Donic/Newgy Robo-Pong 2000) was used to deliver a table tennis ball (DHS Three Star Ping Pong) from the opposite end of a standard table tennis table. The position of the ball machine was identical to that in the previous study (Liao & Masters, 2001). The frequency of ball delivery was 25 balls per minute for both young and older adults (Liao & Masters, 2001). The scoring system was identical to that in Liao and Masters' (2001) study, where the table was divided into different scoring regions and participants were asked to hit the table tennis ball to the region with the highest score as accurately as possible.

2.3. Design and procedure

The study consisted of two sessions, conducted 2 days apart. The first session started with the completion of the screening tests (digit-span memory test; MMSE-C) and a general introduction of the table tennis task and the scoring system. This was followed by the demonstration of the shake hand grip and the standard standing position (Tepper, Rosario, & Pruyn, 2002) to ensure that all participants used the same grip and standing position. All participants were then presented with a diagram showing the rotation of the ball in a topspin stroke. If the participant could not perform the topspin stroke, they received no score and were presented with the diagram again.

Participants were then randomly assigned to one of two instruction groups (analogy instruction group and explicit instruction group). In the analogy instruction group, participants were instructed to move the racket as if it was traveling up the side of a mountain (Poolton et al., 2007). In the explicit instruction group, participants were asked to follow instructions taken from a teaching manual (see Table 1). Participants then started the learning phase. Participants were required to perform 180 strokes in six blocks of 30 trials. A 3-min rest period was allowed between blocks. Upon completion of the learning phase, participants were asked to complete a verbal protocol questionnaire (refer to Appendix I), which required them to recall any techniques or strategies that they used during the learning phase (Liao & Masters,

Table 1
Instructions to Analogy and Explicit Groups.

Analogy Instruction	Explicit instruction
Move your racket such that it is traveling up the side of a mountain	<ol style="list-style-type: none"> 1. Feet are side on at 45° to the table 2. Knee bent and leaning slightly forward 3. Racket and freehand above the table and behind the end line 4. Racket in front of the body 5. Hips, waist, and shoulders rotate forward when serving 6. Elbow angle closes quickly 7. Weight transfer on the front foot 8. Snap the wrist at contact 9. The racket starts low and vertical (approximately knee height), with the racket moving forward and up, brushing the ball, finishing above head height

2001).

Following completion of the verbal protocol questionnaire, participants were given a 3-min rest before they continued with the dual-task test. In the dual-task test, participants were asked to perform 30 strokes concurrently with a backward counting task. Participants were asked to count backwards from 203 in sevens. To facilitate the process, each participant was asked to verbally count backwards from 30 for practice prior to the start of the dual-task test.

Finally, a 15-min rest was given to participants before the immediate retention test, in which they were required to perform 30 trials without the secondary task. This completed the first session. In the second session 2 days later, a skill consolidation test consisting of a block of 30 trials was conducted. The test was identical to the immediate retention test.

2.4. Data analysis

Performance during the learning and test phases was measured as the total score achieved by the participant in each task. Normality of the distribution of the performance scores and homogeneity of variance were checked with the Kolmogorov–Smirnov test ($p > 0.05$) and Levene's test ($p > 0.05$). To test whether there was an age-related learning rate, multilevel regression was used to examine changes in performance score across the learning tasks (B1–6 as a continuous variable) between young and older adults. To analyze the performance difference between the analogy and explicit instruction groups, we used a 2 (Age: Young adult vs Older adult) \times 2 (Group: Analogy instruction vs Explicit instruction) \times 3 (Test: DT, IR, SC) repeated measures analysis of variance. Post hoc t-tests with Bonferroni corrections were performed to account for any differences between different age groups and different tasks. To analyze working memory capacity differences between young and older adults, digit-span memory test scores were calculated by adding the number of lists reported correctly across forward span (maximum score of 18) and backward span (maximum score of 16). Independent samples t-tests were used to compare digit-span memory test scores between groups. In all analyses, Alpha (α) was set at 0.05 (two-tailed) for the significance criterion, and partial eta-squared (η^2) values were computed for the total variability of individual or combined factors.

Information reported in the verbal protocol questionnaires was categorized by two independent raters to assess the number of explicit rules written down by each participant. To be counted, rules had to be relevant to either the instructions or the motor skill execution. The scores of the two raters were averaged to give verbal protocol scores and a Pearson product-moment correlation

coefficient was used to assess the inter-rater reliability.

3. Results

3.1. Learning rate

The slope of the regression indicated that young adults (slope = 4.02) acquired the motor skill significantly faster than older adults (slope = 8.26, difference = 4.24, $p < 0.001$). The results are shown in Fig. 1.

3.2. Performance scores

Results revealed a significant main effect of Test ($F [1.87, 67.14] = 66.93, p < 0.001, \text{partial } \eta^2 = 0.65$), a significant main effect of Group ($F [1, 36] = 29.14, p < 0.001, \text{partial } \eta^2 = 0.45$) and a significant main effect of Age ($F [22, 36] = 5.01, p < 0.001, \text{partial } \eta^2 = 0.75$) on total performance scores. In addition, the analysis revealed significant interaction effects for Group by Test ($F [1.87, 67.14] = 13.44, p < 0.001, \text{partial } \eta^2 = 0.527$), Test by Age ($F [41.03, 67.14] = 1.71, p < 0.001, \text{partial } \eta^2 = 0.25$), and Test by Group by Age ($F [18.65, 67.14] = 1.85, p < 0.05, \text{partial } \eta^2 = 0.34$).

In the DT test, post hoc t-tests showed that performance in the analogy instruction groups was better than in the explicit instruction groups, for both young ($t [34] = 4.25, p < 0.001$) and older adults ($t [32] = 3.11, p < 0.001$).

In the IR test, post hoc t-tests also showed that performance in the analogy instruction groups was better than in the explicit instruction groups, for both young ($t [34] = 2.76, p < 0.001$) and older adults ($t [32] = 3.27, p < 0.001$). When comparing performance between the IR and DT tests for young adults, both instruction groups demonstrated significantly higher performance scores in the IR than in the DT test (Analogy: $t [19] = -7.85, p < 0.001$; Explicit: $t [15] = -3.98, p < 0.001$). In contrast, when comparing performance between IR and DT tests for older adults, the analogy instruction group had significantly higher performance scores in the IR than the DT test, whereas the explicit instruction group performed equally in the IR and the DT test (Analogy: $t [16] = -5.54, p < 0.001$; Explicit: $t [16] = -2.27, p > 0.05$).

Finally, in the SC test, we found no significant age-related differences. The analogy instruction groups demonstrated a significantly prolonged learning effect compared with the explicit instruction groups, for both young ($t [34] = 8.75, p < 0.001$) and older adults ($t [32] = 5.03, p < 0.001$). When comparing the performance between the IR and SC tests, both older and young analogy instruction groups demonstrated similar performance between tests (IR and SC) (young adults: $t [19] = 1.48, p > 0.05$; older adults: $t [16] = 1.13, p > 0.05$), while both older and young explicit instruction groups displayed a decrease in performance scores across the IR and SC tests (young adults: $t [19] = 1.48, p < 0.001$; older adults: $t [15] = 4.25, p < 0.001$). The results are shown in Fig. 2.

3.3. Digit-span memory test score

The results revealed a significant difference between young and older adults ($t [68] = -4.87, p < 0.001$), as shown in Fig. 3. The working memory capacity of older adults was significantly lower than that of young adults.

Meanwhile, moderation analysis was conducted to examine the moderating effect of working memory on the relationship between instruction and performance in both young and older adults. Instruction and working memory were entered in the first step of the regression analysis. In the second step of the regression analysis, interaction between instruction and working memory was then

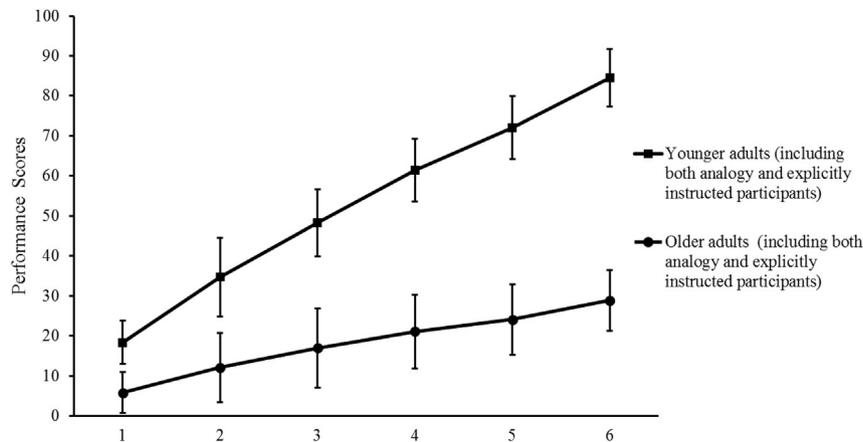


Fig. 1. The change of performance score between two instruction groups across the learning phase (B1 to B6) in each age group. Error bars represent SD.

entered. Results showed that working memory was a significant moderator of the relationship between instruction and performance in order adults ($\Delta R^2 = 0.06$, $F(1, 203) = 14.77$, $p < 0.001$) but not in young adults ($\Delta R^2 = 0.01$, $F(1, 215) = 0.025$, $p > 0.05$).

3.4. Verbal protocol questionnaire

The results of the Verbal Protocol Questionnaire rated by two independent raters showed satisfactory inter-rater reliability ($r = 0.95$, $p < 0.001$). The analogy instruction groups acquired significantly less explicit knowledge than the explicit instruction groups for participants in both age categories (young adults: $t_{34} = -9.02$, $p < 0.05$; older adults: $t_{32} = -8.67$, $p < 0.05$) as shown in Fig. 4. As expected, participants in the explicit instruction groups recalled more explicit knowledge than those in the analogy instruction groups.

4. Discussion

The present study examined the application of analogy instruction in motor learning among older adults, to test whether the motor learning benefits of analogy instruction shown in previous studies (e.g. Lam et al., 2009; Liao & Masters, 2001) could be generalized to an older population. The results showed that older adults were able to acquire a motor skill (performing a topspin

forehand stroke in table tennis) through analogy, as evidenced by increasing performance scores throughout the learning phase (Fig. 1). When a secondary concurrent task was imposed, the performance of analogy instructed older adults was more robust compared with their explicitly instructed counterparts. In addition, performance in the IR and SC tests confirmed the advantage of analogy instruction in motor learning among older adults. We found that older adults receiving analogy instructions retained the skill more reliably compared with those receiving explicit instructions, suggesting that analogy instruction produced a more persistent learning effect than explicit instructions. In addition to older adults, analogy instruction was also more beneficial for the motor performance of young adults. That is, the analogy instructed young adults achieved better performance than their explicitly instructed counterparts during cognitively demanding testing conditions (DT, IR and SC tests) (Fig. 2).

The benefits of analogy instruction shown in the present study may be explained by ‘chunking’. With analogy, complex rule structures involving many ‘bits’ of information relevant to the to-be-learned skill, may be integrated or “chunked” into a form that does not require conscious processing, and is therefore much simpler and easier to understand compared with explicit instructions (Masters & Liao, 2003). For example, the ‘mountain’ analogy used in the current study encompassed a number of task components, such as ‘the racket starts low’, ‘moving the racket

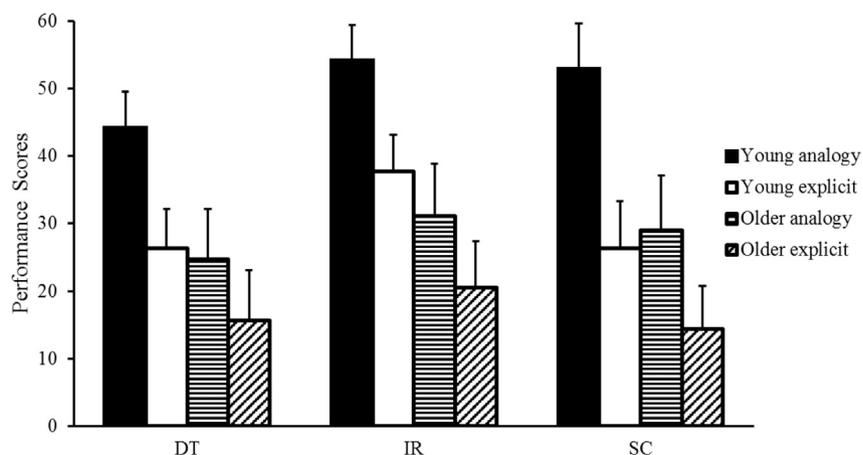


Fig. 2. The change of performance score between two instruction groups through dual-task (DT), immediate retention (IR) and skill consolidation (SC) in each age group. Error bars represent SD.

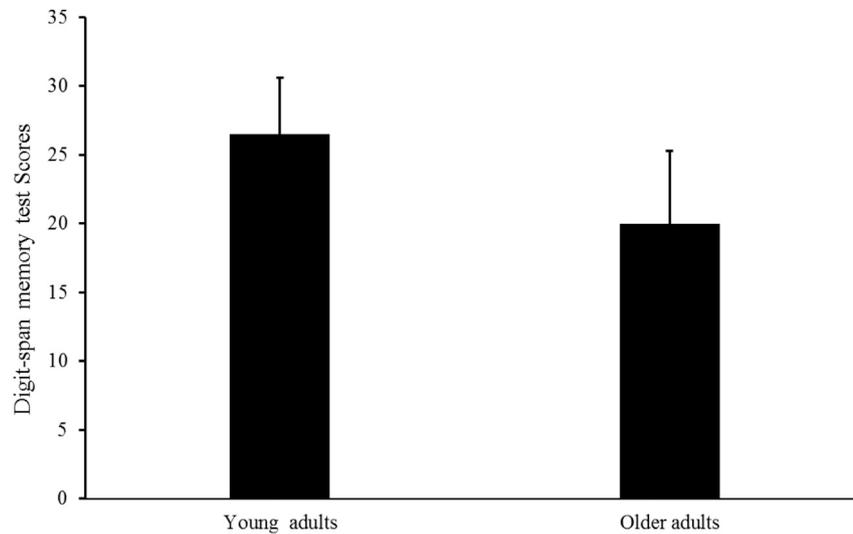


Fig. 3. Mean score of the digit-span memory test by each age group. Error bars represent SD.

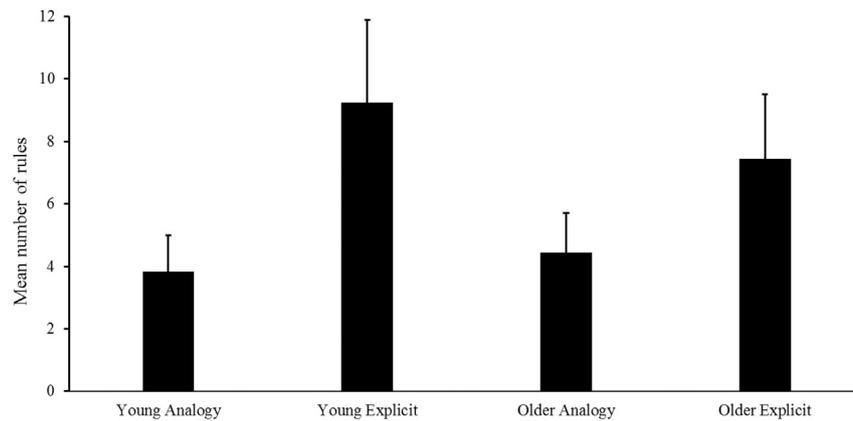


Fig. 4. Mean number of rules reported by each instruction group. Error bars represent SD.

forward and up' and 'finishing the movement above the head'. The use of chunking is also supported by our finding that fewer rules were recalled by the analogy instructed participants compared with the explicitly instructed participants in the verbal protocol questionnaire (see Fig. 4). If chunking was used, more attentional resources may have been freed up to cope with the extra cognitive demands posed by the secondary tasks (Poolton et al., 2007), leading to more resilient motor performance in the analogy instructed group. Moreover, if less cognitive resources were required in learning induced by analogy instruction, more resources would then be available for memorizing the structure of the motor movement, resulting in better consolidation of the motor skill (Fig. 2).

The present study also examined age-related differences in motor learning. The results revealed that the average learning rate of young adults was higher than that of older adults (Fig. 1), in accord with several previous studies (e.g. McNay & Willingham, 1998; Seidler, 2007b). One possible explanation is related to a difference in working memory capacity between young and older adults. A number of studies have suggested that young adults have higher working memory capacity than older adults (Brockmole & Logie, 2013; Craik & Grady, 2002; Hulstsch & Dixon, 1983; Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012; Salthouse & Babcock, 1991; Wingfield, Stine, Lahar, & Aberdeen, 1988).

Consistent with these previous findings, the current results showed that the working memory capacity of young adults was greater than that of older adults (Fig. 3). Moreover, the role of working memory capacity may be more significant in older adults than in young adults as suggested by moderation analysis between the instructions and motor performance. With greater working memory capacity, more of the declarative and procedural knowledge obtained from the learning process (see Anderson, 1982 for review) can be stored, allowing faster motor skill acquisition and better performance (Maxwell, Masters, & Eves, 2003).

However, this age-related difference appeared to be diminished by the effect of instruction type. In the present study, both young and older analogy instructed groups exhibited a similar performance pattern during the testing conditions, with both analogy instruction groups performing better than their age-matched explicit instruction groups. These findings further support the notion that the motor learning benefits of analogy instruction shown in young adults can be generalized to older adults.

Although the current findings supported both of our hypotheses (that analogy instruction is appropriate for motor learning in older adults, and that the benefits of analogy instruction in young adults can be generalized to older adults), several limitations should be considered when interpreting the results. First, there is a possibility that older adults were using adaptive learning strategies or

previous sports experience instead of relying on the instructions. Several previous studies (e.g., Bock & Girgenrath, 2006; Bock, 2005; Seidler, 2007a) showed that older adults were able to transfer adaptive motor skills to new movements when provided with extended practice or with previous experience. Older participants in the current study might have possessed pre-existing similar motor skills (e.g., another form of racket-type exercise) and adapted these motor skills to the current task. To avoid this potential confounding variable, participants should be screened with their past exercise experience in future studies. A skill-transfer test (e.g., badminton) with a similar movement to that in the experimental motor task (i.e., performing a topspin forehand stroke in table tennis) could also be implemented to examine whether an adaptive effect was involved. In addition, a 2-day separation may not have been long enough to test whether the skill was consolidated. Future studies should test the effects of a longer separation (e.g., a 1-week separation) on the skill consolidation test. Finally, the different number of instructions between the instruction groups may also affect the present findings. The reported results could be caused by the number of instructions (1 vs 9 instructions) rather than the nature of the instructions (analogy vs explicit instructions). Therefore, future studies in this field should control for the number of instructions to examine if the advantage of analogy could still hold true when the number of instructions between groups is equal.

5. Conclusions

The present findings suggest that analogy instruction may be beneficial for motor learning in older adults, leading to more resilient and persistent learning than explicit instructions. We propose that these benefits may be due to the implicit characteristics of analogy, which leave more cognitive resources available for additional cognitive load under divided attention conditions, and enable skill maintenance over a longer period of time. These characteristics of analogy may be particularly beneficial for older adults, whose working memory capacity, information processing speed and coordination abilities deteriorate with age. Further investigations should focus on more complex motor skill acquisition, and on elucidating the cognitive mechanisms of analogy learning in older populations. From a practical point of view, analogy instruction should be considered as an alternative option for sports coaches to teach older adults, and for physiotherapists to instruct their older clients in rehabilitation.

Appendix I

Verbal Protocol Questionnaire.

請閣下回想詳細闡述在剛才的學習環節上，你是怎樣發球。

Please describe how you perform the stroke throughout the learning phase.

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