



Research report

Sex differences in motor performance and motor learning in children and adolescents: An increasing male advantage in motor learning and consolidation phase gains

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ABSTRACT

We investigated gender differences in motor performance in 9-, 12-, and 17-year-olds. The tasks included simple thumb tapping (sTT), handwriting (HW) and finger-to-thumb opposition sequence (FOS) learning. In sTT there was a significant advantage for the 17-year-old males. In HW, 12-year-old females were faster, initially, than the males, but this gap was closed by a single training session; in the 17-year-olds although no significant difference was found initially, the males became faster than the age-matched females post-training. In the FOS, there were no initial gender differences (speed or accuracy). However, males benefited more from training, with the 17-year-old males attaining a significant post-training speed advantage. Moreover, males, of all three age-groups, evolved significantly larger delayed (“off-line”) performance gains in the FOS task compared to females; gains which were retained 6-weeks post-training. There may be a male advantage in motor learning rather than in motor performance per-se; this advantage is enhanced during adolescence.

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Many studies have addressed the question of whether or not motor performance abilities, in terms of either speed, accuracy or both, differ between the sexes at some stages of development [for reviews see 11,12]. Although there is compelling evidence that in physical strength and in many athletic domains adult males may perform better than age-matched females [for example, 9] it is not clear whether “peripheral” factors such as aerobic capacity, bone length or muscle mass [9,11,40,48] are at work or whether central nervous system factors also contribute to the males’ advantage, i.e., males have a real advantage in gaining skill (procedural knowledge) from training. It is also not clear whether differences between the sexes, in motor task performance, exist in childhood, and moreover whether gender differences are established during development [12,42]. Maturation factors, such as sex hormones [e.g., 54], may contribute to the establishment of gender differences in motor performance in puberty [34] however, it is not clear whether gender-related performance differences should be related to central nervous system differences rather than to peripheral factors, or even to cultural constraints on motor activities.

1. The nature of the motor task

There are some indications for gender-related differences in performance on tasks other than straightforward motor ones such as a male advantage in navigation [for example, 19] and mental rotation [for example, 1], as opposed to a female advantage in handwriting, [e.g., 3,10,17,55; but see 20]. Thus the nature of the task requirements may play a role in determining gender differences in performance, with, presumably, a male advantage in tasks requiring spatial manipulations and a female advantage when language skills were important.

An alternative proposal is that task complexity, or some aspects thereof, constitutes a factor in determining gender differences in motor performance [e.g., 22]. Thus, in simple (acute) motor tasks performed by adults, such as simple index finger tapping, there was often a male advantage in speed, although not in accuracy [22,36,42]. However, in pegboard tasks [5,42], handwriting tasks [3,10,52,55], and whenever more complex motor planning abilities were required [e.g., mirror drawing, 28], the performance of females was often found to be superior to that of males [5]. Nevertheless, other studies, using similar tasks, found no clear advantage for either male or female adults in the speed or accuracy of performance [12,20,22,36,50].

An example of the mixed results obtained on gender differences comes from handwriting studies. In both primary school children

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(8–12-year olds) [55] and high-school students (15–18-year olds) [10] females were found to have a significant advantage in hand-writing rate over males in a short copying task. On the other hand, in a longitudinal study that investigated the development of hand-writing in primary school children (7–11-year olds) using copying tasks, no significant differences, between males and females, in the speed of handwriting were found [20]. In addition, gender did not constitute a significant factor in the prediction of speed or accuracy of copying or of typing in 10-year olds [38].

2. A difference in motor learning?

There may however be another factor, or confound, that may significantly affect gender differences in motor performance, specifically, the potential for motor learning and the level of motor experience afforded in task acquisition. A recent study in motor learning in rats [7] has suggested that the learning of a motor skill may evolve in a somewhat different manner in males and females. Thus, on the one hand gender differences in performance may reflect gender differences in the level of experience in a given task (cultural effect), but on the other hand it may be the case that males and females differ in the rate of improvement in task performance even when an identical training experience is afforded. Given the former proposal one would predict that gender-related advantages may disappear or shift as a function of practice; a difference in the ability to acquire new motor skills would constitute strong support for a neurological difference between the sexes. The mixed results, on gender differences, obtained in studies of motor performance may reflect therefore the fact that most studies compared performance at a single time-point, i.e., without taking into account motor learning processes.

Recent studies of motor skill learning suggest that the evolution of skilled performance (procedural, “how to”, implicit, knowledge) in adults occurs during two major phases: the first, a “fast learning” phase, occurs during the training session with performance gains accrued concurrently with the training experience. This phase however was found to be relatively short and after a given number of task iterations, performance tended to reach asymptote [e.g., 21,26,31,43]. The second phase in the evolution of practice-related performance gains occurs during the hours and days after the termination of an effective training session. It was proposed that this phase reflects procedural memory consolidation processes that are triggered by the training experience but require time (and sometimes sleep) to reach completion. The procedural memory consolidation phase is characterized by significant delayed gains in performance—gains that appear hours and more after the termination of training, as well as by the evolution of robustness to interference [e.g., 6,16,26,27,29,31,41,46,51]. Delayed gains in motor performance were recently described also in children before and after the onset of puberty [14].

The aim of the two experiments reported here was to test the possibility that a gender difference in the ability to perform a motor task, as well as to acquire and retain a novel motor skill may contribute to gender differences in motor performance. Three well studied experimental paradigms were used to test these different aspects of motor performance. Because some aspects of motor memory consolidation were found to change in adolescence [14] we tested whether gender differences become more pronounced after adolescence. In the first study, performance speed in thumb-tapping task, and in a handwriting task was compared. The tapping task is considered a simple, highly stable motor agility measure [e.g., 30] while handwriting is a complex motor, language-related task [e.g., 4] that has been previously studied in the context of gender differences in performance, but not in learning. We surmised that a female advantage in handwriting may reflect a bias

in prior experience and that a practice session may result in the closing of the gender gap. In the second study we compared the initial performance, the fast within-session gains, the delayed, between-sessions gains and the retention at 6 weeks post-training of males and age-matched females in the FOS learning task. The aim was to follow the practice-dependent evolution of skilled motor performance, in the two sexes, in a task which was specifically designed to study training-dependent motor sequence learning and intensively studied in the context of motor memory consolidation [14,16,27,31,51]. The FOS task is unrelated to language and could be of equal novelty for participants of both sexes. Because no prior study has suggested a gender difference in motor memory acquisition we expected that no such differences would be found. Contrary to our expectations, our results clearly indicated a male advantage in motor learning (rather than in motor performance *per-se*) and that this advantage may be enhanced during adolescence.

3. Methods

3.1. Participants

One hundred and sixteen participants, of three age-groups, took part in the two experiments: Group 1: 9-year-olds (17 girls and 20 boys, $M=8.55$ years, range = 8.24–9.2), Group 2: 12-year-olds (21 girls and 19 boys, $M=11.51$ years, range = 11.2–12.2), Group 3: 17-year-olds (19 girls and 20 boys, $M=16.63$ years, range = 16.33–17.5). Four 9-year-old males, three 12-year-olds (1 girl and 2 boys), and one 17-year-old male did not participate in the writing task. Participants were recruited from schools in a suburban neighbourhood of middle to high socioeconomic level, by fliers addressed to parents. Participants were right-handed, had no outstanding medical conditions that could impair fine motor performance, reported at least 6 h of sleep per night, and had no sleep–wake-cycle disruptions. All were native Hebrew speakers, attending elementary, middle and high school in accordance with their age. Inclusion criteria included 5/5 digits remembered in a forward digit span test. The experiment was approved by the University of Haifa human experimentation ethics committee and Israeli Ministry of Education; informed parental consent was obtained.

3.2. Tasks and procedures

Three different tasks were used. Experiment 1 included two tasks: (a) the simple thumb-tapping task, performed with the dominant and the non-dominant hand, and (b) an invented word writing task with the dominant hand before and immediately after a practice session. Experiment 2 included two sessions, a day apart, of the FOS learning task, as well as a retention test by 6 weeks post-training.

In the simple thumb-tapping task participants were instructed to press a counter key with their thumb, repetitively, as many times as possible in a 30 s measurement interval. Participants were asked to perform the tapping task with each hand separately in turn. Participants performed the instructed movements in a comfortable sitting position. The dependent variable in the thumb-tapping task was the number of tapping movements executed during the 30 s interval.

In the handwriting task, participants were instructed to write one of two invented pronounceable target non-words (a 5 letter string and its reverse). The non-words were written in the participants' native language, Hebrew, on a sheet of A4 paper positioned on top of a digitizing tablet (WACOM Intuos 2, 17.5 in. × 17.1 in. × 1.5 in. active area 12 in. × 12 in.) using an inking stylus (i.e., participants were able to see their writing product). The handwriting movement recordings were acquired at 100 Hz sampling rate and a nominal accuracy of 0.02 mm. The task was performed in the seated position with the distance from, and the height of, the workspace, individually adjusted so as to maintain an angle of about 90° at the elbow. The target non-word was continuously presented, in print, on the top of the writing workspace and participants were instructed to write as fast and as accurately as they could, filling in a column of pre-indicated spaces. Participants were instructed to continue with the task without pause if any error occurred. The session consisted of 11 consecutive columns (blocks), each containing 14 repetitions (trials) of the target non-word. The dependent variables in the handwriting task, measured and analyzed separately, were: (a) mean word writing time—calculated as the mean time of completing two successive columns (each column representing an experimental block) (1 column, 14 trials) of writing divided by the number of trials; (b) the number of spelling errors per block.

Experiment 2 included two videotape-recorded sessions, on successive days, of the FOS task as previously described [14] as well as a retention test. Participants were instructed to oppose the fingers of the left (non-dominant) hand to the thumb in a given five movement sequence “as fast and accurately as possible”. Two sequences of equal length and complexity were used, each being the reverse of the other. These were (numbering the fingers 1–4, with one designating the index finger and four the

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