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Perceptual and Motor Performance of Combat-Sport Athletes Differs According to Specific Demands of the Discipline

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Abstract

The specific demands of a combat-sport discipline may be reflected in the perceptual–motor performance of its athletes. Taekwondo, which emphasizes kicking, might require faster perceptual processing to compensate for longer latencies to initiate lower-limb movements and to give rapid visual feedback for dynamic postural control, while Karate, which emphasizes both striking with the hands and kicking, might require exceptional eye–hand coordination and fast perceptual processing. In samples of 38 Taekwondo athletes (16 females, 22 males; mean age = 19.9 years, *SD* = 1.2), 24 Karate athletes (9 females, 15 males; mean age = 18.9 years, *SD* = 0.9), and 35 Nonathletes (20 females, 15 males; mean age = 20.6 years, *SD* = 1.5), we measured eye–hand coordination with the Finger–Nose–Finger task, and both perceptual-processing speed and attentional control with the Covert Orienting of Visual

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Attention (COVAT) task. Eye–hand coordination was significantly better for Karate athletes than for Taekwondo athletes and Nonathletes, but reaction times for the upper extremities in the COVAT task—indicative of perceptual-processing speed—-were faster for Taekwondo athletes than for Karate athletes and Nonathletes. In addition, we found no significant difference among groups in attentional control, as indexed by the reaction-time cost of an invalid cue in the COVAT task. The results suggest that athletes in different combat sports exhibit distinct profiles of perceptual–motor performance.

Keywords
Karate, Taekwondo, elite athletes, perceptual-processing speed, eye–hand coordination, attentional control

Introduction

Athlete selection and training is critical to the development of future Olympic gold medalists and champion sports teams. Reliable knowledge of the abilities that contribute to elite performance in a particular sport might aid the early identification and training of talented athletes (Abernethy, 1994; Magill, 1993). Athlete selection has previously relied on anthropometric measurements, such as height, weight, arm length, and body mass (Kerr et al., 2007), and dynamometric measurements of muscle strength and muscle power (Lawton, Cronin, & McGuigan, 2013). Some have used more complex assessment methods, such as tests of anticipation and decision-making skills (Baker, Cote, & Abernethy, 2003; Roca, Williams, & Ford, 2012). However, much less is known about how specific measurements of perceptual and motor performance might inform the selection and development of athletes for combat-sports activities.

Perceptual Performance of Elite Athletes

Outstanding performance in combat sports requires expert skill, high levels of muscle strength and power, and a well-developed ability to coordinate multiple muscle groups to execute appropriate movements (Markovic, Suzovic, Kasum, & Jaric, 2016). Perceptual performance also makes a significant contribution to an athlete's success. Fast and accurate processing of perceptual information facilitates decision making, helps athletes to anticipate the movements of opponents or teammates, and allows more time for the preparation and execution of motor behaviors (Houlston & Lowes, 1993; Ripoll, 1991).

Several studies have demonstrated that skilled athletes have distinct profiles of perceptual performance that are suited to the nature of their sport. For example, expert soccer players perform a more efficient visual search for informative elements of an open-play video sequence compared with beginners; eye-tracking data indicate that expert soccer players exhibited more fixations (4.5 vs. 3.9, $\eta_p^2 = .36$) of shorter duration (933 ms vs. 1,163 ms, $\eta_p^2 = .40$) than beginners (Williams, Davids, Burwitz, & Williams, 1994). Starkes (1987) reported that, among field-hockey players, members of the national team were more accurate (79%) than university-level players (62%) and novices (61%) in determining the optimal offensive move based on brief (< 20 ms) visual exposure to a game scenario ($\eta_p^2 = .43$). Similarly, experienced tennis players were superior to inexperienced players in predicting the terminal location of a ball by using motion cues in an opponent's swing ($\eta_p^2 = .05$, Isaacs & Finch, 1983; $\eta_p^2 = .31$, Jones & Miles, 1978). These studies, and many others, emphasize the relationship between perceptual performance and elite performance in ball sports.

Elite performance in combat sports also depends critically on perceptual performance. During competition, two athletes face each other at a small distance and make offensive attacks. Because of the proximity of the two athletes, an opponent's position, heading, and movements need to be rapidly analyzed so that appropriate offensive and defensive maneuvers can be executed. Consistent with this notion, Williams and Elliot (1999) reported that rapid initiation of a response movement after detecting the initiation of the opponent's attack was more accurate for expert Karate athletes (41%) than for their novice counterparts (16%; $\eta_p^2 = .74$).

Eye–Hand Coordination

Successful execution of visuomotor tasks requires good eye–hand coordination. For example, while reaching for a coffee cup, limb movements are continuously adjusted by the motor system through feedback from the visual and proprioceptive systems (Bekkering & Sailer, 2002). In these situations, humans initiate a saccade toward the target about 30 microseconds before beginning the accompanying hand movement, and the eyes land on the target around the time that the hand reaches peak acceleration (Lavrysen, Elliott, Buekers, Feys, & Helsen, 2007). Past studies have demonstrated superior eye–hand coordination among athletes, including swimmers (Hsu et al., 2010; Wong et al., 2011) and Tai Chi practitioners (Pei et al., 2008; Wong et al., 2011). Wong et al. (2011) found that training in Tai Chi improved both balance and eye–hand coordination, whereas swimming training improved only eye–hand coordination. While their study assessed elderly participants who were already practitioners at the time of recruitment, it nevertheless demonstrates that eye–hand coordination may differ according to the requirements of a given sport. In a similar fashion, we propose that the practitioners of two different combat sports might differ in their eye–hand coordination owing to differences in the nature of the two disciplines.

Perceptual-Processing Speed

Kim and Petrakis (1998) demonstrated that speed of perceptual processing varied between Karate athletes at three stages of learning: white belt (beginner), blue belt (intermediate), and black belt (advanced). They measured perceptual speed with the Identical-Pictures Test, a time-constrained multiple-item test of perceptual judgments. Their results indicated that perceptual-processing speed improved with increasing Karate experience ($\eta_p^2 = .19$). Kim and Petrakis also noted that the superior performance of black-belt athletes might reflect their experience and resulting perceptual development; or it might suggest that those athletes with inherently superior perceptual abilities were simply more likely to excel at the sport. Several other studies also indicate that relative to novices, expert Karate athletes exhibit superior processing of visuospatial stimuli—for example, in a simple reaction-time task (204 vs. 238 ms; Fontani, Lodi, Felici, Migliorini, & Corradeschi, 2006).

Mori, Ohtani, and Imanaka (2002) have shown faster perceptual processing among Karate athletes than among Nonathletes in choice reaction-time tasks requiring spatial discriminations on a vertical axis. Their participants were asked to judge whether the offensive action observed in a video stimulus would terminate at the upper or the middle level of their own body. Response time for correctly judging the height of the blow was significantly shorter for Karate athletes than for Nonathletes ($\eta_p^2 = .64$). Similarly, Karate athletes were faster than Nonathletes to report whether a dot stimulus appeared above or below a fixation point ($\eta_p^2 = .10$). However, owing to the longer movement times required for the lower extremities, Taekwondo athletes may be expected to show even faster perceptual processing than Karate athletes.

Attentional Control

Few previous studies have investigated attentional control among combat-sport athletes. In a notable exception, Del Percio et al. (2009) used the Covert Orienting of Visual Attention (COVAT) task with Karate athletes and Nonathletes to investigate how fatigue influences attentional control. In the COVAT task, participants must make a speeded response to a target: On *valid* trials, the target appears in a location indicated by a pre-cue, and on *invalid* trials, the target appears in a location different from that indicated by the pre-cue. Del Percio et al. found that the proportion of correct responses to invalid trials declined significantly following a muscular fatigue protocol for Nonathletes but not for Karate athletes. However, it is difficult to rule out the possibility that a difference in general fitness and conditioning, rather than Karate expertise per se, was the primary reason for the observed differences in attentional control.

Purpose and Primary Hypotheses of the Present Study

The primary purpose of the present study was to examine potential perceptual–motor performance criteria for selecting elite combat-sport athletes. We hypothesized that the specific nature of a combat-sport discipline would be associated with a distinct profile of performance on perceptual and motor tasks. For example, Taekwondo—which emphasizes kicking techniques—might require fast perceptual processing to compensate for longer movement times of the lower extremities and to provide rapid visual feedback to facilitate dynamic postural control. In contrast, Karate—which emphasizes both kicking and hand techniques (for example, punching and throwing)—might require superior eye–hand coordination.

Taking into account the different demands of Karate and Taekwondo, we propose the following primary hypotheses.

> H1 (*eye–hand coordination*): Karate athletes will be faster than Taekwondo athletes and Nonathletes in the Finger–Nose–Finger (FNF) test of eye–hand coordination.
>
> H2 (*perceptual-processing speed*): Taekwondo athletes will have faster simple reaction time than Karate athletes and Nonathletes in the COVAT test of perceptual-processing speed.
>
> H3 (*attentional control*): Both Karate and Taekwondo athletes will have a smaller difference in response time between valid and invalid trials (*invalid-cue effect*; ICE) than Nonathletes in the COVAT test of attentional control.

Methods

Participants

We recruited subjects in three groups: (a) experienced Taekwondo athletes ($n = 38$; 16 females, 22 males; mean age = 19.9 years, $SD = 1.2$), (b) experienced Karate athletes ($n = 24$; 9 females, 15 males; mean age = 18.9 years, $SD = 0.9$), and (c) a control group of Nonathletes who did not practice any sport ($n = 35$; 20 females, 15 males; mean age = 20.6 years, $SD = 1.5$). Athletes were recruited from one of the top three sports-related universities in Taiwan, and all had more than 8 years of competition experience in combat sports. At the time of recruitment, they were undertaking regular training sessions totaling at least 6 hours per week. All participants reported normal or corrected-to-normal visual acuity and color vision and had no obvious sports injury at the time of testing. After explaining the purpose and procedures of the study, informed consent was obtained from each participant. The study was approved by the Ethical

Committee of the National Taiwan University of Sport and supported by the Ministry of Science and Technology in Taiwan.

Measures

Each participant completed the full testing regime within a single day. The order of the tasks was counterbalanced between participants within each group.

FNF task. The FNF task is commonly used to examine eye–hand coordination in neurological patients such as those with cerebellar disorder or action tremor (Louis, Applegate, Borden, Moskowitz, & Jin, 2005; Louis, Ford, Wendt, Lee, & Andrews, 1999). The FNF task is simple to perform and is highly valid and reliable, both for patients with neurological disorder and for neurologically normal individuals (Louis et al., 2005). The validity of the FNF task is demonstrated by strong correlations with gross and fine finger dexterity ($r = .82$–$.84$) and global upper-extremity performance ($r = .74$–$.79$) among patients with ataxic disorder (Gagnon, Mathieu, & Desrosiers, 2004). In adults with traumatic brain injury, intraclass correlation coefficients (ICCs) for interrater reliability were .92 and .91, and ICCs for intrarater reliability were .97 and .99, for right and left upper extremities, respectively (Swaine & Sullivan, 1993). However, performance on the FNF task is usually measured with a stopwatch, which may not be a suitably sensitive instrument to quantify the perceptual–motor performance of athletes. For the purposes of this study, we designed an electronic assessment tool for use with the task (the FNF apparatus). The FNF apparatus consisted of two spheroid sensors mounted at opposite ends of a T-shaped stand (Figure 1). The two spheroid sensors, and an additional nose-case sensor, were connected to a computer for data collection.

The participant was seated in a comfortable chair with a back support—which discouraged him or her from leaning forward to reduce the distance to the spheroid sensors—and was asked to put on the nose-case sensor. The stand was placed in front of the participant, at a distance equal to his or her shoulder width. The height of the stand was adjusted to the level of the nose-case sensor, and the distance between the two spheroid sensors was adjusted to the participant's shoulder width. After the FNF apparatus was adjusted, the participant completed 10 practice trials. At the beginning of each trial, the index finger of the testing hand was touching the nose-case sensor. The participant was required to move the index finger to touch one of the two spheroid sensors, then to return it to touch the nose-case sensor again. Timing began when the finger left the starting position and ended when the finger returned to the nose-case sensor. Participants were asked to avoid head and body rotation toward either of the spheroid sensors. We excluded any trial in which the participant did not accurately touch the spheroid sensor or the nose-case sensor. In total, fewer than 5% of trials were excluded.

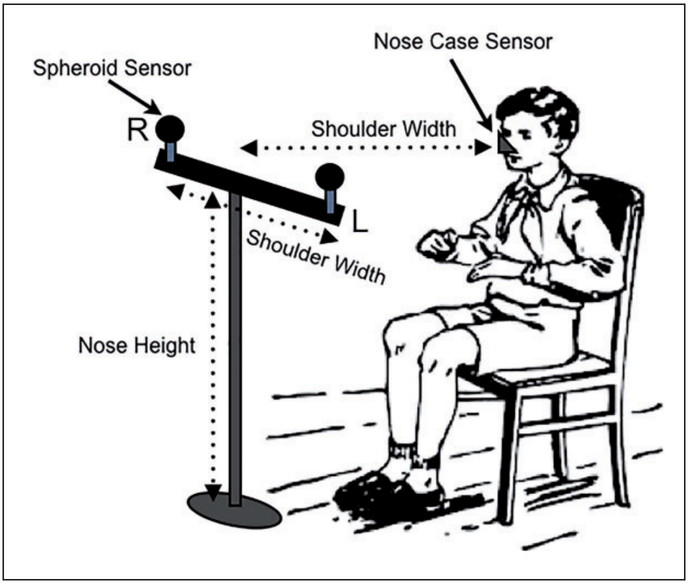

Figure 1. Schematic of the Finger–Nose–Finger task.

Each participant completed four testing sessions of 40 trials each, comprising 20 right-touching and 20 left-touching trials. In two of the sessions, participants used their dominant hand, while in the other two sessions, they used their nondominant hand. Within each session, participants alternated between right-touching and left-touching trials, performing each movement as quickly and as accurately as possible with no break between trials. There was a minimum break of 5 minutes between sessions. Our index of eye–hand coordination was calculated separately for the dominant and nondominant hands by taking the mean duration of all trials successfully completed with that hand.

COVAT task. The COVAT task is derived from Posner's (1980) classic cueing paradigm, which measures both perceptual speed and attentional control. In this task, a central symbolic cue (such as an arrow) indicates the subsequent location of a target on a majority of trials. In these *valid* trials, the target might appear (for example) on the right of the screen after a right-pointing arrow appeared in the center of the screen (Figure 2). Valid cues direct attention to the target location, reducing the time taken to indicate that a target is present. In contrast, on *invalid* trials, the target appears in the location opposite to that which is cued. For example, the target might appear on the right of the screen after a left-pointing arrow appeared in the center of the screen. Here, the invalid cue misdirects attention to a location in the contralateral visual hemifield, increasing reaction time. Attentional shifts on invalid trials are believed to

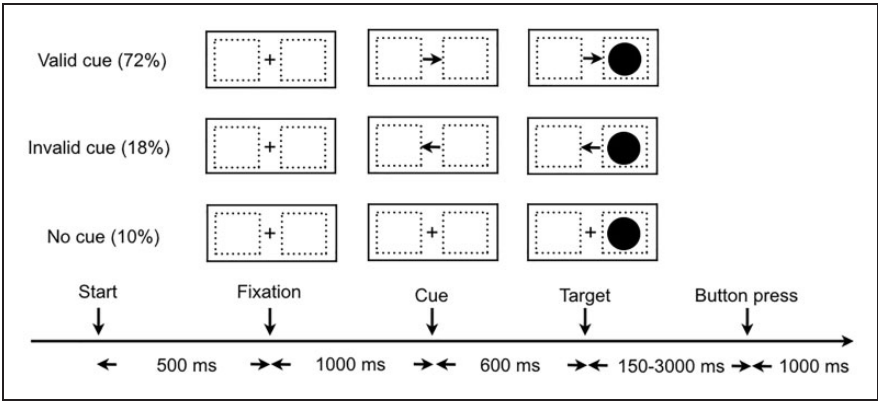

Figure 2. Sequence of events during a trial of the COVAT task.

involve three sequential cognitive operations: (a) disengagement of attention from the incorrect location, (b) an attentional shift to the target location, and (c) engagement on the target (Posner, 1988). The difference in response time between invalid and valid trials, known as the invalid-cue effect, is commonly interpreted as a measure of the speed of attentional disengagement or attentional control (Chen, Wilson, & Wu, 2012; Wilson & Maruff, 1999); we used this measure in the present study as our index of attentional control. In addition, we used simple reaction time in this COVAT task as our measure of perceptual-processing speed.

The sequence of events during a trial is depicted in Figure 2. The participant sat approximately 60 centimeters from a computer screen. Each trial began with a warning signal; 500 ms later, a white fixation cross subtending 0.5° × 0.5° appeared in the center of screen. The fixation marker was flanked by the white outlines of two boxes, each subtending 2.0° × 2.0° and centered 2.0° to the left or right of fixation. The boxes were displayed continuously throughout the trial. After a further 1 second, a yellow pre-cue arrow (1.5° length) replaced the fixation cross in the center of the screen. Next, 600 ms after the cue appeared, a green circular target stimulus (2.0° diameter) appeared in one of the two boxes. The participant was required to respond to the appearance of the green circular target within 3 s. After a response was given, the screen was cleared, and the next trial began 1 s later. Two response devices were used for this task. To measure reaction times for the upper extremities, two response buttons were placed on a desk in front of the participant. Participants rested their forearms on the surface of the desk, with the index finger of the right hand resting on the right response button and the index finger of the left hand resting on the left response button. Participants were asked to press the left response button when the green circular target appeared on the left of the screen and to press the right response button when the green circular target appeared on the right. To measure reaction times for the lower extremities, two response buttons were placed on the floor, and each bare foot rested upon the corresponding button. The participant was asked to maintain visual fixation on the central cross and to press a response button as quickly as possible. We used the STIM^2 software package (Neuroscans Ltd., El Paso, TX) running on a PC to present stimuli and to record responses with 1-ms resolution.

The task contained three cue conditions. In 72% of trials, the green circular target appeared at the location indicated by the pre-cue (*valid-cue condition*); in 18% of trials, the target appeared at the opposite location to that indicated by the pre-cue (*invalid-cue condition*); and in the remaining 10% of trials, no pre-cue was presented (*no-cue condition*), with the fixation cross instead remaining in position throughout the trial (Figure 2). Each participant completed 240 trials in each of two testing sessions, one for the upper extremities and one for the lower extremities. The order of the two sessions was counterbalanced between subjects within each group. Prior to testing, the participant completed 10 practice trials to ensure that he or she understood the experimental protocol.

Statistical Analysis

We used a two-way, mixed-design analysis of variance (ANOVA) to compare eye–hand coordination among groups and between dominant and nondominant hands. The ANOVA model contained *group* (Karate, Taekwondo, or Nonathletes) as a between-subject factor, *hand* (dominant or nondominant) as a within-subject factor, and mean duration of a trial in the FNF task as the dependent variable.

We used a four-way, mixed-design ANOVA to compare reaction time on the COVAT task among groups. The ANOVA model contained *group* (Karate, Taekwondo, or Nonathletes) as a between-subject factor, *extremity* (upper or lower), *side* (dominant or nondominant), and *cue type* (valid or invalid) as within-subject factors, and mean reaction time as the dependent variable.

Consistent with other studies on the COVAT task, we also calculated the ICE for each participant within each condition as a measure of attentional control. The ICE was defined as the difference between the mean reaction time for invalid and valid trials (Wilson, Maruff, & McKenzie, 1997). We used a three-way, mixed-design ANOVA, containing *group* (Karate, Taekwondo, Nonathletes) as a between-subject factor, *extremity* (upper or lower) and *side* (dominant or nondominant) as within-subject factors, and ICE as the dependent variable. For all tests, a significance level was set at $p < .05$. Effect sizes are reported as partial eta-squared (η_p^2) for F tests, or as Cohen's d for t tests.

Results

Eye–Hand Coordination

Table 1 shows the mean duration of a trial in the FNF task as a function of group and hand. A two-way, mixed-design ANOVA revealed a significant main effect of group, $F(2, 94) = 4.43$, $p = .015$, $\eta_p^2 = .09$, and hand, $F(1, 94) = 20.03$, $p < .001$, $\eta_p^2 = .18$, but no significant interaction between the two factors. Holm–Šídák post-hoc analysis indicated that the dominant hand was significantly faster than the non dominant hand ($p < .001$). Karate athletes were significantly faster than Taekwondo athletes ($p = .047$) and Nonathletes ($p = .014$), but there was no significant difference between Taekwondo athletes and Nonathletes. Our hypothesis (H1) that karate athletes would be faster than Taekwondo athletes and Nonathletes in the FNF task was thus supported.

Perceptual-Processing Speed

Table 2 shows mean reaction time in the COVAT task as a function of group, extremity, side, and cue condition. A four-way, mixed-design ANOVA revealed significant main effects of group, $F(2, 94) = 16.06$, $p < .001$, $\eta_p^2 = .26$, extremity, $F(1, 94) = 744.23$, $p < .001$, $\eta_p^2 = .89$, and cue type, $F(1, 94) = 291.04$, $p < .001$, $\eta_p^2 = .76$; however, the main effect of side was not significant. Holm–Šídák post-hoc analysis indicated that Nonathletes were slower than both Taekwondo ($p < .001$) and Karate ($p = .003$) athletes, but there was no significant difference between Taekwondo and Karate athletes. Upper extremities were faster than lower extremities ($p < .001$), and responses in the valid-cue condition were faster than those in the invalid-cue condition ($p < .001$). The omnibus ANOVA revealed a significant two-way interaction between group and extremity, $F(2, 94) = 3.28$, $p = .042$, $\eta_p^2 = .07$.

To further investigate this interaction, we conducted three-way, mixed-design ANOVAs separately for each of the two extremities, with group, side, and cue condition as factors. For upper extremities, the ANOVA revealed a significant main effect of group, $F(2, 94) = 22.21$, $p < .001$, $\eta_p^2 = .32$, and of cue type, $F(1,$

Table 1. Mean and *SD* of Movement Time in the FNF task (ms) as a Function of Group and Hand.

	Taekwondo ($n = 38$)	Karate ($n = 24$)	Nonathletes ($n = 35$)
Dominant hand	502 ± 93	453 ± 51*,¶	520 ± 77
Nondominant hand	526 ± 80†	486 ± 72*,†,¶	532 ± 75

*$p < .05$ (Taekwondo vs. Karate). ¶$p < .05$ (Karate vs. Nonathletes). †$p < .05$ (Dominant vs. Nondominant hand).

Table 2. Mean and *SD* of Reaction Time in the COVAT task (ms) as a Function of Extremity, Side, Cue Condition, and Group.

	Taekwondo ($n = 38$)	Karate ($n = 24$)	Nonathletes ($n = 35$)
Upper extremity, Dominant side			
Valid cue	234 ± 20	$252 \pm 21^{*}$	$269 \pm 29^{\ddagger,\P}$
Invalid cue	253 ± 19	$276 \pm 35^{**}$	$291 \pm 32^{\ddagger}$
Upper extremity, Nondominant side			
Valid cue	232 ± 21	$252 \pm 22^{**}$	$266 \pm 33^{\ddagger}$
Invalid cue	249 ± 19	$270 \pm 33^{*}$	$287 \pm 32^{\ddagger,\P}$
Lower extremity, Dominant side			
Valid cue	291 ± 30	303 ± 31	$326 \pm 51^{\ddagger,\P}$
Invalid cue	353 ± 37	356 ± 45	$383 \pm 52^{\dagger,\P}$
Lower extremity, Nondominant side			
Valid cue	293 ± 33	299 ± 33	$341 \pm 52^{\ddagger,\P}$
Invalid cue	351 ± 34	349 ± 36	$387 \pm 58^{\dagger,\P}$

$^{*}p < .05$ (Taekwondo vs. Karate). $^{**}p < .001$ (Taekwondo vs. Karate). $^{\dagger}p < .05$ (Taekwondo vs. Nonathletes). $^{\ddagger}p < .001$ (Taekwondo vs. Nonathletes). $^{\P}p < .05$ (Karate vs. Nonathletes).

94) = 121.02, $p < .001$, $\eta_p^2 = .56$. Holm–Šídák post-hoc analysis indicated that for upper extremities, Taekwondo athletes were faster than both Karate athletes ($p = .003$) and Nonathletes ($p < .001$), and Karate athletes were faster than Nonathletes ($p = .038$). Responses in the valid-cue condition were faster than those in the invalid-cue condition ($p = .001$). For the lower extremities, the ANOVA again revealed a significant main effect of group, $F(2, 94) = 10.29$, $p < .001$, $\eta_p^2 = .18$, and of cue type, $F(1, 94) = 313.30$, $p < .001$, $\eta_p^2 = .77$. Holm–Šídák post-hoc analysis indicated that for lower extremities, Nonathletes were slower than both Taekwondo ($p < .001$) and Karate ($p = .003$) athletes, but there was no significant difference between Taekwondo and Karate athletes. Independent-samples t tests confirm that regardless of cue type and side, Taekwondo athletes were significantly faster than Karate athletes for upper extremities but not for lower extremities (see Table 2 and Figure 3(a)).

Two other significant interactions were revealed by the omnibus ANOVA; these are depicted in Figure 3(b) and (c). We observed significant interactions between cue type and extremity, $F(1, 94) = 180.95$, $p < .001$, $\eta_p^2 = .66$, and between cue type and side, $F(1, 94) = 5.36$, $p = .023$, $\eta_p^2 = .05$. No other significant interactions were found.

In summary, our hypothesis (H2) that Taekwondo athletes would have faster simple-reaction times than Karate athletes and Nonathletes in the COVAT task was supported for the upper extremities but only partially for the lower extremities—that is, for the lower extremities, both Taekwondo and Karate athletes were faster than Nonathletes.

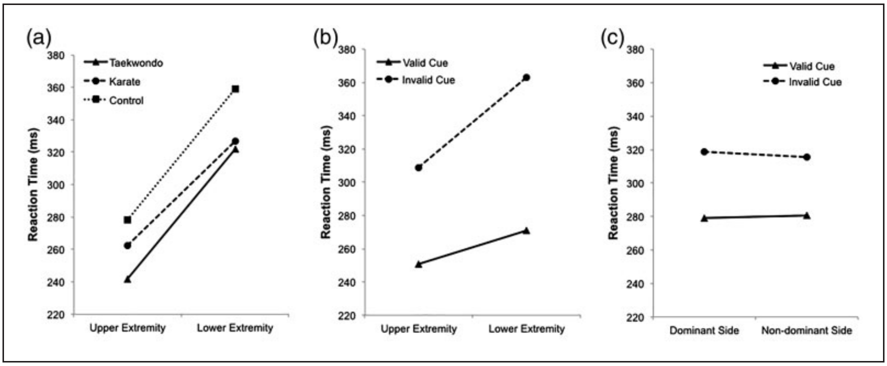

Figure 3. Reaction time on the COVAT task. (a) Reaction time as a function of extremity, shown separately for Taekwondo, Karate and Nonathletes. (b) Reaction time as a function of extremity, shown separately for valid and invalid cues. (c) Reaction time as a function of side, shown separately for valid and invalid cues.

Table 3. Mean and *SD* of Invalid-Cue Effect as a Function of Side, Group, and Extremity.

	Dominant side		Nondominant side	
	Upper extremities	Lower extremities	Upper extremities	Lower extremities
Taekwondo ($n = 38$)	18.9 ± 15.9	62.4 ± 34.6**	17.1 ± 14.7	58.1 ± 35.2**
Karate ($n = 24$)	25.2 ± 21.0	52.8 ± 31.3**	16.9 ± 19.9†	50.0 ± 23.6**
Nonathletes ($n = 35$)	21.6 ± 25.9	55.4 ± 37.6**	20.6 ± 20.9	46.9 ± 36.9**

**$p < .001$ (Upper vs. Lower extremities). $^{\dagger}p < .05$ (Dominant vs. Nondominant side).

Attentional Control

Table 3 shows mean ICE as a function of group, extremity, and side. A three-way, mixed-design ANOVA showed a significant main effect of extremity, $F(1, 94) = 180.95$, $p < .001$, $\eta_p^2 = .66$, and a significant main effect of side, $F(1, 94) = 4.86$, $p = .030$, $\eta_p^2 = .05$, but no significant main effect of group. Note that the significant main effect of extremity on ICE is exactly equivalent to the significant interaction effect of cue type and extremity on perceptual-processing speed (see previous section), because ICE is calculated as the difference in mean reaction time between invalid and valid cues.

The absence of a group effect indicates that Karate athletes, Taekwondo athletes, and Nonathletes are similar in their ability to disengage attention from a miscued location and shift attention to a target location. We observed no significant interactions between factors. Thus, our hypothesis (H3) that both Karate and Taekwondo athletes would have a lower ICE than Nonathletes in the COVAT task was not supported. As expected, attentional control was not statistically distinguishable between Karate and Taekwondo athletes; but contrary to expectation, neither group of athletes performed significantly better than Nonathletes.

The significant main effects of extremity and side we observed for ICE values are consistent with the significant interactions observed between extremity and cue type (Figure 3(b)) and between side and cue type (Figure 3(c)) for mean reaction time on the COVAT task described in the previous section. Regarding the relationship with extremity, the difference in reaction time between valid and invalid cue conditions (ICE) was substantially larger for the lower extremities than for upper extremities (110 ms vs. 40 ms, $p < .001$). Regarding side, we found higher mean ICE for the dominant side than the nondominant side (79 ms vs. 70 ms, $p = .030$); t tests suggest that this difference was particularly marked for the upper extremities of Karate athletes (paired-samples t test, $t\ (23) = -3.01$, $p = .006$, $d = .41$; see Table 3).

Discussion

The present study asked whether specific aspects of visuo-motor performance varied in line with the specific nature of a combat-sport discipline, by comparing eye–hand coordination, perceptual-processing speed and attentional control among Karate athletes, Taekwondo athletes, and Nonathletes. Each of these two combat sports emphasizes different motor skills and, accordingly, was suspected to have different perceptual and attentional requirements. As Taekwondo is primarily focused on kicking maneuvers executed with the lower extremities and Karate additionally focuses on throwing, punching, and striking maneuvers executed with the upper extremities, we compared performance on the FNF and COVAT tasks among Karate and Taekwondo athletes as well as Nonathletes to detect any differences in their skill profiles. Our study provides the first evidence, to our knowledge, that athletes in different combat sports exhibit distinct profiles of performance across several different tests of visuomotor function.

Eye–Hand Coordination

We found that Karate athletes were faster than Taekwondo athletes and Nonathletes in making accurate, repetitive, ballistic pointing movements to a nearby target. Performance on the FNF task depends on both the speed of arm movements and the ability to integrate visual and proprioceptive information to guide those movements. Regarding the former aspect of performance, the arm movements of Karate athletes are already known to be faster than normal: Vos and Binkhorst (1966) directly measured the speed of arm movements during offensive strikes using a calibrated stroboscopic lamp, and found that those of Karate athletes were about 25% faster than those of controls. Regarding the latter aspect, good integration of visual and proprioceptive information is required during competition to score points by delivering clean hits to specific target zones of the opponent's body. Taken together with the findings of Vos and Binkhorst, the present study suggests that practitioners of Karate (and perhaps other sports emphasizing movements of the upper extremities) show superior eye–hand coordination.

Perceptual-Processing Speed

The COVAT task revealed a clear distinction between Taekwondo and Karate athletes on our measure of perceptual-processing speed. In accordance with our hypothesis (and in a reversal of our findings for eye–hand coordination), Taekwondo athletes were faster than both Karate athletes and Nonathletes to make a response with the upper extremities, regardless of whether a target appeared in the cued location (valid trials) or in the opposite location (invalid trials). Faster perceptual processing in Taekwondo may be required to compensate for the longer time required to execute a movement of the lower limbs compared with the upper limbs; indeed, we found much slower reaction times and increased interindividual variability for responses given with the lower extremities compared with the upper extremities. The difference in physical length between the respective neural pathways is known to contribute to these differences (Basmajian & De Luca, 1985), which in our study may have resulted in an inability to statistically distinguish the perceptual-processing speeds of Taekwondo and Karate athletes when measured with the lower extremities.

Rapid perceptual processing is necessary for elite performance in many sports, helping an athlete to make timely and accurate decisions about future actions. In combat sports, an athlete must perceive an opponent's heading and velocity of motion before making a decision on the appropriate offensive or defensive maneuver. Previously, Kim and Petrakis (1998) measured perceptual-processing speed among beginner, intermediate, and advanced Karate athletes and found that advanced athletes exhibited faster perceptual processing than intermediate and beginner athletes ($\eta_p^2 = .19$). Our study indicates that when measured via responses from the upper extremities, perceptual-processing speed of Taekwondo athletes is faster than that of Karate athletes and Nonathletes ($\eta_p^2 = .32$).

The superior reaction times of Taekwondo athletes on the COVAT task could also point to a greater need to anticipate an opponent's attack to execute an appropriate defensive maneuver, such as assuming a stance to withstand the force of a kick. Previously, Mori et al. (2002) asked participants to judge whether the offensive action in a video stimulus would contact the upper or the middle level of their own body. They found that Karate athletes could successfully anticipate the location of contact on 90% of trials based on just the first 7 frames (230 ms) of action; to reach a similar level of performance, Nonathletes required first 10 frames (330 ms). Their findings suggest that elite combat-sport athletes are more effective than Nonathletes at anticipating opponents' movements. In the present study, we found that Taekwondo athletes perform faster in the COVAT task than Karate athletes and Nonathletes; perhaps, then, Taekwondo athletes employ more effective anticipatory strategies than Karate athletes.

An alternative explanation of this finding is that Karate athletes have a higher degree of inhibitory self-control than Taekwondo athletes. Del Percio et al. (2009) found that reaction times on the COVAT task were substantially *slower* for Karate athletes than for Nonathletes; however, the proportion of correct responses was significantly *higher* among Karate athletes than among Nonathletes. The authors suggested that Karate athletes employ an inhibitory self-control mechanism, which extends reaction times but allows deeper analysis of an opponent's actions for the sake of reducing errors. In the present study, all groups showed similar proportions of correct responses on the COVAT task: One-way ANOVA showed no significant difference among Taekwondo athletes, Karate athletes, and Nonathletes (upper extremities, 97.5%, 98.35%, vs. 98.5%; lower extremities, 96.0%, 96.8%, vs. 97.8%, respectively). Thus, in this case, it is unlikely that the inhibitory self-control hypothesis can explain the difference between Taekwondo and Karate athletes in the speed of perceptual processing.

Attentional Control

While we found differences among Karate, Taekwondo athletes and Nonathletes in eye–hand coordination and perceptual-processing speed, all groups showed similar attentional control. The ICE, calculated as the difference in reaction time between invalid and valid trials in the COVAT task, did not differ significantly among the three groups. In an invalid trial, observers must first disengage attention from a miscued location, and then shift to engage attention at the target location. Our findings suggest that this ability is similar in all groups.

Previous research indicated that attentional control did not vary with level of athletic experience. Fontani et al. (2006) tested high-experience and low-experience groups of Karate and volleyball players on a Go/No-Go task, finding no significant difference in reaction time as a function of discipline or experience. These results, alongside those of the present study, suggest that attentional-control capabilities may not be a criterion for identification of talented Karate and Taekwondo athletes, and that combat-sport training does not significantly affect attentional-control mechanisms.

A curious finding in the present study is that mean ICE was significantly larger for the lower extremities than for upper extremities, and substantially larger for the dominant side than the nondominant side. One possible explanation is that the temporal cost of suppressing a planned action to a miscued location is greater in one condition than in the other. For extremity, this would suggest that it is costlier to suppress an already-prepared action for the feet than for the hands. For side, it would suggest that it is costlier to suppress an already-prepared action for the nondominant side than for the dominant side.

Dissociation of Perception and Action

In the present study, we found a double dissociation between eye–hand coordination, which was superior among practitioners of Karate, and the speed of perceptual processing, which was superior among practitioners of Taekwondo. This is consistent with Goodale and Milner's (1992; Milner & Goodale, 1995) celebrated theory of dual pathways for perception and action. Although eye–hand coordination has both perceptual and motor components (Lavrysen et al., 2007), Karate athletes showed faster movements in the FNF task while having slower reaction times in the COVAT task. This may indicate that their benefit is primarily motor in nature, perhaps because Karate emphasizes rapid punching and striking in training and competition. The reverse pattern of performance among Taekwondo athletes suggests that their benefit is primarily perceptual in nature: Taekwondo emphasizes kicking, which requires exceptional dynamic balance; and such dynamic postural control requires rapid processing of perceptual information (Negahban, Aryan, Mazaheri, Norasteh, & Sanjari, 2012). Rapid perceptual processing in Taekwondo may also offset the longer time required to execute movements of the lower limbs compared with the upper limbs. Thus, our findings support the commonly held dissociation between perception and action and suggest that the two processing streams may be differentially engaged in different combat sports.

Athlete Selection and the Effects of Training

We propose that exceptional performance on certain tests of visuomotor function indicates a greater potential to become an outstanding athlete of a particular combat sport. According to this proposal, the effects we observed in the present study arise because athletes with certain visuomotor skills are more likely to be attracted to a particular sporting discipline and more likely to show natural aptitude; thus, they are more likely to continue with training, and more likely to reach elite status. However, it is also likely that because training programs are tailored to the specific demands of a combat sport, the extensive training completed by elite athletes will disproportionately affect certain aspects of visuomotor performance. Under this interpretation, the effects we observed in the present study arise because athletes with extended practice in particular techniques are likely to develop a certain profile of visuomotor skills. Owing to the cross-sectional design of the present study, we are unable to distinguish between these possibilities. Although we cannot determine which here is the cause and which is the effect, we believe that it is highly plausible that both interpretations are correct. This would be a fruitful area of investigation for future research with a longitudinal design.

Limitations of the Study

We cannot determine from the present study whether these distinct performance profiles result from the innate abilities of individuals who subsequently become elite athletes, or rather from extensive training programs. Future longitudinal or intervention research should assess the relative contributions of talent and training to the perceptual–motor performance of athletes. Another limitation of the study is the considerable overlap between the sets of skills required for Karate and Taekwondo. Both combat sports emphasize kicking techniques, but to different extents. While Taekwondo athletes spend a majority of time developing kicking techniques, Karate athletes pay additional attention to throwing and striking techniques. Although we found Karate athletes have superior eye–hand coordination, while Taekwondo athletes have faster perceptual processing, further investigations using specific training programs could further tease out the relationship between kicking techniques and perceptual-processing speed, and between striking techniques and eye–hand coordination.

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