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Abstract

Purpose: This study investigated whether within-task expertise affects the reported asymmetry in execution time exhibited in reactive and self-initiated movements. *Method*: Karate practitioners and no-karate practitioners were compared performing a reverse punch in reaction to an external stimulus or following the intention to produce a response (self-initiated). The task was completed following the presentation of a specific (i.e., life-size image of opponent) or general stimulus, and in the presence of click trains or white noise. *Results*: Kinematic analyses indicated reactive movement had shorter time to peak velocity and movement time, as well as greater accuracy than self-initiated movement. These differences were independent of participant skill level although peak velocity was higher in the karate practice group than in the no-karate practice group. Reaction time (RT) of skilled participants was facilitated by a specific stimulus. There was no effect on RT or kinematic variables of the different type of auditory cues. *Conclusions*: The results of this study indicate that asymmetry in execution time of reactive and self-initiated movement holds irrespective of within-task expertise and stimulus specificity. This could have implication for training of sports and/or relearning of tasks that require rapid and accurate movements to intercept/contact a target.

Key words: reaction, intention, control, combat sports

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Human movements can be made in reaction to an external stimulus (reactive) or when the individual decides it is appropriate to do so (self-initiated). Findings from participants with Parkinson's disease (Jahanshahi et al., 1995; Siegert, Harper, Cameron, & Abernethy, 2002), imaging studies (Cunnington, Windischberger, Deecke, & Moser, 2002; Deiber, Honda, Ibanez, Sadato, & Hallett, 1999; Waszak et al., 2005) and electrophysiological recordings (Obhi & Haggard, 2004), have led to the suggestion that reactive and self-initiated movement have different neural bases (but for evidence of a common preparatory mechanism, see Hughes, Schutz-Bosbach and Waszak, 2011). For instance, pre-supplementary motor area (SMA) is activated earlier and more extensively in self-initiated than reactive conditions (Cunnington et al., 2002; Soon, Brass, Heinze, & Haynes, 2008).

The different neural bases of movement in reactive and self-initiated conditions have been suggested to result in an asymmetrical movement time (MT). Using a behavioral paradigm, Welchman, Stanley, Schomers, Miall and Bulthoff (2010) investigated how quickly individuals could respond in a simulated gunfight. The authors reported that reactive movement was completed in a shorter time than self-initiated movement, which they suggested conveys an evolutionary advantage. Also, the MT difference was evident irrespective of stimulus agency (i.e., computer or human), thus indicating that stimulus specificity and/or the presence of motion does not override the advantage in the reactive condition. Supporting evidence has recently been reported but only for simple, ballistic manual actions (Pinto, Otten, Cohen, Wolfe, & Horowitz, 2011). No difference between reactive and self-initiated conditions was evident for the second step in a two-step movement (see also Welchman et al., 2010), and the opposite effect was observed when participants had to choose which action to make.

Although participants in Welchman et al. (2010) and Pinto et al. (2011) were familiarized with the experimental task, the question of whether within-task expertise affects the movement execution time asymmetry in reactive and self-initiated conditions has yet to be considered. For ballistic motor skills such as fencing (Nougier, Stein, & Azemar, 1990) and karate punching (VencesBrito, Rodrigues Ferreira, Cortes, Fernandes, & Pezarat-Correia, 2011), experts exhibit faster and better coordinated movement. Even when the task (i.e., karate punch) does not involve anticipation or decision making, expert-novice differences are evident in motor control (e.g., peak hand velocity), and have been attributed to the microstructure of white matter in the cerebellum (i.e., superior cerebellar peduncles) and primary motor cortex (Roberts, Bain, Day, & Husain, 2012). Accordingly, it follows that changes in the cortical areas associated with expert motor control could modulate any movement time advantage in reactive compared to self-initiated conditions (i.e., within-subject effect). The study of combat sports such as karate also provides opportunity to compare reactive and self-initiated movement with or without an opponent, and thus different levels of stimulus agency and motion. In this respect, while agency and/or the presence of motion was shown not to influence movement execution time of novices performing a simple button-pressing task (Pinto et al., 2011; Welchman et al., 2010), experts may respond differently when faced with specific stimuli because this would be more salient than general stimuli, thus leading to greater allocation of processing resources.

As well as being influenced by factors such as task-specific experience and complexity, it has been reported that cognitive processing is faster when listening to click trains (i.e., short duration auditory tones separated by similar duration silent intervals) (Jones, Allely, & Wearden, 2011). The suggestion is that the pace of an internal clock is increased by click trains, which then alters the speed of other psychological processes such as those involved in time perception (Penton-Voak, Edwards, Percival, & Wearden, 1996; Wearden, Norton, Martin, & Montford-Bebb, 2007), mental arithmetic and recall/ recognition memory (Jones et al., 2011). Treisman, Faulkner and Naish (1992) also studied the effect of click trains on motor control and reported in their first experiment that four participants who listened to click trains during response execution of a choice reaction time (RT) task exhibited a shorter response time. However, as response time does not distinguish between RT (i.e., interval between stimulus appearance and response onset) and MT (i.e., interval between response onset and completion of movement), it is not clear if one or both of these aspects of behavior were altered, and importantly whether the shorter response time is replicable in other motor tasks.

Here, then, we report on a novel comparison between karate practitioners and no-karate practitioners performing a reverse punch (gyaku-tsuki) in reaction to an external stimulus or following their intention to produce a response (i.e., self-initiated). The task was performed in the presence of a specific (i.e., life-size image of opponent) or general stimulus. A detailed kinematic analysis was conducted in order to better determine how any changes in movement execution time manifest in punch motion. In addition, participants were presented with click trains or white noise to determine if these influenced the processes involved in execution of reactive and self-initiated movement. Importantly, by using a protocol that did not require participants to choose which action to make, we minimized the influence of decision making and thus focused on whether movement time per se is modified by click trains.

Method

Participants

Participants were thirty-two men between 18 and 45 years of age. All were healthy individuals and had normal or correct-to-normal vision. The karate practice group comprised fifteen participants (mean age 32.9 ± 9.4) who had more than 3 years of experience in karate training (mean experience 15.23 ± 7.4). Thirteen of the karate practice group were graded to black belt (one 4th Dan; two 3rd Dan; two 2nd Dan; 8 1st Dan), while the other two were 5th kyu level. In terms of competition results, there were two senior and two junior UK Shotokan champions, and one Netherlands Junior all-styles champion. The no-karate practice group included seventeen participants (mean age 28.41 ± 6.6) who had never practiced any combat sport. All participants provided informed consent to take part in the study, which was conducted in accord with ethical procedure approved by the host university.

Apparatus

Stimuli were generated by a computer using the Cogent 2000 toolbox (v1.25) operating within Matlab 7.5. As shown in Figure 1, visual Stimuli were displayed on a large screen (4 m wide, 3m high) by a ceiling-mounted LCD projector (Hitachi Ed-A101 3LCD). Audio stimuli were presented from 2 speakers located on either side of the projection screen at floor level. The stimulus computer was synchronized with a second computer that recorded the participant's movement using an Ascension trakSTAR (Model 800) electromagnetic tracker system. The trakSTAR sampled at 240 Hz the location (static spatial resolution of 0.5mm) of a sensor fixed with medical tape to the back of the participant's hand between the metacarpophalangeal joints of the index and second finger. A punching mitt was fixed to a wooden beam that extended vertically by 1.25 m from a base on the floor. The height of the punching mitt was adjusted for each participant such that it was located just below shoulder height at full extension of the arm.

Procedure

The experiment was carried out in a single session lasting about one hour. Participants were asked to follow 5 minutes of general warm-up exercises. During this time the karate practice group performed some specific karate exercises, which included different types of punching movements. Both groups were then given verbal instructions regarding the task and stimuli, after which they completed 3 familiarization trials in the 4 conditions. Next, participants performed 8 blocks of 10 trials (total = 80 trials). Participants rested for approximately 2 minutes between blocks in order to minimize fatigue. There were 2 blocks per condition (n = 20 trials), which were pseudo-randomly ordered across participants such that each of the 4 conditions was received once before they were repeated. In order to minimize incorrect responses (i.e., reactive rather than self-initiated and vice versa), participants were told prior to each block what condition would be presented.

On each trial participants were required to perform a reverse punch (gyaku-tsuki) as quickly and accurate as possible. They were instructed that the initial and final position of the punch should be the same (i.e., the fist held beside the body). The distance from the fist to the target was set for each participant such that they had to fully extend the arm and rotate the body in order to make contact. Participants were instructed to punch towards the mid-point of the pad (marked with a cross), come to a stop just before making contact, and then return to the start position. Before each punch, participants listened for 5 seconds to either a click train (i.e., 10 ms 5 Hz pulses separated by a 30 ms blank interval) or white noise (Jones et al., 2011). The audio cue was received in a pseudo-random order within a block, with the constraint that there were an equal number of trials preceded by click trains and white noise. After listening to the audio cue, participants were presented with the stimulus corresponding to one of the four experimental conditions. In the reaction specific condition, a video of a karate attack was presented on the screen and participants had to react with a counterattack (gyaku-tsuki). The video was life-size and showed a male opponent who remained in guard without any movement for one of five fore-periods (400, 800, 1200, 1600 and 2000 ms), after which he executed an attack using a back fist strike (uraken-uchi). Participants were required to perform a counterattack punch as soon as the opponent started the attack. There were 2 videos of the same action for each fore-period, thus providing 10 possible video clips that were presented in pseudo-random in order to minimize anticipation of the moment of the attack and any sequence effects. In the second condition, self-initiated specific, a static life-size image of the opponent in guard was presented on the screen and participants were required to execute an attack (gyaku-tsuki). They were not to react to the appearance of the static image but instead to perform an attack when they felt ready to do so. In the reaction general condition, participants executed the punch as soon as a white “X” (10 cm high) appeared in the centre of screen. The “X” appeared against a black background after a fore-period of 400, 800, 1200, 1600 and 2000 ms. In the self-initiated general condition, the “X” appeared on the screen against a black background, and participants were required to perform an attack when they felt ready to do so.

Data Analysis

Data were extracted using a custom-written routine realized in Matlab 7.5, which required the experimenter to manually identify movement onset, peak positive velocity, peak negative velocity and movement end. The semi-automatic routine used this information to segregate each trial and calculate the following dependent variables: reaction time (ms) - the time elapsed between the start of the attack in the specific condition, or the appearance of the “X” in the general condition, and movement onset defined as the first moment when the speed was more than 10 mm/sec for 40 ms consecutives; movement time (ms) - time elapsed from movement onset to the moment of zero crossing in velocity (i.e., end of the extension phase); peak velocity (m/s) - maximum positive velocity during the extension phase of the punch; time to peak velocity (ms) - time from onset of movement to peak velocity; mean deceleration (m/s^2); accuracy (mm) – constant error (horizontal axis) between the position of the fist at the end of movement extension and a baseline measure of target location. The baseline was taken at the beginning of each block of trials and involved participants slowly extending their arm towards the target to achieve what they believed to be the ideal endpoint.

In accord with previous literature, several criteria were applied resulting in some trials being removed from further analysis. In the reactive conditions, RT under 100 ms was deemed an anticipatory response and thus omitted (Welchman et al., 2010). In the self-initiated conditions, a response initiated within 400 ms of the stimulus presentation was considered as a reaction, and was also omitted (Welchman et al., 2010). Furthermore, when movement onset occurred more than 2000 ms after the end of the click train, the trial was deleted because it could not be compared with the reactive condition due to the potential dissipation of the click train effect (Jones et al., 2011). Finally, trials were deleted in which the movement was not completed as a single punch. Across all participants, the number of deleted trials never exceeded 5% (i.e., 4 of 80).

The intra-participant means of each dependent variable were calculated for all combinations of independent variable and then submitted to log transform. With the exception of RT, the transformed data were submitted to separate 2 group (karate practice group, no-karate practice group) x 2 movement (reactive, self-initiated) x 2 stimulus (specific, general) x 2 audio (clicks, white noise) ANOVA, with repeated measures on the last 3 factors. By definition, the response in the self-initiated movement condition cannot be reactive, and thus the data for RT were submitted to a 2 group (karate practice group, no-karate practice group) x 2 stimulus (specific, general) x 2 audio (clicks, white noise) ANOVA, with repeated measures on the last two factors. Main and interaction effects were further investigated using Tukey's HSD post hoc procedure. Alpha level was 0.05.

Results

For RT, there was a main effect of stimulus, $F(1, 30) = 6.91$, $p < .05$, $\eta_p^2 = .19$, and a group x stimulus interaction, $F(1, 30) = 6.68$, $p < .05$, $\eta_p^2 = .18$. Karate practitioners reacted quicker to the specific (231 ± 51 ms) than general (266 ± 52 ms) stimulus, whereas the no-karate practice group was unaffected (271 ± 51 ms and 270 ± 43 ms). There was no main effect or interaction involving audio, thus indicating that there was no speeding-up effect associated with click trains.

For MT, there was a main effect of movement, $F(1, 30) = 31.10$, $p < .001$, $\eta_p^2 = .51$, which was shorter in the reactive compared to self-initiated movement condition. There was no main effect or interaction involving group. For PV, there was a significant main effect of group, $F(1, 30) = 5.10$, $p < .05$, $\eta_p^2 = .15$, and stimulus, $F(1, 30) = 24.71$, $p < .001$, $\eta_p^2 = .45$, as well as a group x stimulus x movement interaction, $F(1, 30) = 4.53$, $p < .05$, $\eta_p^2 = .13$. Karate practitioners executed the punch with greater peak velocity than no-karate practitioners, with group means of 4.55 m/s and 4.06 m/s, respectively. Also, as can be seen in Table 1, for the no-karate practice group only, peak velocity was significantly increased when reacting to the specific stimulus compared to all other combinations of stimulus and movement. As for time to peak velocity, there was a significant main effect of stimulus, $F(1, 30) = 4.69$, $p < .05$, $\eta_p^2 = .14$, and movement, $F(1, 30) = 37.13$, $p < .001$, $\eta_p^2 = .55$. Time to reach peak velocity was shorter in the reactive compared to self-initiated movement condition, and for the general compared to specific stimulus (Table 1). Finally, for deceleration there was a significant group x movement interaction, $F(1, 30) = 6.69$ $p < .05$ $\eta_p^2 = .18$. Karate practitioners exhibited a higher deceleration (67.13 ± 13.89 m/s²) than no-karate practitioners (54.47 ± 17.55 m/s²), and more so in the self-initiated than reactive conditions.

In terms of punch accuracy, there was a main effect of movement, $F(1, 30) = 8.97$, $p < .05$, $\eta_p^2 = .24$, with reactive movements performed to higher end-point accuracy (-4.30 ± 17.04 mm) than self-initiated movements (-8.59 ± 17.29 mm). In all cases, the fist was stopped closer to the target (i.e., less undershoot) in the reactive conditions. There were no other main or interaction effects.

Discussion

The current study investigated for the first time whether within-task expertise affects the reported asymmetry in movement execution time in reactive and self-initiated conditions (Cunnington et al., 2002; Pinto et al., 2011; Welchman et al., 2010). By comparing karate practitioners to no-karate practitioners performing the reverse punch, we also examined the influence of providing a task-specific or general imperative stimulus to cue the movement response. Finally, participants were presented with white noise or click trains prior to the imperative stimulus to determine if the reported speeding up of information processing (Jones et al., 2011; Penton-Voak et al., 1996; Wearden et al., 2007) and motor control (Treisman et al., 1992) generalizes to interceptive motor tasks performed by karate practitioners and participants without karate experience.

Extending upon previous work reporting that MT in an aiming task is shorter in reactive compared to self-initiated movements (Pinto et al., 2011; Welchman et al., 2010), we found the same effect here for both karate and no-karate practitioners performing the reverse punch. Many years of practicing this and other specific movements when performing kumite (i.e., sparring with an opponent) and kata (i.e., practice of technique and sequences of movement) did not result in a ceiling effect. Analysis of movement kinematics revealed an earlier time to peak velocity in the reactive compared to self-initiated movement condition. Given the finding of no difference in peak velocity as a function of movement, the implication is that there was also greater acceleration in the reactive condition. Importantly, the speeding up of movement by karate and no-karate practitioners in the reactive condition did not result in greater end-point error. To the contrary, the fist was stopped closer to the target at the end of the extension phase in the reactive compared to self-initiated conditions, thus indicating an improved speed-accuracy relationship. In this respect, the current findings diverge somewhat from Welchman et al. (2010), who found a greater proportion of failures (i.e., pressed incorrect button) in the reactive condition; but see Pinto et al. (2011) for findings of no difference in failure rate. It would seem, then, that task constraints and instructions play an important role in mediating the speed-accuracy relationship, which is consistent with rapid aiming being subject to strategic influences (Elliott et al., 2010).

As expected based on behavioral (Zehr, Sale, & Dowling, 1997) and neurophysiological data (Roberts et al., 2012), we found that karate practitioners executed the punch with greater peak velocity than no-karate practitioners. This was not associated with shorter MT or increased end-point error. However, karate practitioners did exhibit higher average deceleration than no-karate practitioners, which was necessary to bring the fist to a soft contact with the pad in a similar amount of time after peak velocity. In this respect, the reverse punch studied here was like a manual aiming task that requires accurate end-point control. This task requirement was different to previous work on control of punching action, where different contact requirements (e.g., maximum impact force) have typically been studied (Gulledge & Dapena, 2008; Neto, Silva, Marzullo, Bolander, & Bir, 2011; Zehr et al., 1997). Karate and no-karate group differences in RT were also evident for stimulus specificity. Karate practitioners exhibited a shorter RT to the specific than general stimulus, whereas RT of no-karate practitioners did not differ. An effect of stimulus in the karate practitioners cannot be explained by decision making related to motor planning because participants knew in advance how to respond. Furthermore, anticipation was minimized by using two videos in which the attack was initiated from a stationary position after a randomized fore-period ranging from 400 to 2000 ms. Thus, although we did not measure processes involved in anticipation (Shim, Carlton, Chow, & Chae, 2005), and decision making, such as visual search strategies (Abernethy, 1991), it is unlikely that these could account for the karate and no-karate group differences. Recent work by Carter, Bowling, Reeck and Huettel (2012) has shown brain activation patterns differ when a participant is competing against a challenging opponent compared to one considered to be of lower level. A reasonable suggestion, then, is that experts' interpretation of the opponent in the video differed from that of the novices, thus leading to greater allocation of processing resources (see Treue, 2003).

Contrary to previous reports, we found no effect of click trains on RT (Jones et al., 2011) or measures of motor control (Treisman et al., 1992). In terms of RT, it is relevant to note that previously reported differences between conditions involving click trains and white noise were only evident when participants had to make a decision regarding the correct response (i.e., 4-choice RT task). As noted above, there was no requirement to decide and plan a response dependent on the stimulus conditions in the current study, thus potentially minimizing any effect of click trains. It should also be bore in mind that the reported difference in response time (Treisman et al., 1992) does not differentiate whether the effect of click trains acted upon RT and/or measures of motor control. Indeed, the motor tasks used in both experiments (i.e., manual aiming and typing) required participants to choose and then plan a correct response, which we suggest most likely led to an increase in RT. Here, we have provided preliminary evidence that processes involved in motor execution are not modified by click trains. It will be interesting in future work to further examine the effect of click trains in motor tasks where there is greater opportunity to compare actual and expected sensory consequences such as in goal-directed aiming.

The results of the current study could have some implication for training in sports that require rapid movements to intercept/contact a target. It will be interesting to determine if the greater acceleration and reduced MT exhibited in reactive movement conditions transfers positively after practice to self-initiated movement conditions. Related, one might question the value of practicing rapid interceptive movements in self-initiated movement conditions because in competition they would normally be performed in reaction to an external stimulus (e.g., defensive movement in karate, boxing or fencing). Also, the finding that movement is executed quicker in reactive conditions could have implications for relearning of tasks following a muscular and/or neural injury. For instance, it has been found that C6 tetraplegics who have undergone musculotendinous transfer exhibit lower peak velocity and longer MT in aiming tasks (Robinson, Hayes, Bennett, Barton & Elliott, 2010). It could be worthwhile in future studies to train such movements in reactive conditions in order to see if this facilitates more rapid and accurate aiming movement, and thus aids rehabilitation.

In conclusion, karate and no-karate practitioners exhibited asymmetrical movement execution of the reverse punch in reactive and self-initiated conditions. This difference was independent of participant skill level, even though karate practitioners did respond with greater peak velocity and average deceleration. These findings imply that the difference in neural processing underlying reactive and self-initiated movement production remains after years of specific practice of a rapid interceptive task, and are not explained by unfamiliarity with the task and underlying processes.

What does this paper add?

Recent studies have shown that the different neural bases of self-initiated and reactive movements result in an asymmetrical movement execution time. Here, we found that self-initiated and reactive differences remain after years of specific movement training. We also extend previous research by determining how such conditions influence measures of movement control. These findings are potentially meaningful for training in sports that require rapid and accurate movement control. Also, the finding that movement is executed quicker in reactive conditions could have implication for relearning of tasks by participants whose movement production is limited by muscular and/or neural injury.

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Table 1. Group mean and SD (between parentheses) of movement time (MT), peak velocity, time to peak velocity, deceleration and accuracy in karate practice and no-practice groups in the four experimental conditions.

		Condition			
Kinematic Variable	Group	Reaction Specific	Self-initiated Specific	Reaction General	Self-initiated General
Movement time (ms)	No-practice	315 (37)	367 (80)	324 (49)	358 (71)
	Practice	307 (28)	357 (64)	298 (24)	344 (54)
Peak velocity (m/s)	No-practice	4.20 (0.59)	4.02 (0.78)	4.03 (0.60)	3.99 (0.79)
	Practice	4.61 (0.62)	4.58 (0.55)	4.52 (0.61)	4.48 (0.57)
Time to peak velocity (ms)	No-practice	238 (34)	286 (72)	245 (42)	276 (61)
	Practice	235 (33)	290 (69)	226 (27)	277 (60)
Mean deceleration (m/s^2)	No-practice	56.66 (14.40)	54.23 (20.07)	53.57 (16.07)	53.44 (20.31)
	Practice	66.02 (13.15)	69.68 (14.01)	64.41 (14.79)	68.41 (14.77)
Accuracy (mm)	No-practice	-5.25 (17.86)	-10.12 (19.81)	-7.61 (14.51)	-9.71 (19.07)
	Practice	-1.79 (18.2)	-6.43 (15.3)	-1.64 (17.4)	-7.53 (15.8)

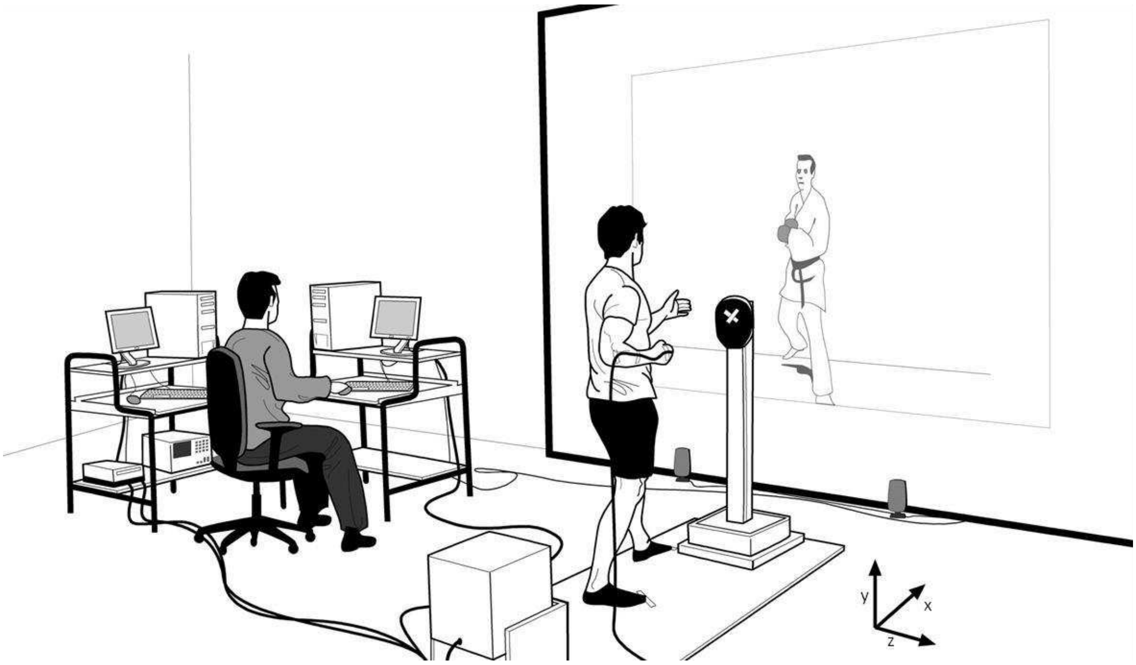

Fig. 1. Pictorial representation of the experimental set-up.

Author's note

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