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External focus of attention delivers superior punches with the preferred hand but not with the non-preferred: A comparison of internal, external and holistic focus of attention

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This study investigated the degree to which differences in the effects of external, internal and holistic focus of attention relate to movement automaticity by comparing performance between the preferred and non-preferred hand in a karate punching task. Thirteen experienced karate players (age 35.9±16.6 years) completed reverse punches (i.e., gyaku-zuki) on a boxing bag with external, internal and holistic focus instructions using both their preferred and non-preferred hand. Results confirmed the advantage of an external focus relative to an internal focus. No differences were found with holistic focus. In addition, for peak wrist velocity this differential attentional focus effect only occurred in the preferred hand. For impact force, no difference of attentional focus was found between the two hands. These observations are consistent with the constrained-action hypothesis, entailing that an external focus delivers superior performance compared to an internal focus for movement control that is (more) automatized, as per preferred hand.

KEY WORDS: Karate, Focus of Attention, Constrained-Action Hypothesis, Hand Preference, Automatization.

Introduction

In recent years, an increasing body of evidence has emerged to support the conjecture that instructions and feedback that elicit an external focus

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of attention lead to superior motor performance and learning compared to instructions and feedback that induce an internal focus of attention (e.g., (Chua, Jimenez-Diaz, Lewthwaite, Kim, & Wulf, 2021; Lewthwaite & Wulf, 2017; McNevin, Shea, & Wulf, 2003; Wulf, 2013)). For example, Halperin, Chapman, Martin, and Abbiss (2017) found that when boxers were invited to adopt an external focus of attention toward the outcome of the movement by instructing them to punch the *target* as fast and forceful as possible, they hit faster and with more power than when they were asked to focus internally on movement execution by telling them to move their *arm* as fast and forceful as possible. Indeed, the evidence for the benefits of external focus of attention is so overwhelming that it has led to suggestions that its advantage is omnipresent "whether the individual is a child or adult, has a clinical condition or not, and is considered to be a novice, experienced or an expert at the motor skill" (Chua et al., 2021, p. 618; Wulf, Hossner, & Wenderoth, 2007).

The most widely used explanation for this advantage of external focus over internal focus is the constrained-action hypothesis (Wulf, McNevin, & Shea, 2001, p. 1144). It holds that adopting an internal focus of attention, which is supposedly associated with a conscious control of movement, "constrains the motor system by interfering with automatic motor control processes that would 'normally' regulate the movement" (Wulf et al., 2001, p. 1144). By contrast, an external focus would allow "the motor system to more naturally self-organize, unconstrained by the interference caused by conscious control attempts" (Wulf et al., 2001, p. 1144). To substantiate this hypothesis, Wulf et al. (2001) had participants perform a probe reaction time task while concurrently practicing a balance task. They showed that adopting an external focus of attention resulted in shorter probe reaction times in comparison to an internal focus of attention. This indicates that an external focus reduces attentional demands, presumably because movements rely more strongly on automatic, non-conscious control processes compared to an internal focus of attention. Indeed, healthy adults show more fluent movements under external control, suggesting fewer active or conscious interventions during the unfolding of the task (Kal, Van der Kamp, & Houdijk, 2013).

One interpretation of the constrained-action hypothesis is that the advantage of an external focus of attention over an internal focus is a function of the degree of movement automaticity. The more movement control is automatized, the more vulnerable it would be for conscious interference associated with an internal focus of attention (see also Masters & Maxwell, 2008). And vice versa, when the movement is mostly consciously controlled, this would offer fewer opportunities for promoting non-conscious automatic control processes with an external focus of attention. The constrained-action hypothesis thus raises issues whether the advantage of an external focus of attention is equally strong for less compared to more automatized movement control.

In this respect, a comparison between performers of different skill levels is of interest, since automatized control is typically considered more prevalent in skilled movers (Shiffrin & Schneider, 1977). That is, if control is more conscious, being less reliant on automatic processes, as is typical for less skilled performers, then it stands to reason that an internal focus would be less disruptive and perhaps even beneficial in comparison to an external focus of attention. Yet, the evidence is equivocal (Nicklas, Rein, Noël, & Klatt, 2022). Wulf and Su (2007) reported an advantage of external focus for both novices and experts in golf shot performance. Similarly, Ille, Selin, Do, and Thon (2013) found that both novice and expert track and field athletes had faster sprint start times with an external compared to an internal focus of attention, and Halperin et al. (2017) reported benefits from external focus of attention in both intermediate and expert boxers. By contrast, also in golf, Perkins-Ceccato, Passmore, and Lee (2003) found that unlike high skilled players who showed superior performance with an external focus, performance of less skilled players profited more from an internal focus, although these differences were restricted to performance variability. Likewise, Wulf, McConnel, Gärtner, and Schwarz (2002) reported that the performance of novice volleyball players, but not the more skilled players, benefitted more from an internal focus than an external focus in the initial practice sessions. Finally, Saemi, Amo-Aghaei, Moteshareie, and Yamada (2023) recently found that experienced young swimmers' front crawl performance was enhanced with an external focus of attention compared to an internal focus of attention, while in novice swimmers no differences for attentional focus was found.

These discrepant findings may partly be attributed to the use of different groups of participants to uncover the effects of skill level. With a between-subject design, it is hard to rule out that individual characteristics mediate any skill level effect on attention focus. Participants may systematically differ in their preference for adopting an internal or external focus of attention (Ehrlenspiel, Lieske, & Rübner, 2004; Marchant, Clough, Crawshaw, & Levy, 2009; Maurer & Munzert, 2013; Nicklas et al., 2022). For example, Weiss, Reber, and Owen (2008) showed that novice participants increased performance across practice if the instructed focus of attention matched the participants' preferred focus. Hence, participants who preferred an internal focus improved their basketball free throw when instructed to focus internally, but those who preferred an external focus did not improve (and vice versa) (see also (Kal et al., 2015). This and other differences in individual characteristics can be better controlled by using a within-subject design for examining movement automaticity effects on attentional focus.

To this end, we compared punching performance with the preferred and non-preferred hand among skilled karate players. Similarly, to skill level, hand preference has been associated with different degrees of movement automaticity, with the preferred hand showing increased movement automatization (Jäncke et al., 1998; Mattay et al., 1998; Strenge & Niederberger, 2008; Yamashita, 2010). For example, Strenge and Niederberger (2008) had participants perform a grooved pegboard test with the preferred and non-preferred hand while concurrently performing a cognitive random number generation task. They found reduced performance for the cognitive task while performing with the non-preferred hand but not with the preferred hand. This indicates that more cognitive or conscious resources are allocated to perform movements with the non-preferred hand. This underlines that the nonpreferred hand shows reduced levels of movement automaticity compared to the preferred hand. Kal et al. (2013) compared the effects of focus of attention in simple stepping movements with the preferred and non-preferred leg. They did not find a differential effect of focus of attention related to leg. The external focus of attention resulted in faster stepping compared to internal focus of attention in both the preferred and the non-preferred leg. Yet, it is not immediately clear why stepping speed would be a valid indicator for task performance (i.e., participants were not instructed to move as fast as they could), or what optimization criterion participants used. Hence, we further address the role of movement automaticity for a karate punching task. That is, we compare performance under internal and external focus of attention conditions in skilled karate athletes who punch with their preferred and non-preferred hand.

The large majority of studies examined the relative benefits of internal and external focus of attention without considering alternative foci of attention, while obviously focus of attention is a more complex, rich and dynamic concept than reflected in the dichotomy between internal and external foci (Fairbrother, Post, & Whalen, 2016; Hutchinson & Tenenbaum, 2007). For highly demanding and competitive situations, athletes' focus of attention has been reported to also include a holistic focus, such as 'I was thinking of making an explosive throw' in judo (Bahmani, Bahram, Diekfuss, & Arsham, 2019, p. 2323), a "sensation of release in the hand" in golf (Bernier, Codron, Thienot, & Fournier, 2011, p. 333), or "feeling smooth and fluid" in swimming (Saemi et al., 2023, p. 3). Hence, rather than toward spatiotemporal characteristics of movement execution or effects, a holistic focus is directed toward a general feeling or experience of the movement (Becker, Georges, & Aiken, 2019). In early studies, Mullen and Hardy (2010) and Mullen, Faull, Jones, and Kingston (2015) found that a holistic focus on the global aspects of the movement task benefited performance and learning compared to a focus that directed attention to the constituting movement parts. More recent work has compared a holistic focus of attention directly to both internal and external foci of attention (Abedanzadeh, Becker, & Mousavi, 2022; Becker et al., 2019). A superior performance was found for the holistic and external focus of attention compared to the internal focus of attention in novice athletes in badminton and long jumping. An advantage of a holistic focus of attention was also reported for experienced track and field athletes, who threw farther with a holistic focus (i.e., "being as explosive as possible") than an internal focus performing an underhand shot throw (Zhuravleva & Aiken, 2023). Yet, no difference with external focus of attention was observed. One interpretation is that, as is reasoned for an external focus of attention, a holistic focus reduces conscious interference of automatic movement control (Becker et al., 2019). If correct, then this implies that a holistic focus may offer larger advantages for more automatic performance compared to less automatic, more conscious performance. In this regard, Saemi et al. (2023) compared front crawl swimming performance of novice and experienced 14-year-old swimmers but did not observe differences between the holistic focus and the external or internal focus conditions. We did not find any study that addressed the benefits of a holistic of attention in relation to movement automaticity by comparing performance between preferred and non-preferred hands or legs.

Hence, the current study investigated the effects of internal, external, and holistic foci of attention as a function of movement automaticity using a within subject-design. To this end, the punching performance of karate athletes with their preferred, presumably more automatized hand and non-preferred, presumably less automatized hand was compared. Punching is a fundamental skill in a variety of combat sports, where success is typically associated with hitting the opponent "as fast and forcefully" at designated locations of the body (Pierce, Reinbold, Lyngard, Goldman, & Pastore, 2006; Smith, Dyson, Hale, & Janaway, 2000). In fact, a recent study showed that both intermediate and high skilled boxers showed faster and more forceful punches with an external focus of attention compared to an internal focus of attention (Halperin et al., 2017), also suggesting that the advantage of external focus of attention is irrespective of the degree of movement automaticity. We used a similar task but compared the punches of a group of high skilled karate players with the preferred and non-preferred hand for internal, external, and holistic foci of attention. We hypothesized that wrist peak speed and impact force of the punch would be superior in external and holistic focus of attention compared to internal. Critically, this advantage was predicted to be more pronounced for the preferred hand than for punches with the non-preferred hand (or may even be reversed into a benefit for an internal focus), because punching with the preferred hand would proceed more automatically.

Method

Participants

Power analysis (G*Power 3.1) for ANOVA with repeated measures and two within factors (i.e., focus (3) and hand (2)) with $\alpha = .05$, $1-\beta = 0.80$, showed that 14 participants would be adequate to reject the null hypothesis with a moderate to large effect size (f = 0.3). We managed to recruit 13 high skilled karate athletes through advertisement sent by email and via contact with a karate coach. Participants needed to be 16 years or older, have at least one year experience with karate and be without injury in upper and lower limbs in the three months before the experiment to be included in the study. The 13 participants were naïve to the purpose of the experiment. They had an average experience of 14.3 years (SD = 11.6, range 5 to 49 years), with six and two participants having participated in national and international competitions, respectively. The reverse punch is one of first punches learned in karate, and hence we can assume that all participants had automatized the punch, at least for the preferred hand. Eleven participants self-reported to prefer the right hand, and one reported to prefer to punch with the left hand. One participant did not report a preference. We therefore used the average impact force of a bout of five attempts to decide the participant was more skilled with the left hand. The study protocol was approved by the local ethical review committee (VCWE-S-21-00061) and all participants signed informed consent before the start of the experiment.

Apparatus

Demographic questionnaire

Personal data including gender, age, height, weight, hand preference, karate experience and skill level were collected using a demographic questionnaire.

Boxing bag

A custom-made boxing bag was mounted in the middle of the laboratory. The boxing bag (height = 176 cm, circumference = 112 cm, weight = 61 kg) was equipped with a longitudinal aluminium rod embedded in the middle of bag with two accelerometers located at each end of the rod, allowing calculation of the peak impact force of the punch (for a detailed description, see (Orth, McDonic, Ashbrook, & van der Kamp, 2019). Reliability and accuracy of impact force of punches of the bag were previously shown to be excellent (Orth et al., 2019). A cross formed by two small pieces of tape (i.e., length 10 cm, width 0.5 cm) indicated the target location on the bag, which was fixed at the height of each individual participant's abdomen by adjusting the height of the bag.

Motion capture

The motion capture system Optotrak Certus (Northern Digital inc. Waterloo Ontario) was used to capture the punching movements of both hands for 3D kinematic analysis. Two cameras for each hand were used. Sampling frequency was 150 Hz. To determine the position of the wrist, a cluster of three fixed LEDs was attached to each hand (i.e., strapped to the side of the boxing gloves, which were provided to the participants) (Fig. 1). To define the clusters

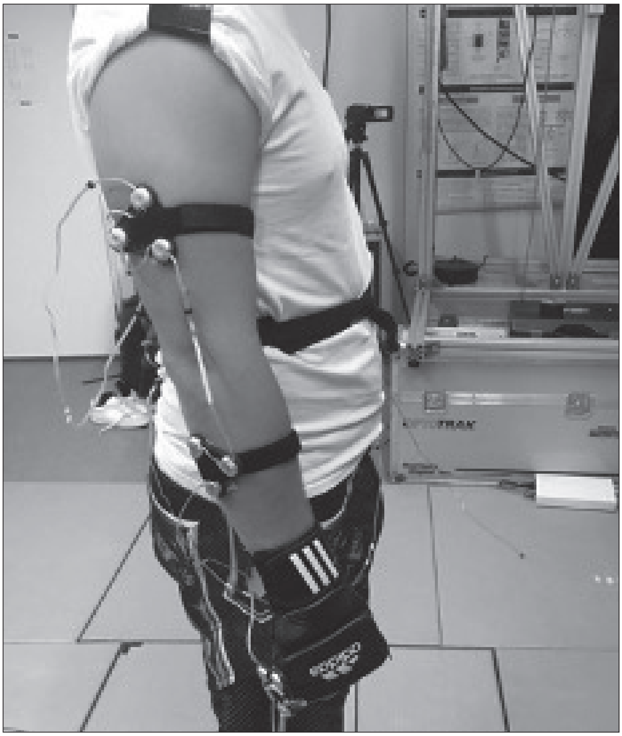

Fig. 1. - Participants showing the LED-clusters on wrist, elbow and shoulder joints. Note: in the present study only data from the wrist cluster was used.

in terms of the anatomical coordinate system, a long tip pointer procedure was used to locate the bony landmarks adjacent to the hand (van Andel, Wolterbeek, Doorenbosch, Veeger, & Harlaar, 2008). Four bony landmarks were digitized for this purpose: the second metacarpophalangeal, the fifth metacarpophalangeal, the radial styloid and the ulnar styloid. Other clusters were attached on the elbow and shoulder, but not used for analyses in the current study. Coordinates were defined such that the x-axis referred to the anterior-posterior plane, the y-axis to the mediolateral plane and the z-axis to the transverse plane. The experiment was recorded with a video camera fixed on a tripod (Canon, Legria HF R86).

Workload questionnaire

The National Aeronautics and Space Administration Task Load Index (NASA-TLX) was used to measure perceived workload (Hart & Staveland, 1988). The NASA-TLX consists of six items for mental demand, physical demand, temporal demand, overall performance, effort and frustration level. Participants scored each item from zero (0) to very high (20) on a visual analogue scale.

Instruction compliance

In order to measure participants' compliance to instructions, we used a scale developed in a previous study (Becker et al., 2019). This scale consisted of two questions: 1) Were you able to focus attention as you were instructed to do? 'Yes' or 'No'. 2) How much of the time were you successful in adhering to the instruction? Participants answered this second question on a 100 mm long visual analogue scale (i.e., between 0% and 100% successful). This provided an estimate in percentage of time that the participants reported to be able to adopt the required focus.

Procedure

Participants came to the laboratory for three separate sessions within 10 days with at least one day interval between sessions. In the first session, participants completed the demographic questionnaire, followed by a self-chosen warm-up of at least 15 minutes which included jogging and dynamic stretching. The type and duration of these exercises were the same across the three sessions. After placing the clusters, participants were asked to punch two or three times with both hands on the bag to get familiar with the setup, to adjust the height of the bag, to demarcate the preferred distance to the bag, and to check visibility of the LEDs. The participants were told to perform reverse punches on the target (i.e., gyaku zuki) in a fighting position with the punching hand contralateral to the leading foot. The distance to the bag was based on the participant's preference. A piece of tape on the mat indicated the position of the back heel of the rear foot for each punch. A beep sound signalled to the participant when they could initiate the punch. The three conditions for internal, external and holistic focus of attention were measured during separate sessions on separate days and counterbalanced among participants, except that one sequence (i.e., non-preferred holistic, internal, external, and preferred holistic, internal, external) was included a second time (for the 13th participant). Instruction was always provided by the same experimenter and based on the participant's native language (i.e., English or Dutch, Table 1). The instructions for the internal and external focus of attention were modified from the study of Halperin et al. (2017). Before the experiment, we verified the adequacy and equivalence of these instructions and additionally generated holistic instructions. To this end, three volunteers who were naïve about study purposes were asked to rate different instructions on a scale from 1 to 5 to indicate the transparency of the formulation in commanding the highest hand speed and/or impact. For example, the holistic focus of attention instructions was originally formulated in two ways: "focus on feeling quick when completing the punch", and "focus on feeling explosive when completing the punch". After summing the score of three participants, the instruction with the highest score was selected for the experiment.

Within each session, participants performed two blocks of 15 trials (30 trials in total) with the preferred and non-preferred hand. This order was also counterbalanced across participants, but remained the same across the three attentional conditions for individual participants. Each punch was followed by a rest period of approximately 5s. During this period, the boxing bag was realigned to its resting position. There was an additional two to five minutes interval between the first and second block. The workload questionnaire was administered after each block, while compliance to instructions was assessed immediately on completion of the two blocks.

Data Analysis

Perceived workload and instruction compliance

For perceived workload, the average score of the six items of the NASA-TLX was calculated (Hart & Staveland, 1988), while the instruction compliance score was taken as the percentage of time participants reported to be able to adhere to the instructed focus.

Impact force

Peak impact force was computed by customized software for the boxing bag and normalized for the participant's body weight (i.e., N/kg) (Halperin et al., 2017). Due to technical error, for three participants the data of one condition was not recorded (i.e., one internal non-preferred hand, one external preferred hand, and one holistic preferred hand).

Table I
Focus Of Attention Instructions For The Three Conditions

Focus of attention		
Internal	**External**	**Holistic**
focus on moving your arm as fast as possible	focus on hitting the target as hard as possible	focus on feeling explosive when punching

NB. In Dutch 'fast' and 'hard' are both translated as 'hard'.

Wrist kinematics

The wrist cluster LEDs were used to determine peak wrist velocity by identifying the local maximum of the tangential velocity of the punching wrist between the onset and termination of the punching movement. To do this, the moment of onset and termination of each punch were determined using visual inspection of the tangential velocity profile. Data of participant in one condition was missing due to technical error (i.e., holistic, non-preferred hand). For the remainder of the participants, due to partial invisibility of the LEDs and after cubic spline interpolation, for the right hand 36%, 21% and 39% of the trials in the external, internal and holistic focus conditions, respectively were missing, while for the left hand 26%, 23% and 34% could not be included. We checked the coefficient of variance (CV) for the peak wrist velocity between trials (for each participant and each condition separately) to confirm the stability of the included data. For the right hand, the mean (and range) of CVs were 7.2% [2.6-18.6%], 4.3% [1.7- 8.4%], and 5.4% [2.4-12.2%], for the external, internal and holistic focus conditions, respectively. For the left hand, these were 4.1% [1.4-11.9], 5.4% [2.2-16.2%], and 6.4% [1.4-13.7%], respectively. This shows that the dispersion is relatively small and the included data relatively stable.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics (V.25, IBM Corp.). The assumption of normality was checked using Shapiro-Wilk tests. For instruction compliance, a 3(focus: internal, external, holistic) analyses of variance with repeated measures was conducted. For perceived workload, a 3(focus: internal, external, holistic) × 2(hand: preferred, non-preferred) analyses of variance with repeated measures was conducted. In case Mauchly's test indicated that the sphericity assumption was violated, Greenhouse-Geisser correction was used. The η_p^2 were reported for estimated effect size, with $\eta_p^2 < 0.06$ classified as small, $\eta_p^2 > 0.06$ and $\eta_p^2 < 0.14$ as moderate, and large for $\eta_p^2 > 0.14$ (Cohen, 1988). For peak impact force and peak wrist velocity, separate linear mixed models were used, because they accommodate all of the available data without excluding participants with missing data points (West, 2009). To do this, two 3(focus: internal, external, holistic) by 2(hand: preferred, non-preferred) models were employed. Focus and hand served as fixed effect variables and participant as a random variable. For both dependent variables, an unstructured repeated covariance type was chosen, because likelihood ratio tests showed a significant improvement for this model when compared to alternative covariance structures. The estimation method used was Maximum likelihood (ML). For the fixed effects, Type III tests were used for the sum of squares estimation. Degrees of freedom were estimated using Satterthwaite approximation (West, 2009). For post hoc analysis Bonferroni adjustments were performed to correct for multiple comparisons.

Results

Compliance of instruction

All participants answered, 'Yes' in reply to the question of 'Were you able to focus on given instruction when told to do so?', except for one participant in holistic focus of attention condition. Fig. 2 shows that participants reported to be able to use the required focus in approximately 70% of the time. A repeated measures ANOVA revealed that there was no significant main effect of focus, $F(2, 24) = 1.54$, $p = 0.23$, = 0.11.

Peak impact Force

For peak impact force, the Type III test of fixed effects yielded a significant effect of focus, $F(2, 14.21) = 6.84$, $p = 0.008$. Post hoc comparisons indicated a higher peak impact force in the external focus condition than in the internal focus condition, M_{diff} (95% CI) = 2.19 (0.91, 3.46), SE = 0.60, df = 14.43, $p = 0.007$, but no differences between holistic and internal, M_{diff} (95% CI) = 0.97(-0.49, 2.43), SE = 0.54, df = 12.99, $p = 0.28$, and holistic and external foci, M_{diff}(95% CI) = 1.21(-0.17, 2.61), SE = 0.51, df = 13.43, $p = 0.09$ (Fig. 3). The Type III test of the fixed effect of hand was also significant, $F(1, 14.52) = 14.92$, $p=0.002$, indicating a higher peak impact force for the preferred hand compared to the non-preferred hand, M_{diff} (95% CI) = 1.66 (0.74, 2.59), SE = 0.43, df = 14.52, $p= 0.002$ (Fig. 3). Finally, no significant interaction of focus and hand was found, $F(2, 10.36) = 1.16$, $p = 0.34$.

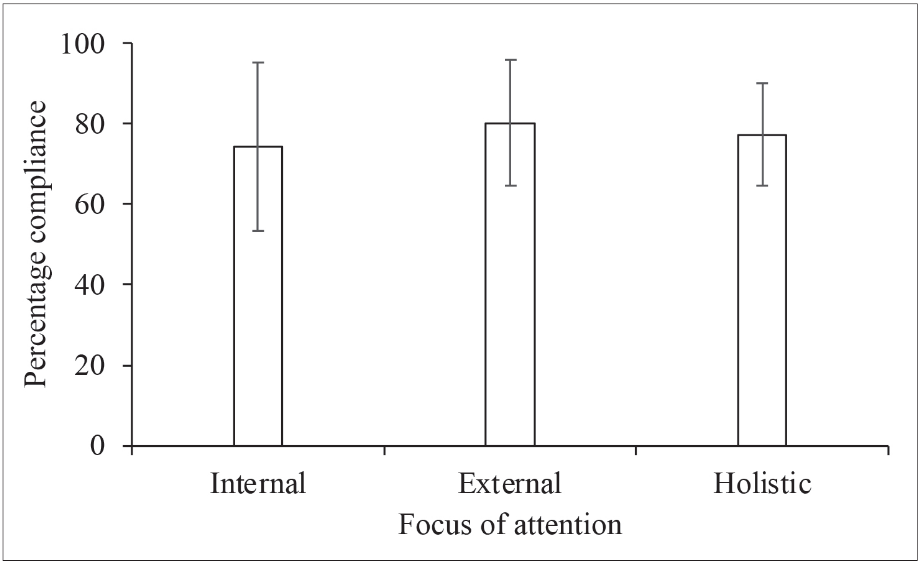

Fig. 2. - Mean (and SD) for the percentage of time participants reported to be able to comply to the instructions as function of attentional focus.

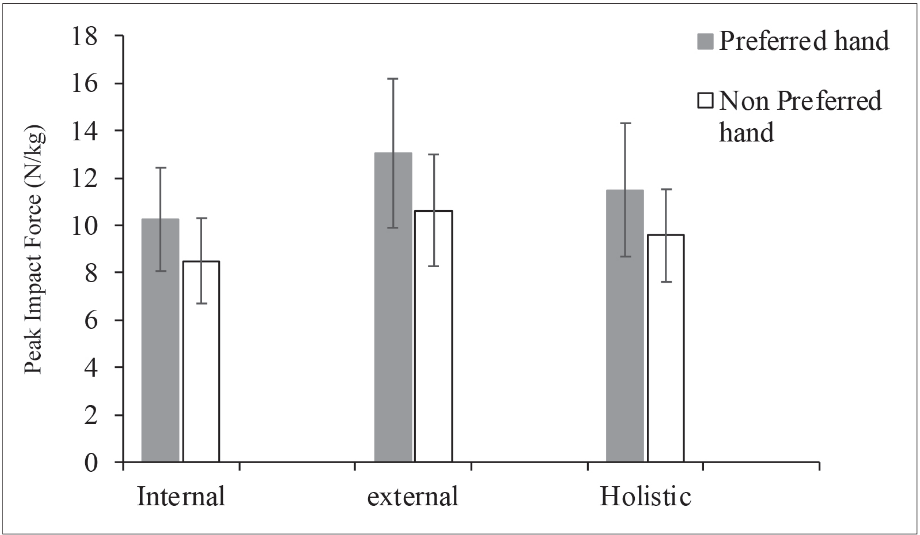

Fig. 3. - Mean (and SD) of impact force for the preferred hand and non-preferred hand as function of attentional focus.

Peak wrist velocity

The Type III tests for fixed effects showed a significant effect for focus on peak wrist velocity, $F(2, 13.10) = 4.45$, $p = 0.033$. Post hoc comparisons indicated a higher peak velocity in the external focus condition compared to the internal focus condition, M_{diff}(95% CI) = 0.50 (0.03, 0.97), SE = 0.17, df = 13.27, $p = 0.03$, but no differences were found between holistic and internal, M_{diff}(95% CI) = 0.02 (-0.44, 0.48), SE = 0.17, df = 13.27, $p = 1.00$, and holistic and external foci, M_{diff}(95% CI) = 0.48 (-0.19, 1.17), SE = 0.25, df = 13.07, $p = 0.21$ (Fig. 4). The Type III test of the fixed effect of hand was also significant, $F(1, 13.30) = 31.0$, $p < 0.001$, indicating higher velocity for the preferred hand compared to the non-preferred hand, M_{diff} (95% CI) = 0.57 (0.35, 0.79), SE = 0.10, df = 13.30, $p < 0.001$. Finally, the interaction between focus and hand was found significant, $F(2, 12.97) = 4.84$, $p = 0.02$ Post hoc comparisons indicated that the higher peak velocity in the external focus condition compared to the internal focus condition was only present for the preferred hand M_{diff}(95% CI) = 0.73(0.13, 1.33), SE = 0.21, df = 13.00, $p = 0.01$, but not for the non-preferred hand M_{diff}(95% CI) = 0.28(-0.12, 0.68), SE = 0.14, df = 13.00, $p = 0.23$ (Fig. 4). Again, no differences with the holistic focus condition were identified.

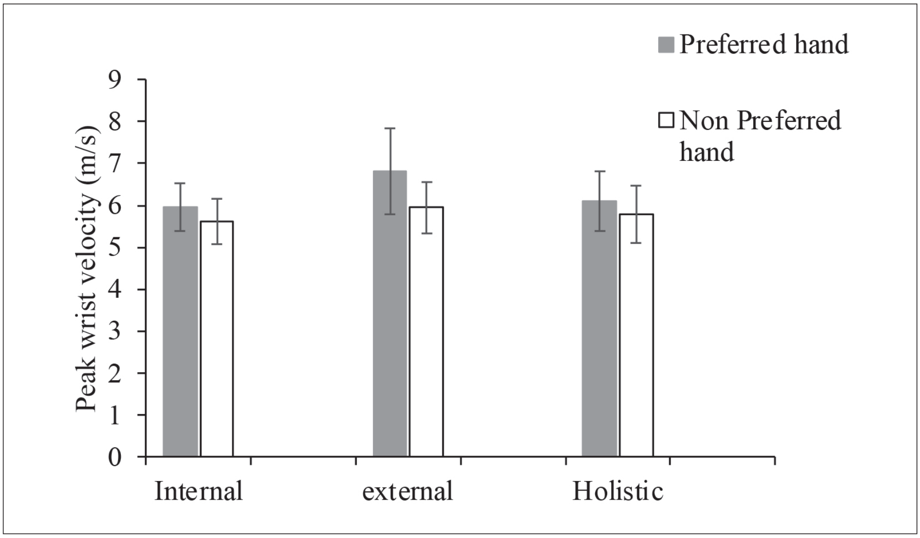

Fig. 4. - Mean (and SD) of peak wrist velocity for the preferred hand and non-preferred hand as function of attentional focus.

Perceived workload

There were no significant main and interaction effects of focus and hand for perceived workload (Fig. 5).

Discussion

According to the constrained-action hypothesis (Wulf et al., 2001), an external focus of attention promotes performance compared to an internal focus of attention because it allows the motor system to self-organize without conscious interference of automatic movement control. Despite arguments that this advantage of external focus of attention would be ubiquitous for all performers and learners (chua et al., 2021; lewthwaite & wulf, 2017; wulf et al, 2007, p. 10), it stands to reason that the advantage would be reduced (or perhaps even reversed) when movement control is less automatized compared to control that is largely automatized; that is, if less automatized an internal focus would be less disruptive. To test this conjecture, we compared reverse punching performance of skilled karate athletes with the preferred (i.e., presumably more automatized) and non-preferred hand (i.e., less au-

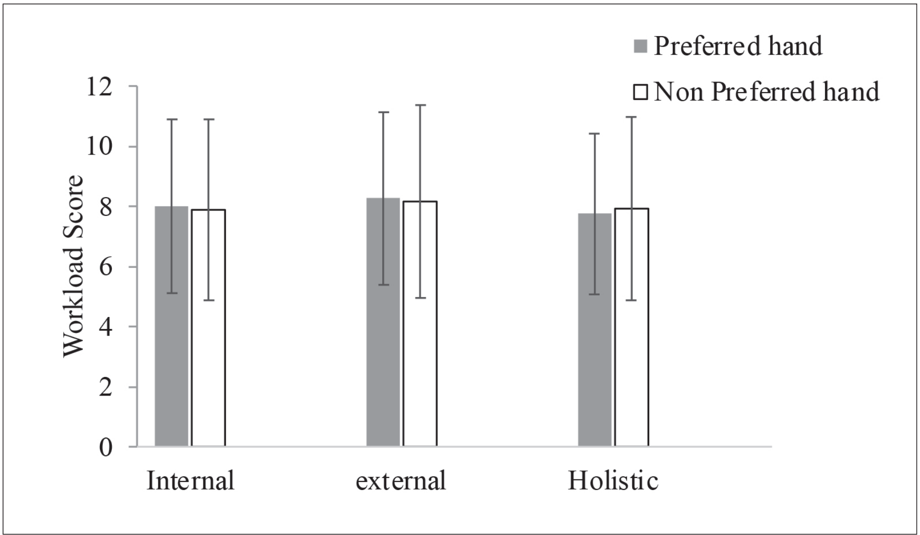

Fig. 5. - Mean (and SD) of perceived workload in preferred hand and non-preferred hand as ion of attentional focus.

tomatized) in conditions with internal, external and holistic focus of attention instructions. The holistic focus was included because it has recently been proposed as an alternative to an external focus that would also advance performance, arguably because it also promotes automatic control (Becker et al., 2019). Overall, the present results indicated that an external focus of attention indeed leads to better performance than performing with an internal focus of attention. In addition, there was partial evidence to suggest that this advantage only emerged in the more automatized preferred hand and not in the non-preferred hand.

The generally enhanced performance with an external focus of attention compared to an internal focus of attention replicates various previous observations (Chua et al., 2021; Nicklas et al., 2022), including in boxing (Halperin et al., 2017), and is consistent with predictions from the constrained-action hypothesis (Wulf et al., 2001). We also showed that these differences are not associated with differences in perceived workload or difficulties in complying with the instructions. Also, whereas an external focus showed an advantage for performance, the holistic focus did not increase punching performance relative to an internal focus of attention. Possibly, the exact way the holistic instruction was formulated did insufficiently direct attention to task-relevant information (e.g., target location). In fact, this argument may be more far-reaching than appears on first sight, because it presumes that attuning to task-relevant information is more critical for performance than increasing automaticity and/or avoiding conscious control (Abedanzadeh et al., 2022; Becker et al., 2019). And accordingly, this would also point to an alternative, information-based explanation for the constrained-action hypothesis for the advantage of an external focus over an internal focus (see Herrebrøden, 2022; Peh, Chow, & Davids, 2011; Van der Kamp, Oudejans, & Savelsbergh, 2003). Hence, directly verifying the degree to which a holistic focus of attention increases movement automaticity is an important aim for further research (see for validated methods to assess movement automaticity, Kal et al., 2013; Lohse, Sherwood, & Healy, 2010; Wulf et al., 2001).

It is most critical to note that external focus of attention enhanced punching relative to an internal focus of attention only with the more automatized preferred hand, while the advantage was not demonstrated with the less automatized non-preferred hand. That is, as far as peak wrist velocity is concerned. For peak impact force, we cannot rule out that the advantage may have generalized to both hands. We discuss this discrepancy below. In fact, we consider the peak wrist velocity the more important indicator for performance than the resulting impact force, as karate athletes aim to optimize movement speed of movement for reverse punching (i.e., gyaku zuki).[1] The observed differential attentional effect between the two hands for peak wrist velocity accords with our conjecture concerning the constrained-action hypothesis that the benefit of an external focus of attention depends on movement automaticity. As has been shown previously (Jäncke et al., 1998; Mattay et al., 1998; Strenge & Niederberger, 2008; Yamashita, 2010), movements with the preferred limb typically show a higher degree of automaticity and are, potentially, more severely disrupted by conscious interference associated with an internal focus of attention in comparison to movements with the non-preferred limb, which typically requires a higher degree of conscious control and monitoring. A similar, automaticity dependent advantage of an external focus has previously been sought by comparing performance and learning of participants with different skill level (e.g.,(Perkins-Ceccato et al.,

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[1] One year after finishing the study, we verified this with five of our participants. They were presented with two propositions: 1) "When I make a straight punch (i.e., a gyaku zuki) toward the opponent's abdomen then for me the most important is to hit the opponent as hard as I can"; 2) "When I make a straight punch (i.e., a gyaku zuki) toward the opponent's abdomen then for me the most important is to make the move as fast as I can". They responded on a 7-point Likert scale form fully disagree to fully agree. Four participants responded with fully disagree and fully agree, respectively, while one participant answered with disagree and agree. In other words, their aim with the reverse punch is to optimize speed of movement.

2003; Saemi et al., 2023)), but with equivocal results (Nicklas et al., 2022). However, a comparison between groups of individuals of different skill level potentially allows (individual) characteristics other than attentional focus, such as the fit with attentional preferences (Klatt & Noël, 2020; Weiss et al., 2008), to conceal any automaticity dependent effect. We demonstrate the automaticity dependent advantage of external focus of attention within rather than between individuals. Previous results of Beilock, Carr, MacMahon, and Starkes (2002) alluded to similar, but not identical effects showing that a dual task, which prevents a skill focus attention (i.e., in skill focus attention, attention is typically directed internally to the body movements) did compromise performance in soccer dribbling with the non-dominant foot, but not with the dominant foot. However, this study did not make a comparison with an external focus of attention. Together, however, these observations suggest that the advantage of an external focus of attention relative to an internal focus of attention is influenced by movement automaticity. Yet, and this a restriction we must make, since most participants were right-dominant, we cannot exclude that our findings (and those from Beilock et al., 2002) are underpinned by hemispheric differences, which may be engaged differently by the two foci instructions (Steenbergen & Van der Kamp, 2008). More generally, since we did not include a control condition without specific focus instruction, we cannot be certain that the advantage for external focus of attention is superior to an individual's preferred focus of attention (Weis et al., 2008)

The current results suggest that the benefit of external focus of attention is indeed dependent on the degree of automatization, which in our reading is consistent with the constrained-action hypothesis. However, in the current study this finding was restricted to peak wrist velocity and did not arise significantly in the impact force. Although impact force and peak wrist velocity have been found to correlate highly (Dinue & Louis, 2020), they are non-identical measures and not only because impact force was scaled to body weight. According to Walilko, Viano, and Bir (2005) impact force is not only defined by peak wrist velocity (or wrist velocity at impact), but also the direction of wrist velocity (i.e., the angle of incidence) and joint stiffness are critical parameters (see also Orth, van der Kamp, & Rein, 2018). Nonetheless, it is perhaps also of relevance that peak wrist velocity refers to aspects of movement execution, while peak impact force is more strongly associated with movement outcome. One may speculate therefore that peak wrist velocity is more sensitive to changes brought about by internal focus instructions. Furthermore, the present study only assessed performance outcomes (as is typically done in this domain of research), but a critical next step would be to understand and uncover how the movements and coordination patterns are regulated to achieve performance outcomes. In this respect, a study by Lohse, Sherwood, and Healy (2014) provides evidence that more enhanced performance under external focus of attention in dart throwing may emerge from external focus of attention enabling increased trial-by-trial variability allowing for higher adaptive flexibility to negotiate the dynamics of movement execution and/or the environment. Similarly, Singh, Shih, Kal, Bennett, and Wulf (2022) and Fietzer, Winstein, and Kulig (2018) used the uncontrolled manifold analysis to measure functional or 'good' variability in volleyball serves and hopping, respectively. This approach measures functional variability using within-trial compensatory variability in joints kinematics related to stabilizing task variables, which is a more direct method to measure functional variability (Scholz & Schöner, 1999). Indeed, Singh et al. (2022) reported that this compensatory variability was enhanced with a (distal) external focus. Hence, future studies should confirm if indeed the advantage of external focus is associated with or induced by enhancing functional variability, and if this advantage depends on the degree of movement automaticity. Finally, we also must be cautious not to overgeneralize the current findings, especially because we were limited to uncover moderate to large effects only, while we also had an incomplete data set.

Conclusion

In conclusion, this study provides partial evidence that an external focus of attention compared to an internal focus of attention resulted in superior motor performance, but more so in the preferred hand than in the non-preferred hand, indicating that the attentional focus effect may depend on the degree of movement automaticity. No performance benefits for holistic focus of attention were found. We take these effects as logically consistent with the constrained-action hypothesis.

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