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Peripheral vision and perceptual asymmetries in young and older martial arts athletes and nonathletes

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Abstract The present study investigated peripheral vision (PV) and perceptual asymmetries in young and older martial arts athletes (judo and karate athletes) and compared their performance with that of young and older nonathletes. Stimuli were dots presented at three different eccentricities along the horizontal, oblique, and vertical diameters and three interstimulus intervals. Experiment 1 showed that although the two athlete groups were faster in almost all conditions, karate athletes performed significantly better than nonathlete participants when stimuli were presented in the peripheral visual field. Experiment 2 showed that older participants who had practiced a martial art at a competitive level when they were young were significantly faster than sedentary older adults of the same age. The practiced sport (judo or karate) did not affect performance differentially, suggesting that it is the practice of martial arts that is the crucial factor, rather than the type of martial art. Importantly, older athletes lose their PV advantage, as compared with young athletes. Finally, we found that physical activity (young and older athletes) and age (young and older adults) did not alter the visual asymmetries that vary as a function of spatial location; all participants were faster for stimuli presented along the horizontal than for those presented along the vertical meridian and for those presented at the lower rather than at the upper locations within the vertical meridian. These results indicate that the practice of these martial arts is an effective way of counteracting the processing speed decline of visual stimuli appearing at any visual location and speed.

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Human visual perception is not uniform across the visual field. Research conducted with young adults using a variety of tasks has shown that performance decreases with eccentricity (e.g., Berkley, Kitterle, & Watkins, 1975; Carrasco & Chang, 1995). Interestingly, performance also varies at isoeccentric locations of the visual field. It is better on the horizontal than on the vertical meridian, and it is also better in the lower than in the upper region of the vertical meridian (Carrasco, Talgar, & Cameron, 2001; Montaser-Kouhsari & Carrasco, 2009; Rovamo & Virsu, 1979). Little is known, however, about whether these perceptual asymmetries also occur in elite martial arts athletes who do intensive physical exercise and, importantly, whether these perceptual asymmetries change with age.

Peripheral vision (PV) plays a crucial role in sports performed under time pressure (Müller & Abernethy, 2012). Martial arts typically impose both physical and perceptual demands and often require the acquisition of certain skills to avoid attacks that frequently come at high speed from the periphery, which makes contact sports a good model with which to study PV in young high-competitive athletes. Although older athletes do not practice martial arts with the same intensity and regularity, they are still active, which make them good candidates for the investigation of possible changes occurring in PV after years of not competing at a professional level.

Human perceivers need more time to detect stimuli that are farther away from fixation (Carrasco, Evert, Chang, & Katz, 1995; Carrasco & Frieder, 1997; Golla, Ignashchenkova, Haarmeier, & Their, 2004). This deterioration of performance at peripheral visual areas has been attributed to the physiological properties of the retina (e.g., reduction in spatial resolution and contrast sensitivity with eccentricity), since visual acuity decreases rapidly from 5° of visual angle from fixation (Anderson, Zlatkova, & Demirel, 2002). Several studies have shown differences in PV between athletes and nonathletes, using stimuli related to their sport (e.g., Memmert, Simons, & Grimme, 2009), while others have also reported differences using simple stimuli not related to the participant's sport (e.g., Ando, Kida, & Oda, 2001; Kokubu, Ando, Kida, & Oda, 2006; Muiños & Ballesteros, 2013). It has been argued that athletes and nonathletes differ not in the visual function itself (i.e., in the visual "hardware"—e.g., visual acuity, depth perception, color vision) but in the visual "software," or the ability to process and interpret visual information more efficiently using different strategies learned with practice (Abernethy, Neal, & Koning, 1994; Helsen & Pauwels, 1993; Williams, Davids, Burwitz, & Williams, 1994; Wu et al., 2013; Zwierko, 2007; Zwierko, Osinki, Lubinski, Czepita, & Florkiewicz, 2010).

We speculated that regular judo and karate activity would improve visuospatial attention and PV, which may translate into faster stimulus processing at more eccentric locations. An important question addressed in the present study is what happens as young athletes age. Do older athletes process peripheral stimuli similarly to competitive young athletes? Do they perform the task better than sedentary young and older adults? It is well known that many cognitive processes decline with age, including working memory, episodic memory, processing speed, and executive functions (Baltes & Lindenberger, 1997; Park, Polk, Mikels, Taylor, & Marshuetz, 2001; Salthouse, 1996), while others are preserved in older adults, including verbal abilities, world knowledge (Park et al., 2002; Park & Reuter-Lorenz, 2009; for a review, see Hedden & Gabrieli, 2004), and implicit memory (Ballesteros, Mayas, & Reales, 2013b, Ballesteros, Mayas, & Reales, 2013c; Ballesteros & Reales, 2004; Ballesteros, Reales, Mayas, & Heller, 2008; Davis, Trussell, & Klebe, 2001). However, it is important to note that despite normal behavioral priming, recent electrophysiological (Osorio, Fay, Pouthas, & Ballesteros, 2010; Sebastián & Ballesteros, 2012) and brain imaging (Ballesteros, Bischof, Goh, & Park 2013a) studies have found altered neural priming, which might be a form of compensatory neural activity.

Many cognitive declines with age have been associated with decreases in processing speed (Salthouse, 1996). Reduced speed in carrying out perceptual tasks is the main cause of the age-related impairments observed in cognitive functions. Processing speed is a robust predictor of age-related cognitive decline (Salthouse & Ferrer-Caja, 2003) and an indicator of independence in older adults (Wahl, Schmitt, Danner, & Coppin, 2010). We expected that older martial arts athletes, who have had and still practice their sport, would perform the visual speeded task better than sedentary older adults.

In human visual performance, aging is associated with the slowing down of processing speed (e.g., Owsley, McGwin, & Searcey, 2013), the decline of visual tracking abilities, and lower accuracy in pursuing targets (Paquette & Fung, 2011) and in performing saccade movements in the correct direction (Butler, Zacks, & Henderson, 1999). Furthermore, the detection of peripheral stimuli diminishes with age, especially at high eccentricities (e.g., Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball, Owsley, & Beard, 1990; Beurskens & Bock, 2012; Itoh & Fukuda, 2002). Thus, we reasoned that continued judo and karate activity could result in better performance in PV tasks, while this might deteriorate with age. Furthermore, studies conducted with sedentary young adults suggest that exercise improves PV, while stopping regular exercise results in a loss of previous gains (e.g., Ando, Kida, & Oda, 2004; Ciuffreda, 2011). This improvement of reaction time (RT) to visual stimuli following regular exercise suggests that athletes may outperform nonathletes due to regular physical activity.

The present study aimed to examine whether visuospatial attention to stimuli at peripheral locations is modulated by regular judo and karate activity and the age of the practitioner. Depending on the speed of the motor maneuvers performed by the athletes in their daily practice, which differs with the type of sport, different patterns of visual skills may develop to enable rapid response to peripheral stimuli. These rapid motor maneuvers mainly occur automatically after a long learning process involving years of intense practice (Kibele, 2006). An important question addressed in the present study is what happens to the PV and perceptual asymmetries of older athletes after not competing for several years. If PV tends to deteriorate with age and to be improved by sports, the performance of older athletes should be similar to that of sedentary young adults. Many studies have shown that a rich physical lifestyle tends to attenuate the decline of many cognitive and perceptual functions. Physically active older adults are usually faster than sedentary older adults in simple and choice RT tasks (Ballesteros, Mayas, & Reales 2013c) and in effortless cognitive tasks (Chodzko-Zajko, 1991; Chodzko-Zajko & Moore, 1994; Chodzko-Zajko, Schuler, Solomon, Heini, & Ellis, 1992). In addition, they show increased brain plasticity, allowing them to perform certain tasks more efficiently (Colcombe et al., 2006a; Colcombe, Kramer, Erickson, & Scalf, 2006; Erickon & Kramer, 2009; Kramer, Bherer, Colcombe, Dong, & Greenough, 2004).

The aims of the present study were threefold. First, we investigated whether the PV of karate and judo athletes is better than that of nonathletes and also whether the type of martial art is important. Second, we investigated whether the possible advantages encountered in the PV of young, highly competitive athletes also emerge in older martial arts athletes, comparing their performance with that of a group of nonathletes of the same age. Finally, we examined whether the visual performance of young and older judo and karate athletes would be heterogeneous at isoeccentric locations. In particular, we explored whether judo and karate (1) young athletes and (2) older athletes yielded a horizontal–vertical anisotropy (HVA) and a vertical meridian asymmetry (VMA), as has been reported in graduate students (see Montaser-Kouhsari & Carrasco, 2009). We expected differences between the two martial arts, because karate and judo use very different techniques. Karate mainly involves discrete punches and kicks. Athletes have to respond rapidly to frontal and peripheral attacks, but it is uncommon to grip the opponent. Judo, however, is characterized by gripping the opponent at a close distance, so it is very likely that the two groups do not develop the same peripheral visual abilities. A recent study by our laboratory has shown that competitive kung fu athletes respond faster than nonathletes to peripheral stimuli (Muiños & Ballesteros, 2013). Kung fu, like karate, is a martial art involving discrete punches and kicks. Athletes develop certain visual skills to enable them to respond rapidly to their opponent's attacks. The present study compared karate and judo practitioners, whose PV performance is likely to be determined by motor skills of balance, coordination, and posture control (Perrin, Deviterne, Hugel, & Perrot, 2001; Sterkowicz, Lech, Jaworski, & Ambrozy, 2012). For older participants, we expected that the athlete groups would outperform sedentary participants of the same age under all conditions, especially those involving more eccentric stimuli. We also predicted that athletes would perform better than nonathletes at the shortest interstimulus interval (ISI), since exercise could have improved their processing speed. Finally, by comparing all groups, we expected that young adults would outperform older participants and that older athletes had a similar performance to that of young nonathletes.

In sum, in Experiment 1, we investigated whether PV in young adults varies as a function of the chosen sport, in comparison with nonathletes of the same age, and whether visual performance varies as a function of stimulus location, producing inhomogeneities at isoeccentric locations, in both athletes and nonathletes. In Experiment 2, we investigated whether the same pattern of results would emerge in older judo and karate athletes, as compared with older nonathletes.

Experiment 1

Method

Participants

Ninety young male observers with normal or corrected-to-normal vision participated voluntarily in the experiment. Thirty were judo athletes (mean age = 27.6 years, *SD* = 3.8 years, range = 21–32 years) and 30 were karate athletes (mean age = 25.3 years, *SD* = 4.8 years, range = 19–34 years). The nonathlete group comprised 30 participants without experience in combat sports (mean age = 23.5 years, *SD* = 3.2 years, range = 19–28 years). Participants in the athlete groups were recruited from various martial arts schools. All were internationally competitive, high-level professional practitioners with a mean experience in their sport of at least 10 years. All participants were right-handed, and none of them were suffering from general health problems, refractive eye disorders, or low visual acuity. The three groups were matched for age and sociocultural level assessed with the Goldthorpe–Hope scale (Goldthorpe & Hope, 1974). As a control measure, participants performed the Rockport Test (Kline et al., 1987) consisting of walking a mile as fast as possible to calculate their maximal oxygen uptake (VO_2 max). The results showed that both athlete groups had higher cardiovascular capacity than the nonathlete group. The VO_2max means were 51.14 for judo athletes, 49.92 for karate athletes, and 38.29 for nonathletes. The ANOVA conducted on this variable showed a statistically significant effect of group, $F(2, 87) = 130.75$, $MSE = 1{,}509.44$, $p < .01$, $\eta^2_{\text{partial}} = .75$. Pairwise comparisons showed significant differences between the nonathlete group and both the judo ($p < .01$) and the karate ($p < .01$) groups. Table 1 shows the demographic and vascular capacity characteristics of the three groups.

All participants signed an informed consent form for participation in the study, which was approved by the Ethical Review Board of the Universidad Nacional de Educación a Distancia. The experiments were conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki as revised in October 2008.

Apparatus and stimuli

The stimuli consisted of black dots presented on a light gray background on the computer screen. The stimulus subtended 1° of visual angle. The computer screen had a luminance resolution of 58 cd/m^2. A fixation dot appeared at the center of the computer screen, while another dot (identical in appearance to the fixation dot) appeared and disappeared at random locations within the visual field. The dots appeared randomly at three different eccentricities from fixation along equally

Table 1 Mean age, VO_2 max, and demographic scores of the groups (standard deviations in parentheses)

Group	Age	VO_2 max	Goldthorpe–Hope Scale
Judo	27.6 (3.8)	51.14 (3.25)	4.10 (0.96)
Karate	25.3 (4.8)	49.92 (3.97)	4.13 (1.01)
Nonathletes	23.5 (3.2)	38.29 (2.88)	4.07 (0.87)

Note. VO_2, maximal oxygen volume.

spaced radial arms (two horizontal, two vertical, and four oblique) at 3°, 6°, and 12° eccentricities. To avoid anticipation, three different ISIs were used at random (250, 700, and 1,500 ms). The task consisted of pressing "b" on the keyboard when the stimulus appeared as quickly and accurately as possible. The experiment was programmed with E-Prime software v2.0 (Schneider, Eschman, & Zuccolotto, 2002) and was conducted on a 19-in. Sony Multiscan G420 CRT monitor connected to a personal computer, with a refresh rate of 120 Hz. The program recorded RTs from stimulus onset to keypressing.

Procedure

Each participant was tested in a quiet room with a luminance of 85 cd/m^2, a temperature of 22 °C, and a noise level maintained between 5 and 13 decibels. The participants were instructed to fixate and view the stimuli binocularly at a distance of 60 cm from the monitor and to press a keyboard button as fast as possible when the stimulus appeared on the computer screen. Each participant completed 25 practice trials and 252 experimental trials (4 blocks of 63 trials each). To avoid eyes movements, stimulus presentation was 150 ms. Participants received feedback on each trial to prevent anticipation or no responses.

Experimental design

Data were analyzed using a 3 (group: judo athletes, karate athletes, and nonathletes) × 3 (eccentricity: 3°, 6°, and 12°) × 3 (ISI: 250, 700, and 1,500 ms) mixed factorial design with repeated measures on the last two factors. To analyze the effects of isoeccentric locations, we used a 3 (group) × 3 (eccentricity) × 4 (location: horizontal right, horizontal left, vertical upper, vertical lower) design with repeated measures on the last two factors.

Results and discussion

RT was the dependent variable in the analysis. Errors were also recorded, although the percentage did not exceed 1 %. Incorrect trials and outlier values were not included in the data analysis. Table 2 displays the mean RTs of the three groups in all the experimental conditions. The mean RTs and standard deviations (in parentheses) were 242.06 (19.9) for judo athletes, 237.02 (19.3) for karate athletes, and 246.75 (18.5) for nonathletes.

A 3 (group) × 3 (eccentricity) × 3 (ISI) mixed ANOVA was conducted with group as a between-subjects factor and eccentricity and ISI as repeated measures. The Greenhouse–Geisser correction for nonsphericity was applied where necessary and is indicated by adjusted degrees of freedom. The ANOVA showed that the main effects of group, $F(2, 87) = 4.49$, $MSE = 1{,}425.64$, $p < .01$, $\eta^2_{partial} = .094$), eccentricity, $F(1.55, 134.92) = 24.38$, $MSE = 368.21$, $p < .01$, $\eta^2_{partial} = .22$), and ISI, $F(1.78, 155.58) = 20.83$, $MSE = 316.42$, $p < .01$, $\eta^2 = .19$, were all significant. The fastest group was the one of karate athletes, followed by judo athletes and nonathletes, but pairwise comparisons indicated that only the karate athletes were significantly faster than nonathletes ($p < .05$). Eccentricity conditions all differed from each other (all ps < .01), with participants being faster at the intermediate eccentricity (6°) and slower at the 12° eccentricity (see Fig. 1). ISI pairwise comparisons showed differences between the 700-ms condition and the other two conditions: 250 ms ($p = .000$) and 1,500 ms ($p = .000$). Participants were faster when the stimuli were presented at the intermediate 700-ms ISI. The two-way group × eccentricity, $F(3.1, 134.92) = 3.027$, $p < .05$, $\eta^2_{partial} = .065$, and eccentricity × ISI, $F(2.94, 255.78) = 3.92$, $p < .01$, $\eta^2_{partial} = .043$, interactions were statistically significant. Simple effects analyses (Kappel, 1991) revealed that karate athletes were faster than nonathletes at the largest eccentricity (12°) ($p < .01$), while judo athletes were marginally faster than nonathletes ($p = .06$). Karate athletes were only marginally faster than judo athletes ($p = .06$), indicating that although both athlete groups performed better than nonathletes, only the karate group was significantly faster than the nonathlete group when the stimuli were presented at the periphery of the visual field (see Fig. 1).

The two-way eccentricity × ISI interaction was statistically significant, $F(2.94, 255.78) = 3.92$, $p < .01$, $\eta^2_{partial} = .043$. At eccentricity 6°, all ISIs differed from each other (ps < .01), while at eccentricity 12°, participants were significantly faster at ISI 700 ms than at both 250 ms ($p < .01$) and 1,500 ms ($p < .05$).

To evaluate the possible inhomogeneities at isoeccentric locations, a group × location (horizontal right, horizontal left, vertical upper, vertical lower) × eccentricity mixed factorial ANOVA was performed. Group was the between-subjects variable, while location and eccentricity were the repeated measures. The main effects of group, $F(2, 87) = 2.94$, $MSE = 15{,}461.56$, $p = .05$, $\eta^2_{partial} = .06$), location, $F(1.77, 154.13) = 4.06$, $MSE = 12{,}572.17$, $p < .05$, $\eta^2_{partial} = .04$, and eccentricity, $F(1.48, 128.85) = 20.61$, $MSE = 3{,}781.48$, $p < .001$, $\eta^2_{partial} = .19$, were significant. Pairwise comparisons showed that karate athletes performed better than nonathletes ($p = .05$), while the main effect of location showed significant differences between the horizontal west and the vertical north meridians ($p = .05$). The two-way group × eccentricity interaction was statistically significant, $F(2.96, 128.85) = 2.95$, $p < .05$, $\eta^2_{partial} = .063$. Pairwise comparisons showed that karate athletes were significantly faster than both judo athletes ($p < .05$) and nonathletes ($p < .001$) at 12° eccentricity. Collapsing the meridians into horizontal and vertical, the ANOVA showed the main effect of meridian, $F(1, 87) = 3.84$, $MSE = 1{,}507.34$, $p = .05$, $\eta^2_{partial} = .042$, with better performance in

Table 2 Mean reaction times and standard deviations (in parentheses) in milliseconds for each group and condition

	E3.250 Mean (*SD*)	E3.700 Mean (*SD*)	E3.1500 Mean (*SD*)	E6.250 Mean (*SD*)	E6.700 Mean (*SD*)	E6.1500 Mean (*SD*)	E12.250 Mean (*SD*)	E12.700 Mean (*SD*)	E12.1500 Mean (*SD*)
Judo athletes	239.7 (23.6)	242.9 (27.8)	244.1 (23.8)	237.7 (14.8)	230.2 (14.9)	243.8 (24.4)	252.5 (14.7)	241.5 (15.8)	248.1 (20.1)
Karate athletes	241.7 (28.8)	233.0 (25.8)	239.6 (25.0)	230.5 (14.8)	230.6 (15.7)	241.1 (20.5)	242.7 (13.3)	235.9 (16.9)	238.1 (12.8)
Nonathletes	250.07 (20.99)	236.6 (26.6)	245.8 (14.3)	240.9 (14.2)	230.8 (16.5)	249.3 (16.0)	259.9 (16.4)	2 248.6 (22.4)	258.8 (19.2)

Note. E3.250, eccentricity 3° with an ISI of 250 ms; E3.700, eccentricity 3° with an ISI of 700 ms; E3.1500, eccentricity 3° with an ISI of 1,500 ms; E6.250, eccentricity 6° with an ISI of 250 ms; E6.700, eccentricity 6° with an ISI of 700 ms; E6.1500, eccentricity 6° with an ISI of 1,500 ms; E12.250, eccentricity 12° with an ISI of 250 ms; E12.700, eccentricity 12° with an ISI of 700 ms; E12.1500, eccentricity 12° with an ISI of 1,500 ms

the horizontal than in the vertical meridian (p = .05). Within the vertical meridian, performance was better in the lower than in the upper region, $F(1, 87) = 4.02$, $MSE = 1{,}792.02$, $p < .05$, $\eta^2_{partial} = .044$. The interaction between group and location was not significant ($p > .05$), indicating that sport did not affect inequalities at isoeccentric locations of the visual field.

This experiment showed that participants performed better with stimuli presented at intermediate positions of the visual field (6° of eccentricity). The results are in agreement with previous findings (e.g., Ando, Kokubu, Kida, & Oda, 2002). As was suggested by Ando et al. (2002), our results could be explained by the orientation of attention toward intermediate positions of the visual field. The better performance observed in all groups at the intermediate ISI suggests that this interval might allow greater predictability, while short ISIs involve neural mechanisms such as the psychological refractory period, and the largest ISI could involve cognitive processes such as expectancies. More research is needed to clarify this issue.

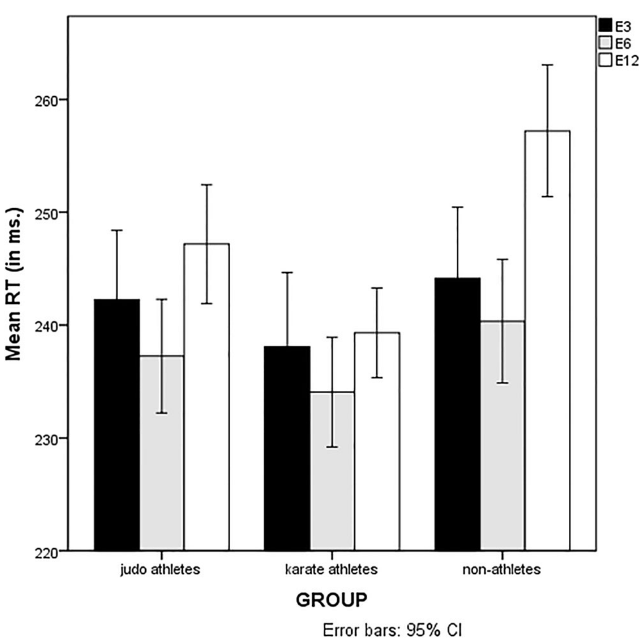

Fig. 1 Mean reaction times (in milliseconds) for all young groups in the three eccentricity conditions: E3, eccentricity 3°; E6, eccentricity 6°; E12, eccentricity 12°. The error bars refer to the *SEM*s

Athletes were faster than nonathletes when stimuli were presented at the periphery of the visual field. This result is consistent with previous findings (Ando et al., 2001; Kokubu et al., 2006; Mori, Ohtani, & Imanaka, 2002; Muiños & Ballesteros, 2013; Zwierko, 2007; Zwierko et al., 2010) that athletes were faster with peripheral stimuli. The karate athletes in particular were significantly faster than the nonathlete group. This result supports the view that the difference in performance between the two athlete groups could be due to the nature of the sport itself (Sánchez-López, Fernández, Silva-Pereyra, & Martinez, 2013).

Importantly, martial arts athletes showed the same inhomogeneities at isoeccentric locations as those found in nonathletes. Our results are consistent with that of Montaser-Kouhsari and Carrasco (2009) with university students. The three groups showed better performance on the horizontal than on the vertical meridian and at the lower than at the upper region of the vertical meridian. Since the interaction between group and stimulus location did not reach significance, we can conclude that regular sports activity does not influence visual performance, since the same perceptual asymmetries were found in athletes and nonathletes.

Experiment 2

Experiment 2 investigated whether PV and perceptual asymmetries were modulated by age and sport. A great deal of research supports the view that the superiority of athletes in some visual functions is due not to the visual function itself, but to the ability to process and interpret visual information more efficiently (Abernethy et al., 1994; Helsen & Pauwels, 1993; Williams et al., 1994; Wu et al., 2013; Zwierko, 2007; Zwierko et al., 2010). If this is the case, older athletes might have an advantage over sedentary older adults in PV tasks because successful performance may depend on the ability to process visual information efficiently, rather than on the physical condition of the visual system, which declines with age. We expected that older athletes would perform better than older nonathletes due to their extended practice and their active lifestyle.

Method

Participants, apparatus, stimulus, procedure, and experimental design

Forty-five older male volunteers participated in this experiment. Fifteen were judo athletes (mean age = 64.1 years, SD = 3.6 years, range = 56–67 years), 15 were karate athletes (mean age = 63.7 years, SD = 3.2 years, range = 55–65 years), and 15 were nonathletes (mean age = 64.7 years, SD = 4.3 years, range = 55–68 years). The two athlete groups were competitive sportsmen when they were young but did not currently participate in high-level competitions, although they still trained in their martial art schools or in the gym, but less intensively. All participants were right-handed and were matched for age and sociocultural level assessed with the Goldthorpe–Hope scale as in Experiment 1. All participants had normal or corrected-to-normal vision. None of them suffered from any general health problem, refractive eye disorders, or low visual acuity. Apparatus, stimulus procedure, and experimental design were the same as in Experiment 1.

Results and discussion

Each participant performed first the Rockport Test (Kline et al., 1987) to determine whether the former athletes had higher cardiovascular capacity than the nonathletes. Participants also performed a series of screening tests, including the Mini-Mental State Examination test (MMSE; Folstein, Folstein, & McHugh, 1975), the Yesavage Geriatric Depression Scale (Martínez et al., 2002), the Blessed Dementia Rating Scale (Lozano et al., 1999), and the Global Deterioration Scale (GDS; Reisberg, Ferris, DeLeón, & Crook, 1988). All the participants showed normal performance on the screening tests and questionnaires (see Table 3). Results on the Rockport Test showed that the two athlete groups had higher cardiovascular capacity than the nonathlete group. The ANOVA conducted on RTs showed that the main effect of group was significant, $F(2, 42) = 43.45$. $MSE = 211.32$, $p < .01$, $\eta^2_{\text{partial}} = .67$. Pairwise comparisons showed significant differences between the nonathlete group and both the judo ($p < .01$) and the karate ($p < .01$) groups (see Table 3).

Athletes and nonathletes did not differ on the screening tests [MMSE, $F(2, 42) = 1.000$, $MSE = 0.02$, $p > .05$, $\eta^2_{\text{partial}} = .04$; Yesavage, $F(2, 42) = 0.61$, $MSE = 0.48$, $p > .05$, $\eta^2_{\text{partial}} = .02$; Blessed, $F(2, 42) = 1.35$, $MSE = 0.05$, $p > .05$, $\eta^2_{\text{partial}} = .06$; GDS, $F(2, 42) = 0.001$, $MSE = 0.000$, $p = .001$, $\eta^2_{\text{partial}} = .001$], indicating that the three groups showed normal performance on the screening tests and questionnaires and did not differ in general cognition.

Table 4 displays the mean performance of the three groups in all the experimental conditions. The mean RTs and standard deviations (in parentheses) were 247.9 (21.1) for judo athletes, 248.5 (19.7) for karate athletes, and 281.3 (16.2) for the nonathlete group. As in Experiment 1, RT was the dependent variable in the analysis. Errors were also recorded, although the percentage did not exceed 1 %. Incorrect trials and outliers were not included in the data analysis.

A mixed factorial ANOVA with group (judo athletes, karate athletes, and nonathletes), eccentricity, and ISI showed that the main effects of group, $F(2, 42) = 39.61$, $MSE = 1{,}244.61$, $p < .01$, $\eta^2_{\text{partial}} = .65$, eccentricity, $F(1.86, 78.14) = 16.71$, $MSE = 317.56$, $p < .01$, $\eta^2_{\text{partial}} = .29$, and ISI, $F(1.83, 77.02) = 15.04$, $MSE = 268.10$, $p < .01$, $\eta^2_{\text{partial}} = .26$, were significant. Pairwise comparisons showed significant differences between nonathletes and the two athlete groups, judo ($p < .01$) and karate ($p < .01$) athletes. Both athlete groups, irrespective of their sport, were faster than the sedentary group. Eccentricity at12° differed from that at 3° ($p < .01$) and 6° ($p < .01$), suggesting that older participants were faster at the intermediate eccentricity (6°), followed by the more central eccentricity (3°), while the 12° eccentricity condition produced the slowest responses. ISI pairwise comparisons showed differences between the 700-ms condition and the other two ISI conditions: 250 ms ($p < .01$) and 1,500 ms ($p < .01$). Participants performed better when the stimuli were presented at an intermediate ISI. The group × eccentricity interaction, $F(3.7, 78.14) = 2.078$, $p = .09$, $\eta^2_{\text{partial}} = .09$, was only marginally significant. Figure 2 shows the performance of athletes and nonathletes under the three eccentricity conditions. While both athlete groups were faster than the nonathlete group under all eccentricity conditions ($p < .01$), the performance of the nonathletes was very slow at the most eccentric condition.

A factorial ANOVA conducted on group × location (horizontal right, horizontal left, vertical upper, vertical lower) × eccentricity showed that the main effects of group, $F(2, 42) = 4.9$, $MSE = 16{,}539.43$, $p < .01$, $\eta^2_{\text{partial}} = .189$, location, $F(1.84, 77.25) = 7.16$, $MSE = 12{,}239.65$, $p < .005$, $\eta^2_{\text{partial}} = .15$, and eccentricity, $F(1.58, 66.31) = 8.57$, $MSE = 5{,}006.90$, $p < .001$, $\eta^2_{\text{partial}} = .17$, were all statistically significant. Nonathletes were slower than both, judo ($p = .05$) and karate ($p = .02$) athlete groups. The ANOVA conducted on visual asymmetries showed that visual performance was better on the horizontal than on the vertical meridian ($p < .005$) and that horizontal right was better than left ($p < .05$). Further analysis with the meridians collapsed showed that performance was better in the horizontal than in the vertical meridian, $F(1, 42) = 7.15$, $MSE = 2{,}522.15$, $p < .05$, $\eta^2_{\text{partial}} = .15$, and in the lower than in the upper meridian, $F(1, 42) = 3.79$, $MSE = 2{,}152.21$, $p = .05$, $\eta^2_{\text{partial}} = .083$, but differences were not found between

Table 3 Mean age, VO_2 max, and test scores on the screening tests and questionnaires (standard deviations in parentheses)

Group	Age	VO_2 max	MMSE	Yesavage	Blessed	GDS
Ex-elite judo	64.1 (3.6)	37.55 (1.96)	30 (0)	0.47 (0.52)	0.07 (0.18)	0 (0)
Ex- elite karate	63.7 (3.2)	37.42 (1.83)	30 (0)	0.73 (0.70)	0.13 (0.23)	0 (0)
Nonathletes	64.7 (4.3)	30.99 (2.72)	29.9 (0.3)	0.67 (0.82)	0.20 (0.25)	0 (0)

Note. VO_2, maximal oxygen volume; MMSE, Mini-Mental State Examination Test; Yesavage, Yesavage Geriatric Depression Scale; Blessed, Blessed Dementia Rating Scale; GDS, Global Deterioration Scale.

groups ($F < 1$), suggesting that regular sport does not affect the performance at isoeccentric locations of older adults.

The results showed that older martial arts athletes performed better than nonathletes under all experimental conditions. Exercise in older age tends to attenuate declines in many cognitive functions (Chodzko-Zajko, 1991; Chodzko-Zajko & Moore, 1994; Chodzko-Zajko et al., 1992). Physically active older adults usually perform RT tasks faster than sedentary elderly participants (Ballesteros et al., 2013c). The literature shows that physical exercise improves cognition by enhancing neuroplasticity (for recent reviews, see Hötting & Röder, 2013; Voelcker-Rehage & Niemann, 2013). The results of this experiment showed that older judo and karate athletes performed faster than sedentary older adults at all eccentricities. Since the three groups were matched for age, general health, and socio-cultural level, differences cannot be attributed to these variables. It therefore seems that a physically active lifestyle tends to attenuate age-related declines in speed of processing. These older athletes may maintain their visuospatial perceptual skills due to regular physical exercise, while those of sedentary older adults decline. This result is consistent with that of Ando et al. (2004) and Ciuffreda (2011), who demonstrated gains and losses on their visual RT task depending on the number of weeks of training, with older athletes who trained at least four times per week performing better than sedentary older adults.

We expected differences between groups at peripheral locations, but we only found a trend (p = .09), suggesting that older athletes detected the more peripheral stimuli slightly faster, but in fact athletes were faster than nonathletes under all eccentricity conditions. The present results suggest that older athletes do not show a different PV pattern, as compared with sedentary older adults, but they maintain their visuospatial perceptual abilities at all eccentricities in general. ISI also yielded significant differences between groups. Older athletes were faster than older nonathletes under all ISI conditions. The older judo and karate athletes performed similarly. As with the young adults, visual performance was heterogeneous at isoeccentric locations of the visual field. It seems, therefore, that it is martial arts in general, rather than a specific martial art, that maintains speed of processing in old age.

Since the experimental design of Experiments 1 and 2 was the same, to compare the performance of older and young adults, we conducted an additional mixed-model ANOVA with age group as a between-subjects factor combining data from both experiments. This analysis revealed significant main effects of age group, $F(1, 129) = 58.71$, MSE = 1,366.7, $p < .01$, $\eta^2_{partial} = .313$, and sport, $F(2, 129) = 35.81$, MSE = 1,366,7, $p < .01$, $\eta^2_{partial} = .357$. The main effect of age group was statistically significant ($p < .01$). Young participants were significantly faster than older adults. Pairwise comparisons of sport showed that judo and karate athletes did not differ ($F < 1$), but both differed significantly from nonathletes (ps < .01), with athletes being faster than nonathletes. The main effects of eccentricity, $F(1.66, 213.96) = 52.08$, MSE = 348.05, $p < .01$, $\eta^2_{partial} = .29$, and ISI, $F(1.80, 232.09) = 31.76$, MSE = 303.39, $p < .01$, $\eta^2_{partial} = .19$, were significant. The results did not yield significant age × eccentricity or sport × eccentricity interactions, but the age × sport interaction was significant, $F(2, 129) = 15.35$, MSE = 1,377.55, $p < .01$, $\eta^2_{partial} = .19$ (see Fig. 3), showing that the effect of sport differs between young and older adults. In young adults, the differences between athletes and nonathletes were smaller, and the type of sport was determinant. Karate

Table 4 Means of reaction times in milliseconds and standard deviations (in parentheses) for each group and condition

Groups	E3.250 Mean (*SD*)	E3.700 Mean (*SD*)	E3.1500 Mean (*SD*)	E6.250 Mean (*SD*)	E6.700 Mean (*SD*)	E6.1500 Mean (*SD*)	E12.250 Mean (*SD*)	E12.700 Mean (*SD*)	E12.1500 Mean (*SD*)
Ex-elite judo	243.8 (24.5)	247.0 (26.7)	252.6 (20.9)	241.4 (16.7)	236.9 (17.1)	251.5 (31.0)	255.6 (15.9)	249.0 (18.9)	253.3 (18.4)
Ex-elite karate	247.1 (24.5)	251.1 (29.2)	247.9 (23.4)	249.3 (17.3)	235.9 (14.1)	248.1 (21.2)	257.3 (14.9)	245.3 (15.6)	254.9 (17.0)
Nonathletes	282.5 (12.5)	264.9 (24.4)	281.1 (13.9)	275.5 (14.8)	264.0 (17.9)	285.5 (10.9)	287.4 (13.8)	289.1 (22.1)	301.8 (15.6)

Note. E3.250, eccentricity 3° with an ISI of 250 ms; E3.700, eccentricity 3° with an ISI of 700 ms; E3.1,500, eccentricity 3° with an ISI of 1,500 ms; E6.250, eccentricity 6° with an ISI of 250 ms; E6.700, eccentricity 6° with an ISI of 700 ms; E6.1500, eccentricity 6° with an ISI of 1,500 ms; E12.250, eccentricity 12° with an ISI of 250 ms; E12.700, eccentricity 12° with an ISI of 700 ms; E12.1500, eccentricity 12° with an ISI of 1,500 ms

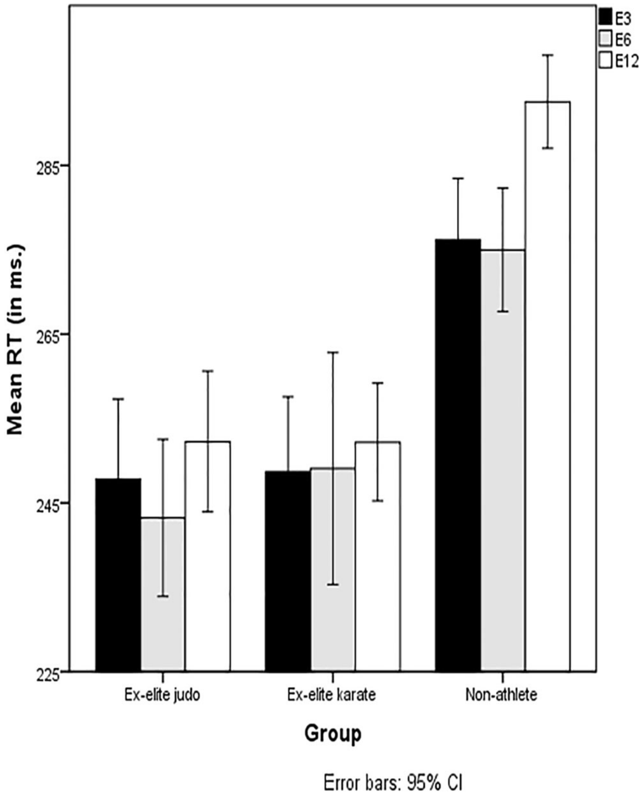

Fig. 2 Mean reaction times (in milliseconds) corresponding to the three groups in the three eccentricity conditions: E3, eccentricity 3°; E6, eccentricity 6°; E12, eccentricity 12°. The error bars refer to the *SEM*s

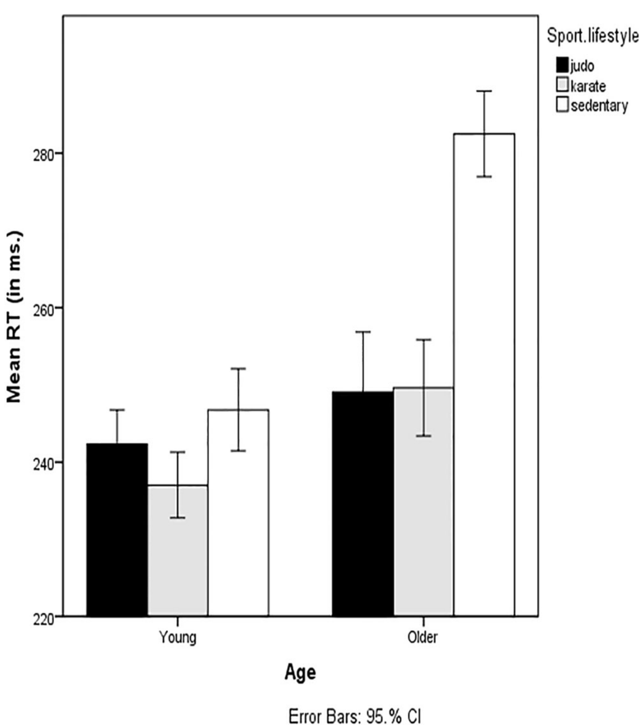

Fig. 3 Mean reaction times (in milliseconds) for young and older athletes and nonathletes. The error bars refer to the *SEM*s

athletes were faster than nonathletes, especially at the most eccentric locations. In older adults, however, differences between athletes and nonathletes were large with no difference between type of sport, since both karate and judo athletes were significantly faster than nonathletes.

The analysis of inhomogeneities at isoeccentric locations of the visual field revealed that age, $F(1, 129) = 7.63$, $MSE = 15{,}826.26$, $p < .05$, $\eta^2_{partial} = .056$), sport, $F(2, 129) = 7.23$, $MSE = 15{,}826.26$, $p < .01$, $\eta^2_{partial} = .1$, eccentricity, $F(1.52, 196.54) = 24.30$, $MSE = 4{,}163.84$, $p < .001$, $\eta^2_{partial} = .16$, and location, $F(1.8, 232.67) = 12.17$, $MSE = 12{,}391.42$, $p < .001$, $\eta^2_{partial} = .09$, were all significant. The young groups ($p < .005$) and the athlete groups ($p < .005$) were fastest. Pairwise comparisons showed that the horizontal west location was better than the vertical upper ($p < .001$) and lower ($p < .05$) locations. Participants performed better at the horizontal east location than at vertical upper ($p < .01$) and lower ($p < .05$) locations. Collapsing vertical and horizontal locations, the ANOVA showed the main effect of meridian, $F(1, 129) = 19.7$, $MSE = 2{,}043.77$, $p < .001$, $\eta^2_{partial} = .13$, the horizontal being better than the vertical locations ($p < .001$). Further analysis revealed that, within the vertical meridian, participants performed better in the lower than in the upper region, $F(1, 129) = 3.6$, $MSE = 1{,}885.77$, $p = .059$, $\eta^2_{partial} = .03$. The three-way age group × sport × location interaction was not statistically significant ($p > .5$), suggesting that the age of the participants and sports activity did not affect performance at isoeccentric locations.

The analysis yielded four main results: (1) The older adults were slower than the younger adults; (2) both athlete groups (judo and karate) were faster than the nonathlete groups at all eccentricities, this effect being slightly more pronounced, although not significant, at the most peripheral locations; (3) athletes performed the task significantly better than nonathletes under all ISI presentation conditions; and (4) both young and older adults performed the task better at the horizontal than at the vertical meridian and, within the vertical, at the lower than at the upper region.

General discussion

The present study examined visuospatial attention and processing speed for dots presented at three different PV eccentricities (3°, 6°, and 12°) and with three interstimulus intervals (250, 700, and 1,500 ms), comparing young and older karate, judo, and nonathlete groups. The results showed that age and sport affected speed of processing in the visual detection task. The study yielded three key findings. First, young karate athletes were faster than both judo athletes and nonathletes when the stimuli appeared at the periphery of the visual field (Experiment 1). Second, older judo and karate athletes performed better than nonathletes of the same age under all the experimental conditions, suggesting that an important factor preventing the slowing of perceptual processing is to be engaged in judo or karate training and to have participated intensively in a sport when young (Experiment 2). Third, neither the practice of a martial art nor the participant's age influenced perceptual asymmetries. Visual performance of younger and older individuals varied across the visual field, even at isoeccentric locations. In all groups, we observed horizontal–vertical anisotropy and vertical meridian asymmetry. Performance was better when stimuli were presented on the horizontal than when presented on the vertical meridian and in the lower than in the upper region of the vertical meridian. These performance inhomogeneities were observed in both younger and older participants, whether they had had an active physical lifestyle or a sedentary one. We focus the discussion below on these three findings.

Effects of the type of martial art on the peripheral vision of young adults

Young karate athletes performed faster than nonathletes when stimuli appeared at the periphery of the visual field (Experiment 1). Our results are consistent with those of previous studies that reported that athletes performed RT tasks better than nonathletes (e.g., Ando et al., 2001; Kokubu et al., 2006; Muiños & Ballesteros, 2013; Mori et al., 2002) but do not agree with those of a previous study that failed to find differences between athletes and nonathletes in the PV (Memmert, Simons, & Grimme, 2009). The results of Experiment 1 replicated the findings of a previous study conducted with kung fu athletes (Muiños & Ballesteros, 2013). In that study, we found that kung fu athletes were faster than nonathletes when the stimuli were presented at peripheral locations at high speed, whereas there were no differences at longer ISIs. We interpreted the result in relation to the nature of the sport. After years of intense practice, kung fu athletes develop the automatic maneuvers required to repel attacks coming from the periphery at high speed. In the present study, the performance of athletes in two different combat sports, judo and karate, was compared with that of a nonathlete group of the same age. The present results are in accord with our previous findings, with martial arts practitioners detecting stimuli presented at the periphery of the visual field faster than nonathletes, especially with short ISIs. To determine whether the nature of the particular martial art and the specific skills developed by the athletes while practicing their sport could affect performance, the present study included a group of karate athletes, due to the similarities with kung fu. The results showed that only the karate practitioners replicated the kung fu results, performing better than the nonathlete group when stimuli appeared peripherally. This specificity of the type of sport is in agreement with the results of a recent study (Sánchez-López et al., 2013) showing that the practice of kung fu improved attention more than did the practice of judo and taekwondo. These findings support the idea of the specificity of sports and the importance of the type of motor learning (Kibele, 2006). Two main possible mechanisms might underlie better central and peripheral performance of athletes: (1) the faster signal transmission in the visual pathways, due to the sport demands, and (2) the higher activity of the visual cortex in athletes, as compared with nonathletes (Zwierko et al., 2010).

Visuospatial processing advantage of older martial art athletes, as compared with nonathletes

The present study showed that the two older judo and karate athlete groups were faster than nonathletes under all experimental conditions (Experiment 2). This finding supports the view of a lack of specificity in old age and stresses the importance of physical activity to avoid the slowing of visuospatial processing. In concrete terms, the intensive practice of a martial art (or perhaps any type of sport) is more important than which particular sport. Although we expected older athletes to perform better than nonathletes of the same age with stimuli at peripheral locations, the results of Experiment 2 did not confirm this hypothesis. It seems that older athletes lose the visuospatial advantage shown by young athletes, presumably due to the slowing that takes place in aging. The relations between age and processing speed are not always completely clear. Salthouse (1996) proposed two main mechanisms involved in age-related decline: processing speed and simultaneity. The first refers to the difficulty older adults have in completing a task because of the time needed to execute early operations. In this case, there is an external time limit for processing concurrent demands. The simultaneity mechanism refers to the difficulty older adults have in carrying out some tasks due to disruptions in synchronization. Since processing is too slow, some relevant information is not available when needed. However, when the speed variable is controlled, there is an attenuation of the age-related differences, so the processing speed theory seems more suitable to account for the age-related decline. In many studies of aging, participants have to perform complex tasks to determine their fluid cognition (e.g., memory, reasoning, spatial skills, etc.), and even in that case, processing speed can account for a large part of the variance. By contrast, the task used in the present study was simple and only involved perceptual speed, with no other cognitive mechanism brought into play. The most likely mechanism underlying older athletes' loss of the PV advantage is the limited time mechanism referred to by Salthouse (1996).

An important conclusion of Experiment 2 is that continued physical exercise is crucial, since older athletes responded much faster than older nonathletes to stimuli at all locations, while differences in speed of processing were smaller between younger athletes and nonathletes. The results suggest that competitive-level sports activity could significantly slow down the decline in processing speed. The differences among young participants were most marked under the peripheral condition, while the differences between older participants were larger and occurred under all the experimental conditions.

By collapsing and comparing the results of Experiments 1 and 2, we found that young adults were faster than older adults and that both athlete groups, judo and karate, performed better than the nonathlete groups. The interaction between age group and sport is consistent with the differences observed between Experiment 1 (specificity of the type of sport and skills developed) and Experiment 2 (larger differences between young and older groups and lack of specificity of the type of sport). In Experiment 1, the young karate athletes had a PV advantage, as compared with nonathletes. In contrast, in Experiment 2, the interaction between eccentricity and group was not significant, indicating a loss of advantage in PV. Age affects the PV of older athletes up to a point.

Perceptual asymmetries are preserved irrespective of sport and age

Finally, the present study revealed no interaction between inequalities of performance in isoeccentric locations and either age or sport. The results were similar for young and older perceivers irrespective of their sport. Performance was better at the horizontal than at the vertical meridian, producing a horizontal–vertical anisotropy and a vertical meridian asymmetry resulting in better results at the lower than at the upper region of the vertical meridian. The results suggest that the inequalities of performance at isoeccentric locations of the visual field—that is, horizontal–vertical anisotropy and vertical meridian asymmetry—are something fixed that occur at all ages and that are not influenced by intensive physical exercise. These results show that stimulus location affects processing speed in a simple detection task. Task performance varies as a function of location. The results are in accordance with previous findings in the field obtained with young adults without specific sports training, using different experimental tasks and different types of stimuli (Carrasco et al., 2001; Montaser-Kouhsari & Carrasco, 2009; Rovamo & Virsu, 1979). The present results could be explained by physiological factors such as the lower density of cones and ganglion cells in the peripheral retina than in the fovea (Perry & Cowey, 1985) and the fact that the density of the cones decreases with distance from the fovea along the vertical meridian more than along the horizontal meridian (Curcio, Sloan, Kalina, & Hendrickson, 1990). There is also a possible ventral versus dorsal visual processing asymmetry, particularly in relation to guiding actions. Recent findings suggest that the premotor cortex ventral areas play a key role in visuomotor transformations required to generate grasping movements (hand posture configuration) and premotor dorsal areas in the hand movement sequencing (Davare, Andres, Cosnard, Thonnard, & Olivier, 2006). These perceptual asymmetries thus depend on the "hardware" and are not changed by factors such as physical activity and age.

Limitations of the present study

The present study has some limitations highlighted below. Although in the present study stimuli were presented only for 150 ms, a limitation was that we did not use a system to keep the head of the participants in a fixed position. Fixating the head would have maintained a constant viewing distance, but this was monitored closely by the experimenter (M.M.), so it unlikely to have affected results. A possible second limitation was that we did not use an eye-tracking system to monitor fixation accuracy. It would be interesting in future studies to maintain the head of the participants in a fixed position, as well as to use an eye-tracking system, to overcome these limitations.

Conclusion

We investigated (1) whether better visuospatial performance emerges in competitive young karate and judo athletes, as compared with nonathletes; (2) whether the pattern of performance observed in younger adults is preserved in older adults; and (3) whether the performance inhomogeneities observed in young university students emerge in younger and old martial arts athletes. The present study revealed that both engaging in sport and the type of sport are important in young adults. Karate athletes performed better than nonathletes at eccentric locations. Judo athletes only showed a trend in this direction. Importantly, this sport specificity and PV enhancement were lost in older karate and judo athletes, since both types of sport produced better performance under all experimental conditions. Finally, performance inhomogeneities emerged at isoeccentric locations irrespective of the participant's sport and age, suggesting that these perceptual asymmetries are fixed in all visual perceivers. These results indicate that a physically active lifestyle is an effective way of counteracting the processing speed decline of visual stimuli appearing at any visual location and speed.

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