Atten Percept Psychophys (2015) 77:2061–2073
DOI 10.3758/s13414-015-0901-x

Sports can protect dynamic visual acuity from aging: A study with young and older judo and karate martial arts athletes

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Published online: 18 April 2015

Abstract A major topic of current research in aging has been to investigate ways to promote healthy aging and neuroplasticity in order to counteract perceptual and cognitive declines. The aim of the present study was to investigate the benefits of intensive, sustained judo and karate martial arts training in young and older athletes and nonathletes of the same age for attenuating age-related dynamic visual acuity (DVA) decline. As a target, we used a moving stimulus similar to a Landolt ring that moved horizontally, vertically, or obliquely across the screen at three possible contrasts and three different speeds. The results indicated that (1) athletes had better DVA than nonathletes; (2) the older adult groups showed a larger oblique effect than the younger groups, regardless of whether or not they practiced a martial art; and (3) age modulated the results of sport under the high-speed condition: The DVA of young karate athletes was superior to that of nonathletes, while both judo and karate older athletes showed better DVA than did sedentary older adults. These findings suggest that in older adults, the practice of a martial art in general, rather than the practice of a particular type of martial art, is the crucial thing. We concluded that the sustained practice of a martial art such as judo or karate attenuates the decline of DVA, suggesting neuroplasticity in the aging human brain.

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Keywords Aging · Karate athletes · Judo athletes · Martial arts · Dynamic visual acuity · DVA

Dynamic visual acuity (DVA) is a measure of the ability to discriminate critical details of an object when there is relative motion between the observer and the object (Miller & Ludvigh, 1962). DVA is a complex perceptual ability with important implications in daily-life activities and in most sports, especially those in which athletes have to detect fast-moving stimuli and respond as quickly as possible. Martial arts are fast-moving sports that require the rapid detection and discrimination of the opponent's attacks. In these sports, an appropriate motor response to moving stimuli is critical in order to avoid injuries (Schneiders et al., 2010). Although older martial arts athletes do not practice their sport with the same intensity or at the same competitive level as young athletes, they are still physically active. This makes them excellent candidates to investigate possible changes occurring in DVA after years of not competing at a professional level.

Cognitive decline and stability with age

Identifying ways that protect older adults from perceptual and cognitive decline is of current concern, due to the aging of the population and the increase in life expectancy. Although several cognitive processes, including verbal abilities, world knowledge (e.g., Park et al., 2002; for reviews, see Hedden & Gabrieli, 2004; Park & Reuter-Lorenz, 2009), and implicit memory (e.g., Ballesteros & Reales, 2004; Ballesteros, Reales, Mayas, & Heller, 2008; H. P. Davis, Trussell, & Klebe, 2001), are preserved in older adults, aging is associated with declines in cognitive functions such as attention, episodic

memory, executive functions, and processing speed (Baltes & Lindenberger, 1997; Nilsson, 2003; Park, Polk, Mikels, Taylor, & Marshuetz, 2001; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005; Salthouse, 1996). It is interesting that despite older adults retaining normal behavioral implicit memory—understood as a type of memory that does not require intentional retrieval of previously encoded stimuli, assessed by indirect tests with no reference to previous experience—electrophysiological (Osorio, Fay, Pouthas, & Ballesteros, 2010; Sebastián & Ballesteros, 2012) and brain-imaging (Ballesteros, Bischof, Goh, & Park, 2013) studies have reported altered neural priming in this age range, perhaps as a form of compensatory neural activity. Neural priming is shown by reduced activity in several brain regions when processing repeated stimuli. An electrophysiological study revealed that both young and older participants exhibited event-related potential (ERP) repetition effects at posterior sites, but only the older adults showed additional frontal activity (Osorio et al., 2010). ERPs to repeated items are characterized by greater positive amplitudes, relative to nonrepeated items. A more recent event-related functional magnetic resonance imaging (fMRI) study showed that both young and older adults exhibited repetition-related activation reductions in fusiform gyrus, superior occipital cortex, middle and inferior temporal cortex, and inferior frontal gyrus and the insula. However, whereas the neural priming effect in young adults was extensive, the neural priming in older adults was markedly reduced (Ballesteros et al., 2013a). These findings indicate altered neural priming in older adults despite preserved implicit memory, and suggest that age-invariant behavioral priming is the result of more sustained neural processing of stimuli in older brains (fMRI results) and of recruiting frontal sites (ERP findings) as a mode of compensation.

Physical activity may attenuate the slowing down of processing speed and DVA in older adults

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). Aging is associated with the slowing down of processing speed in visual perceptual tasks (e.g., Owsley, McGwin, & Searcey, 2013); the decline of visual tracking abilities, with lower accuracy in performing saccade movements in the correct direction (Butler, Zacks, & Henderson, 1999), as well as in pursuing targets (Paquette & Fung, 2011); and importantly, the deterioration of DVA (Long & Crambert, 1990). This is relevant because of the link between car accidents and lower DVA scores (e.g., Long & Rourke, 1989).

Many studies have shown that a physically active lifestyle tends to attenuate the decline of many perceptual and cognitive abilities. Physically active older adults perform better than sedentary older adults in executive control, as well as in both simple and choice reaction time (RT) tasks (Ballesteros, Mayas, & Reales, 2013) and cognitive tasks that require controlled processing, such as free recall (Chodzko-Zajko, 1991; Chodzko-Zajko & Moore, 1994; Chodzko-Zajko, Schuler, Solomon, Heini, & Ellis, 1992). In addition, individuals who engage actively in sports and physical exercise show increased brain plasticity, which allows them to perform certain tasks more efficiently (e.g., Colcombe et al., 2006; Erickson & Kramer, 2009; Kramer, Bherer, Colcombe, Dong, & Greenough, 2004). Physical activity seems to act as a protective factor that slows down age-related perceptual decline, and even delays the onset of some neurodegenerative diseases (Hötting & Röder, 2013), producing structural and functional brain changes that attenuate brain dysfunction (Voelcker-Rehage & Niemann, 2013).

DVA decreases rapidly with age (Long & Crambert, 1990)—even faster than the decline of static visual acuity (SVA; Burg, 1966; Ishigaki & Miyao, 1992). Surprisingly, to our knowledge, no study has explored the changes that occur in the DVA of judo and karate practitioners when they age. Visual functioning is traditionally assessed by evaluating SVA, calculated from the smallest item size in a stationary optotype that an individual is able to perceive from a standard distance. Spatial vision, however, depends on multiples processes; the stimuli in our world are usually not static but moving in relation to the observer. That makes SVA a nonecological measure to assess visual functioning (Committee on Vision of the National Research Council, 1985). Although there are few standardized instruments, the most widely used stimuli to assess DVA are the Landolt-C, Snellen E, or Gabor waves. To assess DVA, a stimulus usually moves from one area to another of the visual field at a given speed, and the observer has to identify a feature of the target. For example, the participant has to identify which way an "E" is facing, or the location of the gap in a "C" (right, left, top, bottom, or at a 45° position in between). DVA measuring methods often include only targets with high contrast. However, it might be more appropriate to include targets with different levels in this variable, to have a more complete and powerful measure of this visual function (Committee on Vision of the National Research Council, 1985).

DVA improves with increasing stimulus contrast (Aznar-Casanova, Quevedo, & Sinnett, 2005; Long & Zavod, 2002) and deteriorates with increasing target speed (e.g., Brown, 1972a, 1972b; Demer & Amjadi, 1993; Miller, 1958). Moreover, performance is better in horizontal than in diagonal trajectories (the so-called *oblique effect*; Appelle, 1972; Gros, Blake, & Hiris, 1998; Loffler & Orbach, 2001; Meng & Qian, 2005). This effect might be due to the larger cardinal (north–south/east–west) versus oblique representation in the primary visual cortex, with the horizontal and vertical orientations

producing greater neuronal responses (Li, Peterson, & Freeman, 2003; Xu, Collins, Khaytin, Kaas, & Casagrande, 2006).

The difficulty of determining fine details of a moving object is largely due to the performance of inappropriate eye movements (Brown, 1972a). Some of the studies that have reported higher DVA in athletes have attributed these differences to the ability to track moving targets (Jacob, Lillakas, & Irving, 2005; Land & McLeod, 2000; Uchida et al., 2013) or to perform visual searches more effectively (e.g., Helsen & Starkes, 1999; Williams & Davids, 1998). Athletes tend to anticipate saccades to localize the gaze on the stimulus, allowing the target to move across the retina (Haywood, 1984). Studies assessing DVA in the general population (Haarmeier & Thier, 1999) and in athletes (Singer, Williams, Frehlich, & Janelle, 1998) have suggested the importance of smoother tracking and pursuit movements to perform the task more efficiently.

DVA is especially relevant in sports involving movements at high speed. Previous studies with young athletes have shown superior DVA in young practitioners of baseball (Uchida et al., 2012, 2013), tennis and badminton (Ishigaki & Miyao, 1993; Rouse, DeLand, Christian, & Hawley, 1988), motorsports (Schneiders et al., 2010), water polo (Quevedo, Aznar-Casanova, Merindano-Encina, Cardona, & Solé-Fortó, 2011), softball (Millslagle, 2000), cycling (Millslagle, Delarosby, & Vonbank, 2005), and cricket (Land & McLeod, 2000), whereas just a few studies have not found any difference between athletes and nonathletes (e.g., Schneiders et al., 2010; Ward & Williams, 2003). As far as we know, no study has investigated DVA in competitive judo and karate martial arts athletes, as compared to sedentary young adults. Most importantly, it is unknown whether DVA declines in older martial artists at the same rate as in sedentary older adults.

Martial arts impose extreme velocity requirements and often require practitioners to develop certain skills to avoid attacks coming from various points of the peripheral space. In a previous study, we (Muiños & Ballesteros, 2013) found that kung fu athletes outperformed sedentary participants in speeded visuospatial and motor tasks, especially when brief stimuli were presented at the periphery of the visual field. We also found (Muiños & Ballesteros, 2014) that young and older karate and judo athletes outperformed nonathletes, but only the young karate practitioners performed better than the other groups when stimuli were presented at the periphery. Among the older groups, the specific sport (judo or karate) did not affect performance, suggesting that the crucial factor for slowing down age-related visuospatial decline is the sustained practice of a martial art, irrespective of which one. The results also showed that differences between the two types of sports were determinant in the young groups but faded in older adults. Similarly, older individuals engaging in intensive martial arts and recreational sports had advantages in postural control, relative to nonathletes (Krampe, Smolders, & Doumas, 2014).

Aims and hypotheses

The aim of the present study was to examine the effect on DVA of the regular practice of two types of martial arts, karate and judo, by measuring the performance of young and older martial arts athletes and comparing their performance with that of young and older nonathlete controls (who did not participate in any sport or practice regular physical exercise). We were interested to find out whether DVA is modulated by the regular practice of these two martial arts, and more importantly, by the practitioner's age. We hypothesized that depending on the speed of the motor maneuvers performed by the athletes in their daily practice, which differs between karate and judo, distinct patterns of visual skills would develop to enable rapid responses to moving stimuli. We expected to find differences between the two martial arts because karate and judo use very different techniques. Karate 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 practitioners of both martial arts would not develop the same visual abilities. The main question addressed in the present study was whether the DVA of older martial arts athletes after years of not competing at a professional level (16 to 37 years, with a mean of 28 years) would be protected, relative to that of nonathlete controls of the same age. Finally, a further goal of the present study was to investigate the validity of the computer software used to assess DVA.

In sum, we were interested (1) to find out whether the DVA of young karate and judo athletes is better than that of nonathletes of the same age, and also whether the type of martial art is relevant; and (2) to examine whether the possible advantages encountered in the DVA of young, highly competitive martial arts athletes would also emerge in older former martial arts athletes, and to compare their performance with that of a group of nonathletes of the same age. If the continuing practice of these martial arts improves the DVA of young martial arts athletes, then older adults who have been experts in these sports and are still active practitioners should exhibit better performance with moving stimuli than would older nonathletes. The correlation between the years without competing at a professional level and the performance in the DVA task would be informative.

Method

Participants

A total of 135 male observers with normal or corrected-to-normal vision participated voluntarily in the experiment. Of these, 45 were judo athletes, 30 of them young (mean age=

27.6 years, *SD*=3.8, range=21–32 years) and 15 older adults (mean age=64.1 years, *SD*=3.6, range=56–67 years). An additional 45 were karate athletes, 30 of them young (mean age=25.3 years, *SD*=4.8, range=19–34 years) and 15 older participants (mean age=63.7 years, *SD*=3.2, range=55–67 years). Finally, 45 of the participants were nonathletes, 30 young (mean age=23.5 years, *SD*=3.2, range=19–28 years) and 15 older adults (mean age=64.7 years, *SD*=4.3, range=55–68 years). The participants in the present study had taken part in a previous investigation conducted to study peripheral vision in young and older martial art athletes and nonathletes (Muiños & Ballesteros, 2014).

The participants in the athlete groups were recruited from martial arts schools in Castellon (Spain). The young athletes were internationally competitive, high-level professional practitioners with a mean experience of at least 10 years. The older martial arts athletes did not practice the martial art with the same intensity or at the same competitive level, although they still practiced their sport (judo or karate) in a martial art school or at the gym. The nonathletes did not carry out any regular physical exercise and had not played any sport for at least the last 5–7 years. All participants were right-handed, and none of them had any general health or mental problem, refractive eye disorder, or low visual acuity. The groups were matched in age and socio-cultural level, as assessed by the Goldthorpe–Hope scale (Goldthorpe & Hope, 1974). See Table 1. As a control measure, all participants performed the Rockport Test (Kline et al., 1987), consisting of walking a mile as quickly as possible in order to obtain their maximal oxygen uptake (VO_2 max). All participants signed an informed consent form for participation in the study, which was approved by the Ethics Review Board of the Universidad Nacional de Educación a Distancia. The experiment was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki, as revised in October 2008.

Apparatus and stimuli

To measure DVA, we used a software program specifically designed to assess this perceptual ability (DinVA 3.0 software; Quevedo, Aznar-Casanova, Merindano, & Solé, 2010) by presenting stimuli moving in straight trajectories in horizontal, vertical, or two diagonal directions. This software has good temporal reliability and adequate construct validity (r_{xy}=.72–.92; see Quevedo et al., 2010). DVA, expressed in decimal units, is defined as the smallest size of a moving stimulus for which an observer can discriminate the gap location, measured according to the velocity of the stimulus on the screen and the distance from the observer (always 2 m). DVA is measured by combining velocity and SVA, a measure of the smallest detail of a stationary target that the visual system can resolve, whereas DVA is the ability to discriminate the smallest detail of a moving stimulus. Target speed is inversely related to DVA; that is, the faster the displacement speed, the lower is DVA. The correlation between SVA and DVA is high when the stimulus speed is low. However, as the displacement speed increases, the correlation between SVA and DVA decreases (Miller & Ludvigh, 1962).

The stimuli were displayed on a 19-in. Sony Multiscan G420 CRT monitor with a refresh rate of 120 Hz, connected to a Pentium 4 CPU of 2.40 GHz and a keyboard that participants used to enter their responses. The moving target in the present study was a ring similar to the Landolt-C, with eight gap directions (up, down, left, right, and the 45° positions in between). The rings were presented at three different contrasts (high contrast, 0.1 cd/m^2; intermediate contrast, 23 cd/m^2; low contrast, 60 cd/m^2) on the white background of the computer screen with a luminance of 75 cd/m^2 (see Fig. 1). To ensure correct contrast between the target and the screen, participants performed the task in a dimly lit room. The three velocity conditions of the target were high speed (0.536 m/s or 15°/s), intermediate speed (0.322 m/s or 9.15°/s), and low speed (0.107 m/s or 3.06°/s). The target trajectories were horizontal (moving from the left to the right of the screen), vertical (moving from the bottom to the top), and oblique (moving from the lower left corner to the upper right corner), with a swinging movement from one part to the other of the screen.

Table 1 Demographic data, VO_2 max, and mean test scores (standard deviations in parentheses)

Group	Age	VO_2 max	Goldthorpe–Hope Scale	MMSE	Yesavage	Blessed	GDS
Young judo	27.6 (3.8)	51.14 (3.25)	4.10 (0.96)	–	–	–	–
Young karate	25.3 (4.8)	49.92 (3.97)	4.13 (1.01)	–	–	–	–
Young nonathletes	23.5 (3.2)	38.29 (2.88)	4.07 (0.87)	–	–	–	–
Older judo	64.1(3.6)	37.55 (1.96)	5.33 (0.9)	30 (0)	0.47 (0.52)	0.07 (0.18)	0 (0)
Older karate	63.7(3.2)	37.42 (1.83)	5.27 (0.96)	30 (0)	0.73 (0.70)	0.13 (0.23)	0 (0)
Older nonathletes	64.7(4.3)	30.99 (2.72)	5.73 (0.96)	29.9 (0.3)	0.67 (0.82)	0.20 (0.25)	0 (0)

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

Fig. 1 Examples of stimuli used in this study, with three different contrasts

Procedure

Participants were tested in a dimly lit room with a temperature of 22 °C and a noise level maintained between 5 and 13 decibels. They were seated 2 m from the monitor. This constant viewing distance was monitored closely throughout the experiment. The participant pressed the appropriate directional key as soon as possible after identifying the direction of the ring gap (right, left, up, down, and the 45° in between). Before the experiment started, participants performed 25 practice trials to familiarize themselves with the various conditions of the experiment and the keyboard directional keys. DVA was expressed in visual acuity decimal units. In the experiment, the target was presented randomly at three different contrasts, trajectories, and speeds. The gap location was also random. On each trial, the speed of the stimulus was kept constant—15°/s for the high-speed condition, 9.15°/s for the intermediate-speed condition, and 3.06°/s for the low-speed condition—but its size varied, starting with the smallest and increasing until the observer was able to discriminate the direction of the ring gap. In the monitor, each pixel measured 0.3016 mm. The initial stimulus had a gap size of 2 pixels with a total target diameter of 10 pixels (equivalent to a visual acuity of 0.964), increasing in size by 1 pixel each 2.3 s. The maximum gap size that a stimulus could reach was 11 pixels. When the moving stimulus reached the edge of the computer screen, it reversed its trajectory (with a swinging movement from one part to the other of the screen).

To compute DVA, the software first calculated the velocity of the stimulus on the screen according to the following formula:

$$\mathrm{Velocity(m/s)} = \mathrm{Frame\,rate\ (Hz;\ frames/s)} \\ {}^{*}\mathrm{Dot{-}pixel(m)}{}^{*}\mathrm{Step(pixels)}.$$

To calculate at what speed the stimulus moved across the retina (to obtain the speed in terms of visual angle), two factors were taken into account—the speed of the target on the screen, in meters per second, and the viewing distance (2 m):

$$\mathrm{Velocity\ on\ the\ retina} = \arctan(\mathrm{Screen\ velocity/Viewing\ distance}).$$

For example, given a target velocity on the screen of 0.420 m/s and a viewing distance of 2 m, the velocity would be 11.86°/s of visual angle. The DVA is then expressed as the smallest detail that the observer is able to perceive at that speed.

Ten trials were presented for each of the 27 experimental conditions, obtained by the combination of the three trajectories, three contrasts, and three speeds. The experiment lasted approximately 30 min.

Experimental design

The experimental had a 2 Age (young and older)×3 Sport (karate athletes, judo athletes, nonathletes)×3 Trajectory (horizontal, vertical, oblique)×3 Contrast (high, intermediate, low)×3 Speed (high, medium, low) mixed factorial design, with Age and Sport as the between-subjects factors and repeated measures in the last three factors.

Results

The DVA score was the dependent variable in the analyses, which were analyzed with SPSS, version 2.0. The results of the Rockport test showed that both the athlete groups had higher cardiovascular capacity than did the nonathlete group. The analysis of variance (ANOVA) conducted on the young adult groups showed that the main effect of group was statistically significant [$F(2, 87)=130.75$, $MSE=1509.44$, $p<.01$, $\eta_p^2=.75$]. Pairwise comparisons showed that the judo ($p<.01$) and karate ($p<.01$) athletes had significantly higher cardiovascular capacity than did the nonathletes. The ANOVA conducted on the Rockport test results of the older groups showed that the main effect of group was statistically significant [$F(2, 42)=43.45$, $MSE=211.32$, $p<.01$, $\eta_p^2=.67$]; the two ex-athlete older groups had higher cardiovascular capacity than the older nonathlete group. Pairwise comparisons showed significant differences between the nonathlete group and both the judo ($p<.01$) and the karate ($p<.01$) groups. Older participants 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, de Leon, & Crook, 1988). All groups showed normal performance on the screening tests and questionnaires (see Table 1). Older athletes and nonathletes did not differ in terms of their MMSE [$F(2, 42)=1.000$, $MSE=0.02$, $p>.05$, $\eta_p^2=.04$], Yesavage [$F(2, 42)=0.61$, $MSE=0.48$, $p>.05$, $\eta_p^2=.02$], Blessed [$F(2, 42)=1.35$, $MSE=0.05$, $p>.05$, $\eta_p^2=.06$], or GDS [$F(2, 42)=0.001$, $MSE=0.000$, $p=.000$, $\eta_p^2=.001$] scores, indicating that the three older groups showed normal performance on the screening tests and questionnaires and did not differ in general cognition. Table 1 shows the age, vascular capacity, and demographic characteristics of the six groups and the results of the screening tests and questionnaires performed by the older adults.

Because the groups differed in VO_2 max, this variable was introduced as a covariate in the analyses. The DVA scores were analyzed using a mixed-model analysis of covariance (ANCOVA). We conducted a 2 Age (young and older)×3 Sport (karate athletes, judo athletes, nonathletes)×3 Trajectory (horizontal, vertical, oblique)×3 Contrast (high, intermediate, low)×3 Speed (high, medium, low) mixed factorial ANCOVA with VO_2 max as a covariate, Age and Sport as the between-subjects factors, and repeated measures in the last three factors. The Greenhouse–Geisser correction for nonsphericity was applied where necessary and is indicated by adjusted degrees of freedom. DVA was the dependent variable. When a main effect reached statistical significance, post hoc pairwise comparisons were performed using the Bonferroni correction. The average DVA scores, obtained by collapsing the data across trajectories, contrasts, and velocities, were 0.440 (SD=0.073) for judo athletes, 0.447 (SD=0.068) for karate athletes, and 0.397 (SD=0.083) for nonathletes (higher scores imply better performance). Errors were also recorded, although the percentage did not exceed 1 %.

The ANCOVA showed that the main effects of age [$F(1, 128)=65.74$, $MSE=1.02$, $p<.001$, $\eta^2=.34$] and sport [$F(2, 128)=18.95$, $MSE=0.29$, $p<.001$, $\eta_p^2=.23$] were statistically significant. Young participants performed significantly better than older adults ($p<.001$). Simple-effect analyses (Kappel, 1991) showed significant differences between nonathletes and both judo ($p<.001$) and karate ($p<.001$) athletes, whereas the judo and karate groups did not differ. The main effect of trajectory [$F(1.98, 253.95)=2.51$, $MSE=0.014$, $p=.08$, $\eta_p^2=.02$] was marginally significant, whereas the effects of contrast [$F(1.49, 190.51)=8.22$, $MSE=0.0114$, $p<.005$, $\eta_p^2=.06$] and velocity [$F(1.55, 198.07)=9.46$, $MSE=0.009$, $p<.001$, $\eta_p^2=0.07$] were significant. The interaction between age and velocity was not statistically significant; however, velocity marginally interacted with sport [$F(3.095, 198.07)=2.39$, $MSE=0.009$, $p=.06$, $\eta_p^2=.04$], suggesting that athletes had better DVA than nonathletes, especially at high speed (see Fig. 2).

The Age×Trajectory interaction [$F(1.98, 253.95)=8.97$, $MSE=0.051$, $p<.001$, $\eta_p^2=.07$] was significant, indicating that young and older participants behaved differently as a function of trajectory; more specifically, the older participants exhibited a more pronounced oblique effect than did the younger groups (see Fig. 3).

The three-way Age×Sports×Velocity interaction [$F(3.09, 198.07)=7.8$, $MSE=0.009$, $p<.001$, $\eta_p^2=.11$] was also statistically significant; sports and velocity were modulated by age. Specifically, in the younger groups, karate athletes performed significantly better than nonathletes ($p<.01$) when the stimuli were presented at the highest speed, whereas judo athletes and nonathletes groups did not differ ($p>.1$); in contrast, in the older groups there was no difference between the two types of sports ($p>.1$) under any velocity condition.

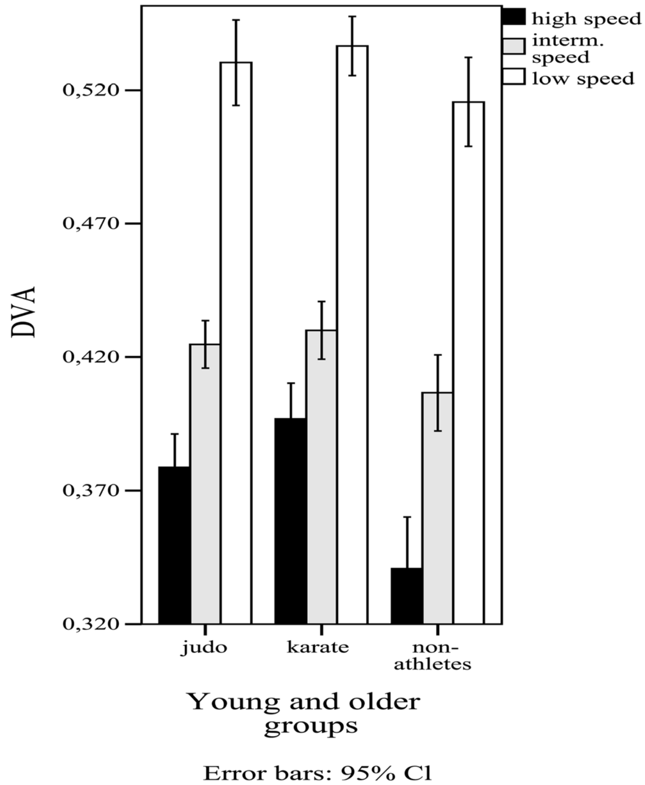

Fig. 2 Mean dynamic visual acuities (DVA) for athlete and nonathlete groups, collapsed over age and under the three velocity conditions: high, intermediate, and low speed. Error bars indicate 95 % confidence intervals

Young adults' performance

To further examine the Age×Sport×Velocity interaction, we conducted an additional ANCOVA with the DVA data while including VO_2 max as a covariate in the analysis of the young participants, using a 3 Group (young karate athletes, young judo athletes, young nonathletes)×3 Trajectory×3 Contrast×3 Velocity mixed factorial design, with Group as the between-subjects factor and repeated measures in the last three factors (see Fig. 4).

The average DVA score for the karate group was 0.475 (SD=0.059); for the judo athletes it was 0.463 (SD=0.061); and for the nonathletes it was 0.443 (SD=0.060). The ANOVA showed that the main effects of group [$F(2, 86)=6.78$, $MSE=0.089$, $p<.05$, $\eta^2=.14$], contrast [$F(1.54, 132.19)=8.92$, $MSE=0.006$, $p<.001$, $\eta^2=.09$], and velocity [$F(1.19, 101.94)=6.62$, $MSE=0.012$, $p<.01$, $\eta^2=.07$] were all significant, whereas the effect of trajectory was marginally significant [$F(1.98, 170.81)=5.53$, $MSE=0.004$, $p=.08$, $\eta^2=.03$]. The karate athletes had the best DVA, followed by the judo athletes and the nonathletes. Pairwise comparisons indicated that karate athletes were significantly better than nonathletes ($p<.05$), but judo athletes did not differ significantly from nonathletes. The oblique trajectory differed from

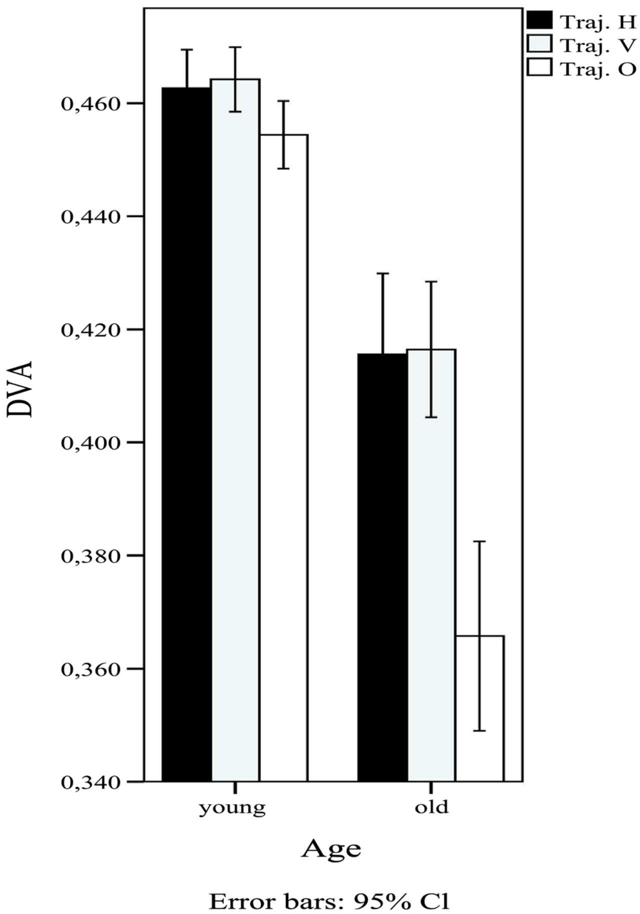

Fig. 3 Mean dynamic visual acuities (DVA) for young and older adults as a function of the trajectory of the moving stimuli: horizontal (H), vertical (V), and oblique (O). Error bars indicate 95 % confidence intervals

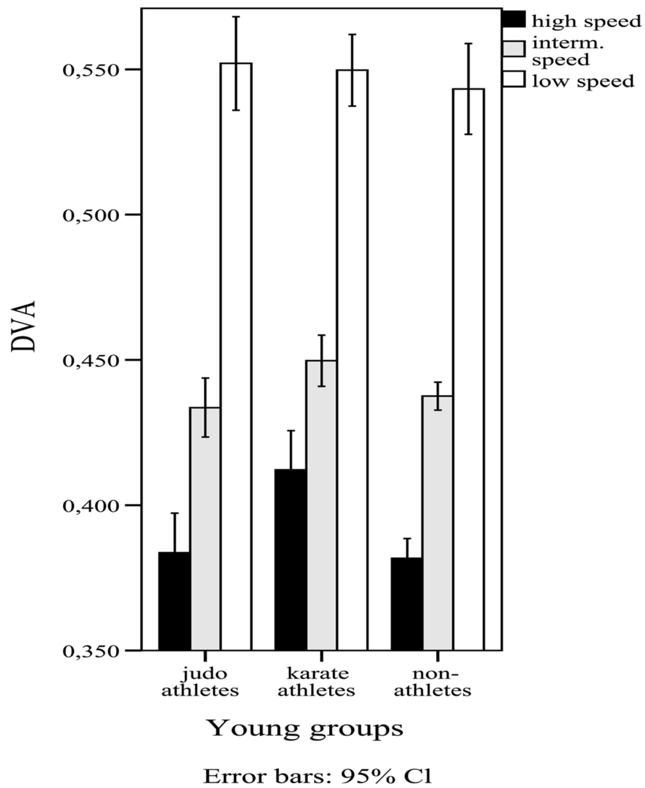

Fig. 4 Mean dynamic visual acuities (DVA) in the three young adult groups—judo athletes, karate athletes, and nonathletes—for the three velocity conditions—high, intermediate, and low speed. Error bars indicate 95 % confidence intervals

both the horizontal (p=.056) and vertical (p<.005) trajectories, showing the oblique effect (Appelle, 1972). Pairwise comparisons showed significant differences between the low-contrast condition and the high- and intermediate-contrast (both ps<.001) conditions, which did not differ from each other.

The two-way Group×Velocity interaction [F(2.37, 101.94)=2.65, p=.06, η^2=.063] was marginally significant. Simple-effects analyses revealed that karate athletes performed better than judo athletes under high- (p<.005) and intermediate- (p<.05) velocity conditions, and also better than nonathletes under the high- and intermediate-velocity conditions (ps<.05). Judo athletes and nonathletes did not differ, suggesting that although both athlete groups performed better than nonathletes, only the karate group was marginally significantly better when the stimuli were presented at high speed.

The three-way Group×Contrast×Velocity interaction was statistically significant [F(6.52, 280.34)=3.32, p<.05, η^2=.07], indicating that the karate group surpassed nonathletes under high-speed and high- and intermediate-contrast conditions (p<.01), and performed better than both the judo (p<.05) and the nonathlete (p<.005) groups under high-speed and intermediate-contrast conditions. Taken together, these results suggest that the DVA of karate experts is superior to that of the other groups when the velocity of the target increases, especially when stimuli are presented with high and intermediate contrasts.

Older adults' performance

To explore the two-way Age×Trajectory interaction found in the general ANCOVA, we analyzed separately the data of the older participants (see Fig. 5). The mean DVAs were 0.418 (SD=0.083) for the judo older martial arts athletes, 0.419 (SD=0.069) for the karate older martial arts athletes, and 0.360 (SD=0.073) for the nonathletes. Errors did not exceed 1 %. A mixed factorial ANCOVA (including VO_2 max as a covariate in the analysis) with the variables group (judo older martial arts athletes, karate older martial arts athletes, older nonathletes), trajectory, contrast, and velocity showed a main effect of group [F(2, 41)=7.52, MSE=0.15, p<.005, η^2=.27]. Pairwise comparisons showed significant differences between nonathletes and the two athlete groups, judo (p<.005) and karate (p<.005). Both ex-athlete groups, irrespective of their martial art, were better than the sedentary nonathlete group.

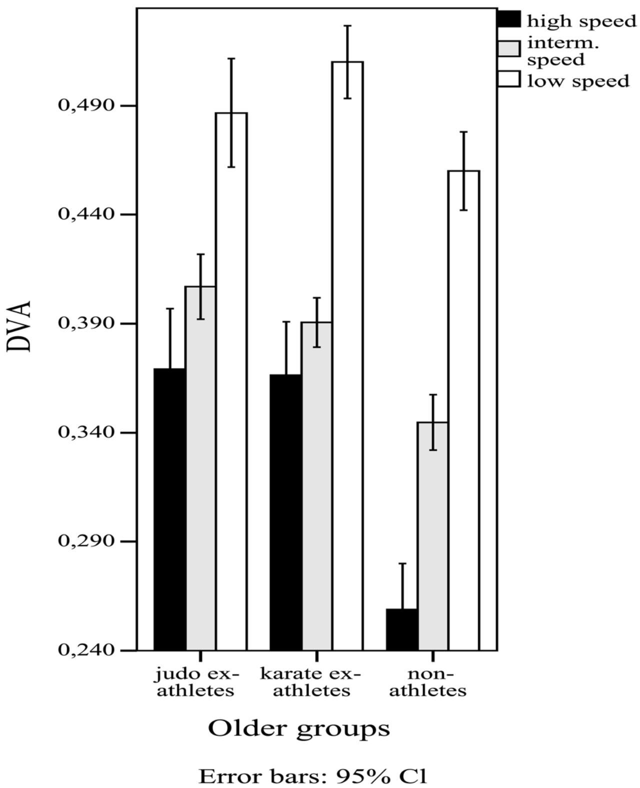

Fig. 5 Mean dynamic visual acuities (DVA) for the three older groups under the three velocity conditions. Error bars indicate 95 % confidence intervals

The two-way Group×Velocity interaction was statistically significant [$F(3.76, 77)=3.77$, $MSE=0.009$, $p<.05$, $\eta^2=.16$]. Simple-effects analyses revealed that both ex-athlete groups performed better than nonathletes at high ($p<.005$) and intermediate ($p<.005$) velocities. This finding suggests that regular practice of judo and karate in old age helps to attenuate age-related DVA decline.

Correlations between age and DVA scores

In young adults, DVA performance seems to depend on the specific martial art. Older martial arts athletes, however, did not show the same specificity. To rule out the possibility that differences between the older martial arts athletes and nonathletes were due to physical activity in general, preexisting aptitudes, or motivational differences, we correlated the DVA scores of older martial arts athletes and years since they had stopped competing at a professional level. DVA marginally correlated inversely with the number of years without competing ($r_{xy}=-.392$, $p=.07$), suggesting that the larger the number of years without competing, the lower the obtained DVA score was. It seems that DVA performance in older martial arts athletes depends at least partially on training in their specific martial art.

Table 2 shows the correlations between age and DVA scores. Both variables correlated negatively ($r_{xy}=-.686$, $p<.001$); that is, the older the participant, the lower the DVA score obtained in all experimental conditions (see Table 2).

We also correlated DVA and peripheral vision scores obtained in our previous study with the same young and older judo, karate, and nonathlete participants (Muiños & Ballesteros, 2014). Both measures correlated negatively ($r_{xy}=-.583$, $p<.001$); that is, participants who performed better in the peripheral vision task obtained higher DVA scores in the present study.

Discussion

The main aim of the study was to investigate possible changes occurring in DVA with age, and whether the attenuation of age-related DVA decline depends on the specific sport. The main results were as follows. First, young observers exhibited better DVA than did older adults, and athletes outperformed sedentary nonathletes. Second, athletes were only better than nonathletes when the task was more difficult (at high and intermediate speeds). Third, the oblique effect was greater in the older than in the younger groups, regardless of whether or not they participated in a sport. Finally, age determined the results for each type of sport when the moving velocity of the stimulus was high.

Our results are consistent with previous studies conducted with nonathletes, which showed that DVA was better with increasing visual contrast (e.g., Long & Zavod, 2002) and worse with stimuli moving at high velocities (e.g., Miller, 1958). The present results with martial arts practitioners reinforce the validity of the computer software DinVA 3.0 (Quevedo et al., 2010). The key factor that determines DVA as a function of stimulus velocity is the type of sport practiced and not the participant's age; athletes differed from sedentary

Table 2 Correlations between age and dynamic visual acuity (DVA) scores as a function of stimulus velocity, trajectory, and contrast

			Age
DVA	Velocity	Rapid	–.527 ($p<.001$)
		Intermediate	–.711 ($p<.001$)
		Low	–.585 ($p<.001$)
	Trajectory	Horizontal	–.493 ($p<.001$)
		Vertical	–.571 ($p<.001$)
		Oblique	–.735 ($p<.001$)
	Contrast	High	–.487 ($p<.001$)
		Intermediate	–.576 ($p<.001$)
		Low	–.724 ($p<.001$)

Values are Pearson correlation coefficients, and the corresponding p-values are in parentheses.

participants of the same age, depending on the target speed. Although all observers performed better at the slowest stimulus speed and worse at the highest speed, the distance between the high- and intermediate-speed scores was smaller in athletes than in the nonathlete groups, with athletes being less affected by the high velocity of the target (see Fig. 2). This result is in agreement with Sanderson (1981), who characterized skilled athletes as being "velocity resistant," suggesting that they are less vulnerable (less deterioration in DVA) than nonathletes at increased velocity.

Our results suggest that age does not modulate the velocity effect, but that the stimulus trajectory is important. The oblique effect was greater in the older groups, producing a larger difference between oblique and both horizontal and vertical trajectories in the older than in the younger groups. As we pointed out in the introduction, the oblique effect is usually attributed to a larger cardinal versus oblique neural representation in the primary visual cortex, and to the fact that horizontal and vertical orientations have a greater neuronal response (Li, Peterson, & Freeman, 2003; Xu, Collins, Khaytin, Kaas, & Casagrande, 2006). Older participants, whether or not they practiced a sport, exhibited a larger oblique effect than did the young adults, suggesting that the neural areas involved in the processing of oblique orientations decline with aging.

The present results reveal that age is the crucial factor determining the results of each type of sport. In young adults, the particular type of martial art induced differences in the detection of stimuli moving at high speed, whereas in older adults, the type of sport and speed conditions were irrelevant. The continued practice of a martial art (judo or karate) by older adults helps slow down age-related declines in DVA skills. Since age was the key factor that determined the results and led to different patterns of performance in young and older adults, these results and their implications are discussed below.

DVA in young martial arts athletes and nonathletes

The results obtained with young participants are in agreement with previous findings suggesting better visual abilities in sportsmen than in the general population (e.g., Arkaru, Çaliskan, & Dane, 2009; Giglia et al., 2011; Mori, Ohtani, & Imanaka, 2002); concretely, our results agree with those showing that athletes perform better than nonathletes in DVA tasks (e.g., Ishigaki & Miyao, 1993; Millslagle, 2000; Quevedo et al., 2011; Uchida et al., 2013; Uchida et al., 2012).

Different approaches have been taken to disentangle the relation between the practice of sports and cognition. Some studies have assessed perceptual or cognitive processes during or just after physical activity. In general, these studies have revealed that exercise improves cognitive processes, such as attention and speed of processing, but that the improvement lessens shortly after the exercise ends (e.g., Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Hillman, Snook, & Jerome, 2003). Other studies have tested participants after a relatively long period (weeks or months) of physical training and compared their performance with that of a control group who did not train during that time (Chang, Tsai, Chen, & Hung, 2012; C. L. Davis et al., 2007), also revealing executive function improvements in participants who performed the exercise training. Another approach consists of comparing the performance of physically active participants who exercise regularly with that of participants who do not take part in any sport (e.g., Krampe et al., 2014; Muiños & Ballesteros, 2014; Quevedo et al., 2011). Our study belongs to the latter category, involving physically active participants practicing a specific martial art.

The DVA of our highly competitive athlete groups was better than that of the nonathletes of the same age. Interestingly, the particular type of martial art was significant only in the young athletes. These results suggest that studies should include participants on the basis of their type of sport, with clear inclusion criteria, rather than mixing athletes from different sports or with different levels of expertise, given that different types of perceptual skills might have developed in each case. The present findings are in agreement with those of a previous study (Muiños & Ballesteros, 2014) conducted to investigate static peripheral vision. The correlation between the results of the two studies was significant, suggesting that participants who performed better in the peripheral vision task obtained higher DVA scores in the present study.

It seems that after years of practice and a sustained learning process, karate athletes develop visual perceptual skills related to detecting central and peripheral visual cues at high velocity, and to tracking objects moving at high speed. By contrast, grappling martial arts, such as judo, do not require velocity skills at the same level as other martial arts.

The idea that different sports lead to the development of different perceptual abilities in their practitioners has been proposed in studies that have argued that superior DVA is especially relevant in sports that demand a high level of eye–hand coordination (for a review, see Banks et al., 2004), and also in studies that have argued that ball players usually display superior DVA because of their ability to track fast-moving objects (e.g., Rouse et al., 1988; Uchida et al., 2012).

DVA in older martial arts athletes and nonathletes

Given the great deal of research linking physical activity to better perceptive and cognitive functioning in older adults, we speculated that martial art sports may contribute to the maintenance of visuospatial skills of older practitioners at a higher level than that of nonathletes, and to a reduced risk of dementia (for reviews, see Hötting & Röder, 2013). Specifically, exercise-induced changes improve executive control and

speed of processing (Ballesteros et al., 2013a; Voss et al., 2010), produce better spatial memory performance (Erickson et al., 2010), and contribute to the enhancement of verbal learning and selective attention (Hötting, Schauenburg, & Röder, 2012), among other cognitive improvements. In addition, regular cardiovascular activity and other types of physical activity, such as coordination training (e.g., Niemann, Godde, & Voelcker-Rehage, 2014), produces neural changes in hippocampal volume (Erickson et al., 2010), reduces the loss of gray and white matter (Colcombe et al., 2006), and contributes to the activation of the anterior cingulate cortex and greater task-related activity in regions of the prefrontal and parietal cortices (Colcombe et al., 2004).

An important finding of the present study is that, whatever the sport, older martial arts athletes showed better DVA than nonathletes of the same age and educational level. This lack of specificity observed in the older martial arts practitioners is consistent with previous findings obtained in peripheral visual (Muiños & Ballesteros, 2014) and postural control (Krampe et al., 2014). Muiños and Ballesteros (2014) found that older judo and karate martial arts athletes performed similarly when static stimuli were presented at the periphery of the visual field, whereas the performance of younger adults varied as a function of the sport. These results confirm the hypothesis that in older adults, the important factor is to participate in a sport, and not the particular sport. In fact, most studies that have shown exercise-induced improvements in several perceptive and cognitive processes have usually involved older "physically active" participants who either carried out regular cardiovascular fitness or aerobic exercise in general, or who participated in sports such as swimming, golf, or walking.

Our older participants practiced a martial art, but the results were in the same direction, suggesting the beneficial effects of sports on major perceptual processes. On the other hand, it is also possible that we failed to find differences between karate and judo athletes in older adults because they did not practice their sport with the same intensity as the young competitive athletes, probably losing some of the specific skills produced by each type of sport. We found a marginally significant relation between the number of years without competing at a professional level and DVA scores, suggesting that more years without competing produces lower DVA scores. Little is known regarding this issue, and further investigation is required. Because physical exercise can take many forms, different perceptual and cognitive functions might be affected. It seems that resistance (Liu-Ambrose et al., 2010), coordination training (Niemann et al., 2014; Voelcker-Rehage, Godde, & Staudinger, 2011), and perhaps other forms of exercise prevent age-related cognitive decline. Liu-Ambrose et al. (2010) showed that older participants (65 years of age and over) who did resistance training had better executive control, as assessed by a Stroop task, than those who did balance and toning exercises. This finding is consistent with our results, since both karate and judo have components that include aerobic, cardiovascular, and coordination exercises. Perhaps our judo and karate older martial arts athletes had lost the specific benefits of their sport shown by young athletes, but they maintained better perceptual abilities than older nonathletes due to their extended general physical activity.

Cassilhas and colleagues (2012) have suggested a possible underlying physiological mechanism in humans and animals to explain why different types of physical activity (aerobic or resistance exercise) lead to the improvement of particular abilities. They found that both aerobic and resistance exercises improved spatial learning and memory, but that each type of exercise led to different signaling pathways and triggered different neurotrophic reactions. Although little is known about physical activity and brain function, brain structure, and connectivity, preliminary but promising results have suggested a positive association between physical activity and brain plasticity (e.g., Voelcker-Rehage & Niemann, 2013; Voss et al., 2010). More research will be needed to clarify the mechanisms that produce differences between athletes and nonathletes in old age, and what type of physical activity determines the neural changes that lead to the maintenance of neuroplasticity and perceptual and cognitive functioning.

Besides the lack of specificity of the type of sport among older adults, we also expected to find a different pattern of results between young and older groups, especially at high velocity. This study showed, however, that in both age groups martial art athletes had better DVA skills than did nonathletes of the same age, especially when stimuli moved at high and intermediate speeds. The results revealed less specificity among older adults, with greater differences between athletes and nonathletes (larger effect sizes), whereas the magnitude of the differences among younger groups was smaller and somewhat concentrated under certain conditions. This result is consistent with the finding that individual differences are usually greater in old age (e.g., Glisky, 2007). This greater between-person variability in older adults could be due to multiple factors, including socio-cultural level. However, the participants in the present study had similar education levels, and the differences could not therefore be explained by differences in education. A physically active lifestyle could be the crucial variable explaining, at least in part, the greater individual differences commonly found in older adults. As Glisky argued, between-person variability in old age could also be greater because age-related decline is not uniform in all cognitive processes. For instance, one older adult may suffer a decline in executive control, while another shows a decline in long-term memory, leading to differences in performance in cognitive tasks.

In sum, the present results agree with previous findings suggesting that physical activity in old age plays an important role in maintaining visuospatial skills as well as other important cognitive functions (e.g., Ballesteros et al., 2013a;

Colcombe et al., 2006; Erickson & Kramer, 2009). If a physically active lifestyle could attenuate age-related brain dysfunction and perceptual and cognitive declines, it is very likely that older athletes may keep their perceptual abilities due to physical exercise, in the same way that sedentary individuals tend to lose it.

A possible limitation is that the present study has not definitively shown (as it has also not yet been shown in other studies) that the superior DVA (or the superior visual skills, in general) found in athletes relative to nonathletes is due to the practice of a particular sport. We recognize that it is possible that athletes had preexisting superior visual abilities that led them to enroll and compete in sports, because they were innately good at these activities. However, we think that this is unlikely, due to the marginal inverse correlation found between the number of years without competing and visual performance on the DVA task.

Summary and conclusions

The results of this study with young and older judo and karate practitioners and sedentary participants of the same age and educational levels suggest that (1) the DVA of young adults is superior to that of older adults, but athletes outperform nonathletes; (2) in young participants, karate practitioners differ in their detection of a moving stimulus; (3) older adult athletes, regardless of which martial art they practice, have better DVA than older nonathletes, suggesting a lack of specificity with age; and finally, (4) older adult athletes have better DVA than nonathletes of the same age, suggesting the importance of a physically active lifestyle with regular exercise to counteract age-related perceptual decline.

In conclusion, the results of the present study suggest that the intensive and sustained practice of judo and karate seems crucial to maintain the DVA of older martial arts practitioners. The regular practice of exercise across the lifespan not only has beneficial effects on physical health, but also helps to maintain DVA, preventing age-related declines and probably enhancing neural plasticity.

Author note This research was supported by grants from the Spanish government (No. PSI2010-21609-C2-01) and the Madrid Community (No. S2010/BMD-2349) to S.B. We thank all of the volunteers who participated in the present study. We also thank José Manuel Reales and Julia Mayas for their valuable comments on the design of the study. We are very grateful to J. A. Aznar-Casanova, L. Quevedo, and J. C. Ondategui for their help on DVA measurement. Finally, we are very grateful to Marisa Carrasco (New York University) for her helpful comments on a previous version of the manuscript. We also thank two reviewers, who with their comments and suggestions helped us to improve this article.

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