School of Health and Human Sciences

2009

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Publication details

Frank, M, Zhou, S, Bezerra, P & Crowley, Z 2009, 'Effects of long-term recreational surfing on control of force and posture in older surfers: a preliminary investigation', *Journal of Exercise Science and Fitness*, vol. 7, no. 1, pp. 31-38.
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Original Article

EFFECTS OF LONG-TERM RECREATIONAL SURFING ON CONTROL OF FORCE AND POSTURE IN OLDER SURFERS: A PRELIMINARY INVESTIGATION

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Surfing has become a popular sport activity in Australia and many other countries since the 1960s. The first generation of surfers is now older than 60 years of age while many of them still surf regularly. Limited information is available with regard to the long-term physiological adaptations of participating in surfing. The aim of this study was to provide evidence on the effects of long-term surfing on neuromuscular function as compared to age-matched non-surfers. Eleven male surfers who had participated in surfing for at least 40 years volunteered for the study. A group of age-matched and physically active men ($n = 11$) were recruited as the control. The physiological variables measured included maximal isometric voluntary contraction force (MVC), rate of force development, steadiness in muscle force production (knee extensors and flexors, and ankle dorsi- and plantarflexors) at 5%, 15% and 25% of MVC levels, joint position sense, and body sway in standing position under four different conditions: eyes open or closed and on a hard or soft surface. The results indicated that older surfers had significantly lower muscle force fluctuations than the control subjects in the steadiness tests. The surfers also showed less postural sway in the standing position with eyes closed and on soft surface. The findings from this preliminary investigation suggest that long-term recreational surfing may cause specific adaptations that benefit participants by maintaining or improving their neuromuscular function, which would ultimately lead to improved quality of life. [*J Exerc Sci Fit* • Vol 7 • No 1 • 31–38 • 2009]

Keywords: aging, balance, joint position sense, long-board surfing, muscle steadiness, postural sway

Introduction

The life expectancy of Australians, as well as in many other countries, has increased over the past several decades, with the percentage of those aged 65 years and older now comprising 13.1% of the entire population (Australian Government—Department of Health and Ageing 2006). Healthy aging has become a priority of the Australian Government.

The loss of muscle strength, power, steadiness and balance is the most commonly found problem in adults aged 60 and over and is reported to be associated with an increased risk of falling and morbidity in elderly populations (Choi et al. 2005; Izquierdo et al. 1999; King et al. 1994; Wolfson et al. 1994). Numerous intervention studies have shown that through participation in regular physical exercise, these muscle and neural dysfunctions may be retarded or even reversed (Manini et al. 2005; Tracy et al. 2004; Xu et al. 2004; Hakkinen et al. 2000; Izquierdo et al. 1999). It has been reported that exercise can help to improve the functional ability of the motor system in maintaining balance and postural stability (Lord et al. 1994). It has also been suggested that proprioceptive exercises, such as yoga, soft gymnastics and Tai Chi, may have greater effect on balance control in the elderly than simple form of bioenergetic physical activities (Gauchard et al. 1999).

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Surfing (surfboard riding) is a sport that has experienced an incredible boom in participants at both recreational and competitive levels over the last decades (Mendez-Villanueva & Bishop 2005). The *Sweeney Sports Report* for the year 2004/2005 found that surfing was continuing to strengthen its development and seemed to be popular amongst both males and females, all age groups, and across different geographical locations (Sweeney 2005). The report also found that on Australian coastlines alone, over two million people had actively participated in the sport. It is now the time that the first generation of surfers are stepping into middle and older ages. Surprisingly, despite the large number of participants worldwide, only a few scientific studies have focused on surfing. In particular, no information is available on the impact of long-term participation in surfing on fitness, health and wellbeing of older surfers.

Surfing has several key physiological aspects. Paddling out in the surf, for instance, requires aerobic power, anaerobic power, intermittent endurance and strength and power of the upper body. Riding the waves requires balance, force development, flexibility, reaction time and coordination of the lower body (Mendez-Villanueva & Bishop 2005). It is therefore hypothesized that older surfers who surf regularly exhibit neuromuscular traits that differ from aged-matched non-exercising population groups or those who participate in other types of physical activity. This study aimed to provide evidence on whether long-term surfing has any effects on proprioception, muscle strength, power, steadiness in force production and postural control as compared to age-matched non-surfers.

Methods

Participants

Two groups of male volunteers were recruited, a surfer group (SURF, $n = 11$) and an age-matched control group (CONT, $n = 11$). The targeted age range of participants was 55–65 years. It has been reported in the literature that there is a significant decline in muscle strength, power, steadiness and postural control towards the sixth decade of life (Petrella et al. 2005; Izquierdo et al. 1999).

The inclusion criteria for both groups were: (1) currently healthy as screened by a modified "Health Status Assessment Prior to Exercise Testing" questionnaire that is commonly used in our laboratory; (2) to have not participated in any systematic strength training in the last 6 months. Two additional inclusion criteria were used for the surfers: (3) they had participated in recreational surfing on a weekly basis for the past 20 years; and (4) currently surfed at least twice per week.

The exclusion criteria for both groups were: (1) lack of independent ambulation (walk with the assistive devise); (2) recent lower limb injuries; (3) neurologic or lower-extremity orthopedic diagnoses; (4) corrected visual acuity worse than 20/100 or presence of a field defect; (5) true vertigo; (6) acute illness; (7) the use of medication known to affect balance (Laughton et al. 2003; Wolfson et al. 1994); and (8) waist circumference greater than 90 cm (Janssen et al. 2004; Zhu et al. 2004).

To justify the minimum sample size, the effect size of the primary outcome measurements was calculated in an attempt to minimize type I and type II errors (Cohen 1988). As there was no information that was specific to surfers in our laboratory, we used data from other research where similar testing had been used in predicting the number of participants to be recruited (Mjolsnes et al. 2004; Aagaard et al. 2002; Konradsen 2002; Ryushi et al. 2000). The sample size calculation, at 80% power and 95% confidence level, indicated that a minimum of 10 participants per group was needed to detect significant differences in maximal isometric voluntary contraction force (MVC) and rate of force development (RFD) using the GPower3 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). The characteristics of the recruited participants are summarized in Table 1.

Functional tests

The participants visited the laboratory twice. The first visit was a familiarization trial during which the volunteers were screened against the inclusion and exclusion criteria. Those who met the recruitment criteria signed informed consent forms and familiarized themselves with the testing procedures.

Formal tests were conducted during the second visit, including joint position sense (JPS) tests for knee and ankle; MVC; RFD; steadiness in force production in knee extension and flexion and ankle dorsi- and plantarflexions (only the right leg was tested); and postural sway tests under four conditions.

For knee extension and flexion MVC, RFD and steadiness tests, participants sat in the testing chair with both the hip and knee joint angles flexed at 90° from full extension. The leg was strapped to a load cell that was positioned 2–3 cm above the ankle joint. The testing position for dorsi- and plantarflexion was similar to that of the knee extension and flexion tests, while the foot was strapped to a metal plate with a load cell

Table 1. Physical and exercise characteristics in surfer (SURF) and control (CONT) groups

	SURF ($n = 11$)		CONT ($n = 11$)	
	Mean ± SD	Range	Mean ± SD	Range
Age (yr)	60.0 ± 2.3	57–64	59.6 ± 2.5	57–63
Height (cm)	175.0 ± 5.0	167–184	173.3 ± 11.1	162–193
Mass (kg)	77.5 ± 11.0	56.1–93.1	84.0 ± 14.2	64.5–110
Body mass index (kg/m^2)	25.1 ± 2.9	20.1–30.4	27.2 ± 3.3	22.6–33.3
Time per week spent surfing (hr)	7.5 ± 2.8	5–15	None	
Surfing experience (yr)	46.5 ± 4.0	40–54	None	

attached underneath. The force signal in isometric knee extension, flexion and ankle dorsi- and plantarflexion was collected by the load cells (2kN, Xtran Load Cells; Applied Measurement Australia Pty. Ltd., Oakleigh, Victoria, Australia), via a custom-written LabVIEW schematic (National Instruments Corp., Austin, TX, USA). The analog-to-digital conversion rate was at 1000 Hz with low-pass at 95 Hz, and the force signals were fed with a 12-bit resolution to a low noise (< 1 μV referred to the input) amplifier. A custom-designed LabVIEW (version 4.0) schematic was used in data collection.

The MVC and RFD in maximal isometric knee extension and flexion and ankle dorsi- and plantarflexion were assessed in three trials. Each trial was to start and end at the researcher's voice signal, "ready…go…stop" and was to last 2–3 seconds. Participants were asked to maximally and as fast as possible exert force while receiving verbal encouragement, and to relax the muscle as quickly as possible when receiving the "stop" signal. A trial was considered successful if there was no notable negative slope in the strength-increasing phase or if the participant did not voice any dissatisfaction with the performance. This procedure was repeated until three successful attempts had been performed. The highest score out of the three attempts was used for the statistical analysis. A rest period of 1 minute was allowed between trials.

After 2 minutes' rest from the MVC test, the steadiness tests were performed in the same setting described above. Each participant was asked to perform an isometric contraction, with force trace shown on a computer screen, to match the target force displayed on the computer screen, and sustain a steady force for 28 seconds. The target force levels were 5%, 15% and 25% of the MVC (Manini et al. 2005; Tracy et al. 2004). The procedure was repeated three times with a 1-minute rest between trials. The steadiness was quantified as absolute (standard deviation) and normalized (coefficient of variation [CV] that was calculated as the standard deviation divided by the mean) fluctuation of force around the target value (Enoka et al. 1999). Isometric steadiness was calculated over a segment of an 8-second period in the middle of the contraction (Manini et al. 2005; Tracy & Enoka 2002). The best score, i.e. lowest fluctuation in force, in three attempts was used in statistical analysis.

A custom-built device was used for testing the JPS in an active angle reproduction test. The JPS was assessed using an open-kinetic chain and active knee and ankle positioning technique. Only the right side was assessed. It involved the participant sitting in a testing chair with legs hanging freely. Three reference points were drawn on the skin, one on the iliotibial tract level with the posterior crease when the knee flexed to 80°, another on the prominence of the lateral malleolus, and the third one on the tuberosity of the fifth metatarsal (Ribeiro et al. 2007). The participants were blindfolded. When testing the knee, the researcher gradually moved the leg from the starting position of 90° of flexion to a flexion angle between 40° and 60°. The participants then held at the target angle for 5 seconds, without manual contact from the researcher. On the command of "return", the participant placed the leg back into the starting position which was then held for 3 seconds (Bullock-Saxton et al. 2000). On the command of "reposition", the participant returned to the position perceived as the target (criterion angle) and reported "target" to the researcher. This position was read from the testing device and recorded, and on the command of "finish", the participant returned to the starting position and opened their eyes. This procedure constituted one trial and was repeated an additional three times, with a new target angle between the knee flexion of 40° to 60° selected for each trial. A similar protocol was used for testing ankle JPS, except that the ankle joint was moved to angular positions between 10° plantarflexion and 5° dorsiflexion (Simoneau et al. 1997). Proprioception of the knee joint and ankle joint was evaluated by measuring the difference between the target position and the replicated position for each of the tests

(Petrella et al. 1997). The mean score of four tests was used in further statistical analysis.

Postural control was assessed by a static stabilometry test (Nordahl et al. 2000). The test was performed on a force plate (type 9287; Kistler, Winterthur, Switzerland) which provided continuous feedback on the position of the center-of-pressure (COP). Each participant stood on the force plate barefooted with the feet apart at a comfortable distance and the big toes of the feet aligned evenly in the anteroposterior (AP) direction. The arms rested on the side. Each participant was asked to look straight ahead at a fixed target point, at eye level, 2 meters away, and for 30 seconds in each test. Four tasks were performed: (1) on a firm surface with the eyes open (SOT1); (2) on a firm surface with the eyes closed (SOT2); (3) on a thick foam rubber mat with the eyes open (SOT3); and (4) on the mat with the eyes closed (SOT4). The procedures were repeated three times under each of the four conditions. The COP displacement was recorded in both AP and mediolateral (ML) directions. The mean COP score out of the three attempts was used in statistical analysis.

The measures of postural control were assessed by the range of the COP trajectory, mean sway speed in AP and ML directions, and the stabilogram diffusion analysis. COP trajectory length is related to the effort of the balance control system to maintain upright posture. The mean sway speed evaluates the postural control in the planes defined. The stabilogram diffusion analysis provides a quantitative statistical measure of the apparently random variations in COP trajectories during quiet upright stance (Nordahl et al. 2000; Collins & De Luca 1993). Peterka (2000) has stated that the stabilogram diffusion function summarizes the mean square COP displacement as a function of the time interval between COP comparisons.

Statistical analysis

Descriptive statistics were performed for calculation of the means and standard deviations of all variables. The data were then analyzed using one-way ANOVA tests to assess differences between the two groups. Significance level was set at $p < 0.05$. All statistical analyses were performed using SPSS version 14.0 (SPSS Inc., Chicago, IL, USA).

Results

No significant differences between the SURF and CONT groups were found in their MVC (Figure 1) and RFD during the isometric knee extension and flexion and ankle dorsi- and plantarflexion tests (Table 2).

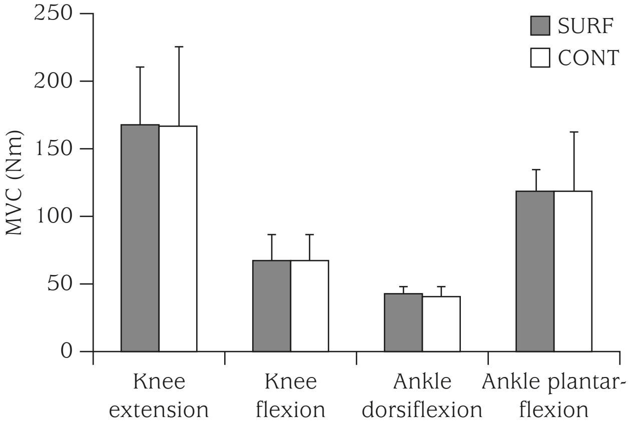

Fig. 1 Isometric maximal voluntary contraction torque (MVC) of lower limb muscle groups in the older surfer (SURF) and age-matched control (CONT) groups. The error bars represent standard deviation.

Table 2. Peak torque (MVC) and rate of force development (RFD) in maximal isometric voluntary contraction in knee extension and flexion and ankle dorsi- and plantarflexion tests for the older surfers (SURF) and age-matched control group (CONT)*†

	SURF	CONT
MVC (Nm)		
Knee extension	167.8 ± 43.1	167.2 ± 58.2
Knee flexion	66.9 ± 19.5	67.6 ± 19.0
Ankle dorsiflexion	42.5 ± 5.5	40.1 ± 7.6
Ankle plantarflexion	118.5 ± 16.5	118.9 ± 43.9
RFD (Nm/s)		
Knee extension	1004.2 ± 388.9	1006.8 ± 272.7
Knee flexion	367.6 ± 164.8	358.9 ± 123.9
Ankle dorsiflexion	205.4 ± 33.4	183.3 ± 55.6
Ankle plantarflexion	519.5 ± 165.0	417.3 ± 155.1

*Data presented as mean ± standard deviation; †no significant difference was detected in the mean values between the two groups.

The results indicated that older surfers had significantly lower muscle force fluctuations in the steadiness tests. The standard deviation of force variations in the surfers was significantly lower than that of the control participants at 15% and 25% of MVC of the knee flexors ($p = 0.027$ and 0.035, respectively), and at 25% of MVC of the ankle plantar flexors ($p = 0.012$) (Table 3). When the steadiness was expressed as the CV, the two groups were deemed different at 5%, 15% and 25% of MVC of the knee flexors ($p = 0.000$; Figure 2) and at 5% and 25% of MVC of the ankle plantar flexors ($p = 0.029$ and 0.001 respectively, Table 3).

Table 3. Steadiness of force production in maintaining isometric contractions at 5%, 15% and 25% of MVC levels for the older surfer (SURF) and age-matched control (CONT) groups*

	Coefficient of variation (%)		Standard deviation (Nm)	
	SURF	CONT	SURF	CONT
KE 5% MVC	0.0160 ± 0.0032	0.0196 ± 0.0097	0.1799 ± 0.0499	0.2344 ± 0.0843
KE 15% MVC	0.0168 ± 0.0035	0.0163 ± 0.0054	0.4649 ± 0.0937	0.4484 ± 0.0939
KE 25% MVC	0.0176 ± 0.0041	0.0206 ± 0.0058	0.7450 ± 0.1154	0.8903 ± 0.2437
KF 5% MVC	0.0100 ± 0.0064†	0.0270 ± 0.0101	0.1150 ± 0.0418	0.1293 ± 0.0367
KF 15% MVC	0.0089 ± 0.0037†	0.0234 ± 0.0082	0.2003 ± 0.0625†	0.2785 ± 0.0962
KF 25% MVC	0.0104 ± 0.0057†	0.0267 ± 0.0104	0.3293 ± 0.1200†	0.4693 ± 0.1538
DF 5% MVC	0.0369 ± 0.0346	0.0820 ± 0.0853	0.0846 ± 0.0481	0.0835 ± 0.0281
DF 15% MVC	0.0526 ± 0.0294	0.0535 ± 0.0440	0.1325 ± 0.0668	0.1547 ± 0.0731
DF 25% MVC	0.0534 ± 0.0258	0.0432 ± 0.0243	0.2272 ± 0.0755	0.2864 ± 0.2102
PF 5% MVC	0.0073 ± 0.0030†	0.0103 ± 0.0030	0.1168 ± 0.0530	0.1455 ± 0.0641
PF 15% MVC	0.0082 ± 0.0027	0.0093 ± 0.0030	0.2169 ± 0.0734	0.2548 ± 0.1871
PF 25% MVC	0.0082 ± 0.0027†	0.0155 ± 0.0053	0.3183 ± 0.1092†	0.5666 ± 0.2780

*Data presented as mean ± standard deviation; $^{\dagger}p < 0.05$ between the two groups. KE = knee extension; KF = knee flexion; DF = ankle dorsiflexion; PF = ankle plantarflexion.

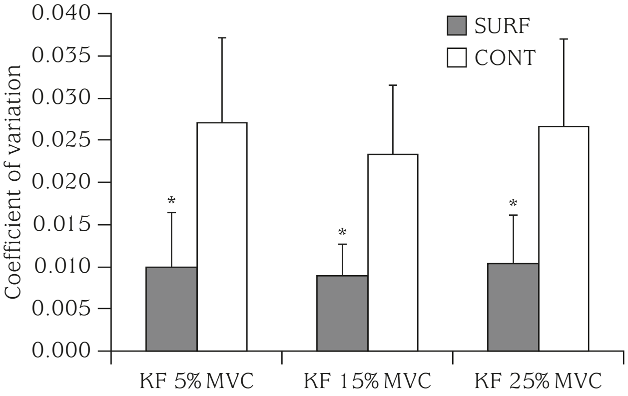

Fig. 2 Coefficient of variation of force fluctuation during isometric knee flexion (KF) performed at 5%, 15% and 25% of isometric maximal voluntary contraction torque (MVC) in older surfer (SURF) and age-matched control (CONT) groups. Error bars represent standard deviation. $*p < 0.05$ between groups.

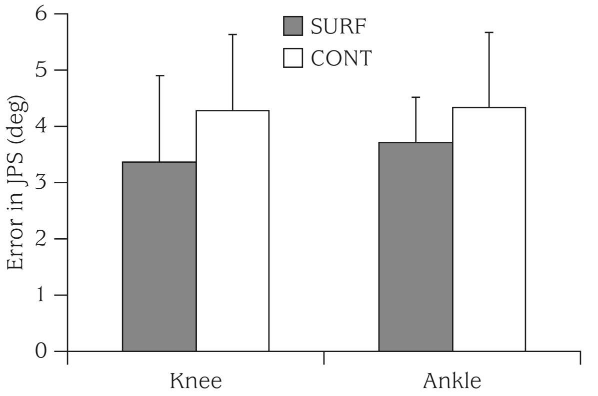

Fig. 3 Joint position sense (JPS) error at the knee and ankle joints of older surfer (SURF) and age-matched control (CONT) groups. Error bars represent standard deviation.

The surfers also showed a trend of better scores than the CONT group in the JPS test (Figure 3). However, the difference did not reach statistical significance ($p = 0.16$ for knee and 0.19 for ankle).

The results of the postural control test indicated that, in general, there was no significant difference in postural sway in standing position between the two groups. However, when the control of posture is assessed by stabilogram, it was found that for the short-term diffusion coefficient in X direction, the SURF group demonstrated less body sway than the CONT group under the condition of eyes closed and on a soft surface (SOT4, $p = 0.03$; Figure 4).

Discussion

This preliminary investigation is the first to demonstrate that long-term participation of recreational surfing caused specific neuromuscular adaptations in control of muscle force production and posture. The surfers demonstrated a better ability in control of steady muscle contraction, particularly in the knee flexors and the ankle plantar flexors, and less body sway when control of posture relied more on proprioception (eyes closed and on a soft surface), than those of an age-matched, healthy and active control group.

With consideration of the physiological demands of surfing (Mendez-Villanueva & Bishop 2005), it was hypothesized that older surfers who surf regularly would exhibit neuromuscular traits that differ from aged-matched

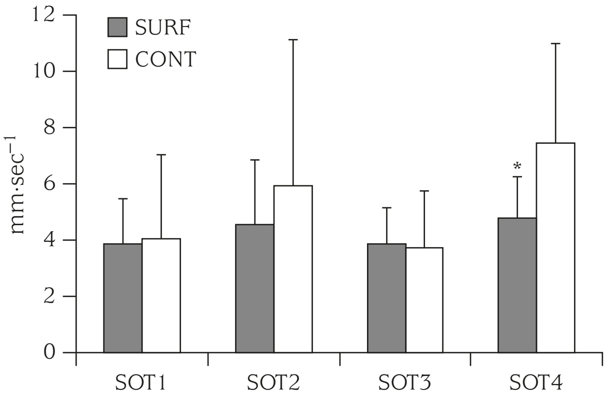

Fig. 4 Range of center of pressure path in X direction, using short-term diffusion coefficient in stabilogram, in older surfer (SURF) and age-matched control (CONT) groups. Error bars represent standard deviation. $*p<0.05$ between groups. SOT1 = eyes open, hard surface; SOT2 = eyes closed, hard surface; SOT3 = eyes open, soft surface; SOT4 = eyes closed, soft surface.

non-exercising population groups, or those who participate in other types of physical activity. With respect to lower body strength and power, the results of the present study found no significant differences in MVC and RFD between the two groups. Previous reports have repeatedly indicated that regular participation in physical exercise can slow down or even reverse the age-related decline in muscular strength and power (Bellew et al. 2003; Ferri et al. 2003; Hakkinen et al. 2000). A possible explanation of our findings might be that the regular exercise (walking, cycling, swimming, 2–3 times per week) taken by the control group had benefited these individuals (Gauchard et al. 1999) in a similar way as the surfing did for the surfers. Surfing does not require repeated exertion of maximal force by the lower limbs, but rapid responses to wave changes. A time-motion analysis study by Meir et al. (1991) found that only approximately 5% of an entire surfing session was spent on wave riding. So, if each of the older surfers surfed an average of 7.5 ± 2.8 hours per week, one could predict that only around 15–30 minutes were spent riding waves each week. So it may be that during a recreational surfing session, only limited occasions arise to exert high intensity contractions and utilize explosive muscle force (during the take off) in the lower limbs. Surfing would require a high level of upper body muscle strength and endurance in paddling out for the surf (Mendez-Villanueva & Bishop 2005).

Surfing requires rapid adjustment of muscular force in response to wave changes. Therefore, it was hypothesized that surfers would exhibit a better ability in control of muscle force as an adaptation in the neuromuscular system. Muscle steadiness has been used as an indicator of the ability to control muscles (Tracy et al. 2004; Laidlaw et al. 1999; Keen et al. 1994). Assessment of muscle steadiness is normally done when participants hold a certain submaximal level of force against a given target level, in either static or dynamic contractions (Tracy et al. 2004; Laidlaw et al. 1999; Keen et al. 1994). The variation of force around the target level is assessed for steadiness. There are two ways to quantify the force variation: one is to use the standard deviation of force variation over a given time (i.e. absolute value of force fluctuation); the other is to use the CV, i.e. the standard deviation divided by the mean force (that is, the relative magnitude of fluctuation to the mean force).

In this study, steadiness in isometric contractions of the knee extensor and flexor, and ankle dorsi- and plantar flexor muscle groups were examined at three submaximal force levels. The standard deviation of force variation increased with target force for both SURF and CONT groups in all four muscle groups, with a general trend that the SURF group demonstrated lower fluctuation than the CONT group. Some previous studies have demonstrated that resistance training may improve steadiness in dynamic contractions but not in isometric contractions (Manini et al. 2005; Tracy et al. 2004). The results of the present study indicated that, although significant differences between the two groups were found only at 15% and 25% of MVC of the hamstrings and at 25% of MVC of the ankle plantar flexors, it should be mentioned that the differences at 5% and 25% of MVC of the knee extensors were also approaching significant levels ($p = 0.08$ and 0.089, respectively). The SURF group also demonstrated a lower CV than the CONT group, at 5%, 15% and 25% of MVC of the knee flexion and at 5% and 25% of MVC of the ankle plantarflexion. The results support the hypothesis that long-term participation in surfing would improve the ability to control force, and the difference between the SURF and CONT groups were seen in isometric contractions. It was interesting to see that greater differences between the two groups were found at the higher force level (25% of MVC). Whether or not this was related to specific adaptations to the force level that was normally used in surfing requires further study.

It has been speculated that at least four factors in motor control would affect muscle steadiness (Laidlaw et al. 2000). These include the average force produced by motor units (Galganski et al. 1993), the pattern of coactivation by the agonist and antagonist muscles

(Enoka et al. 1999), the amount of motor unit synchronization (Semmler et al. 2000), and the motor unit discharge rate variability (Kornatz et al. 2005; Manini et al. 2005). The predominant physiological mechanism to physical exercise-induced steadiness improvements has been found to be the reduction in motor unit discharge variability (Manini et al. 2005). The mediating mechanisms that may reduce discharge rate variability include improvements in transmission efficacy over corticospinal pathways (descending motor output) or increased sensory feedback. It is also possible that the pattern of coactivation of the agonist and antagonist muscles are a major physiological mechanism to physical exercise-induced steadiness improvements. It has been reported that coactivation of the antagonist muscles during knee extension led to increased muscle force fluctuations (Enoka et al. 1999). It would be interesting in future studies to examine whether long-term recreational surfing lowers coactivation of the antagonist muscles during the knee and ankle joint movement, therefore improving steadiness.

The surfers were expected to have superior ability in control of posture because of the specific adaptations to surfing exercise. A number of factors may influence one's ability in posture control, such as vestibular function, visual feedback, proprioception and reaction time (Subasi et al. 2008; Burdet & Rougier 2007). The present study aimed to examine some of these factors, including JPS that reflects proprioceptive function; and body sway in standing position with eyes open or closed and on hard or soft surfaces, that would reflect the influence of visual and proprioceptive inputs.

Even though many studies have shown that taking part in regular physical exercise may slow down or even reverse the age-related decline in neuromuscular function, only a few have investigated the effects of exercise on proprioception in older people, particularly the effects of different types of exercise interventions. One study (Xu et al. 2004) found that long-term participation in Tai Chi not only resulted in better ankle and knee joint proprioception than in sedentary controls, but also better ankle joint proprioception than regular swimmers and runners. The results of the present investigation further support these findings. When riding waves, one is shuffling up or down along the surfboard, or even side to side (mediolateral) with knee and ankle joint angles being continually adjusted to maintain balance, especially when riding a long board. When executed correctly, the movements of surfboard riding ought to be fluent and precise for the exactness of joint angle, and body position are of utmost importance when performing maneuvers with maximal power and precision. As with Tai Chi, surfing requires an acute awareness of body position and movement (Xu et al. 2004). It was therefore logical to expect that the practice of surfing would have benefits to proprioception. In this study, all the members of the CONT group took part in regular physical activity, including cycling, walking or swimming. However, surfing appears to cause unique adaptations that result in better performance in some of the postural control tests, particularly when eyes were closed and standing on a soft surface (SOT4). It was predicted that the average displacement from the mean COP would be lower, the average velocity of the COP would be higher, and the range of COP displacement would be lower for the older surfers. It was also thought that the older surfers would demonstrate lower short-term AP and ML diffusion coefficients compared with the non-surfers. However, out of the 12 variables that were tested, under the four different conditions (SOT1, 2, 3 and 4), only two showed a significant difference between the groups. These might be related to the number of participants in this study that limited the statistical power. Nevertheless, the results indicated that the older surfers were able to correct their postural sway more rapidly whilst standing on a soft surface with their eyes open (SOT3, $p = 0.041$) and closed (SOT4, $p = 0.033$). Under these conditions, the demand for proprioceptive feedback of the ankle joint increased significantly. The differences between the two groups indicated that the surfers were faster at reacting to postural sway when sensory feedback was compromised.

Finally, it was found that both the older surfers and the age-matched controls had a mean body mass index of over 25. Previous studies (Lowdon 1983, 1980; Lowdon & Pateman 1980) have looked at the physiological parameters and somatotype of international surfboard riders. These studies reported that elite surfers (both male and female) carried significantly less fat and more muscle mass than the average college male and female. However, male surfers exhibited more body fat than top athletes in most other individual sports as did female surfers. It has been suggested that extreme leanness offers no particular advantage from a performance perspective as the surfers' body weight buoyed while paddling the board, yet excessive body fat may inhibit riding balance and agility (Lowdon 1983).

In summary, this was the first study to examine the impacts of long-term surfing on the selected neuromuscular function of older surfers. It was found that older surfers demonstrated better performance in control of steady muscle contraction and upright posture compared with age-matched and physically active controls. The possible implications of these findings in relation to aging are that long-term surfing benefits participants by maintaining or improving their neuromuscular function, which would ultimately lead to improved quality of life.

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