A Longitudinal Study on the Relationship Between Aerobic Endurance and Lower Body Strength in Italian Sedentary Older Adults

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Abstract

Functional ageing processes are characterised by a loss of performance capabilities for most physiological systems, such as aerobic endurance and lower body strength, which are important for independent living and active ageing. The present study examines the direction of influence between aerobic endurance and lower body strength over time in Italian sedentary older adults. A three-wave longitudinal model was tested using cross-lagged analysis for 202 individuals aged over 65 years (mean = 73.92, SD = 5.84; 140 females). Analysis revealed that aerobic endurance and lower body strength declines over time. In addition, greater aerobic endurance positively affected lower body strength over time; however, the converse was true only during the first period (first 6 months). These findings emphasise the importance of these relationships for the design and implementation of effective physical intervention for the older adults.

Keywords: older adults, longitudinal study, cross lag

Introduction

Epidemiological studies show that the population of older adults is increasing in Western societies (Leon, 2011). Ageing is a primary risk factor for the development and progression of most chronic degenerative diseases, and an ageing population presents major health, social and economic burdens (WHO, 2002). As populations become both older and more sedentary, it becomes critical to identify protective factors for sustaining high levels of physical and psychological functioning in the older adults. Regular physical activity can play an important role in preventive gerontology by maintaining general health and physical efficiency (Garber et al., 2011). Decrease in physical activity is strongly associated with the frequency of chronic diseases in the 20th century (Beswick et al., 2008). In addition, regular physical activity is essential for healthy ageing (Chodzko-Zajko et al., 2009), and many studies report the positive effect of physical activity on the physical (Blinded for review) and cognitive performance of older adults (Colcombe & Kramer, 2003; Blinded for review). One of the biggest challenges faced by healthcare professionals and policy makers is encouraging older people to adopt physically and socially active lifestyles.

In general, ageing reduces performance in most physiological systems, even in the absence of discernible disease (Chodzko-Zajko et al., 2009). This functional decline affects a broad range of tissues and organ systems; this cumulatively impacts the activities of daily living and physical independence (Chodzko-Zajko et al., 2009). The decline in aerobic capacity and skeletal muscle performance are two important aspects of physiological ageing (Menz, Lord, & Fitzpatrick, 2003; Wallerstein et al., 2012). In fact, variations in these aspects are important determinants in the older adults for both functional abilities (Binder et al., 1999; Guralnik et al., 2000) and exercise tolerance (Toth, Gardner, Ades, & Poehlman, 1994). The ability of older people to function independently is largely dependent on the

maintenance of sufficient aerobic capacity and strength to perform daily activities (Chodzko-Zajko et al., 2009).

Reduction in aerobic capacity is the principal cause in older people for decreases in maximum oxygen uptake and in maximum organic performance capacity (Garber et al., 2011). A decline in maximal aerobic exercise capacity of 10% per decade occurs during the adult years, (Hawkins & Wiswell, 2003) and accelerates in later years. This age-associated decline in aerobic capacity is accentuated by co-morbidities that are common in the older adults, such as cardiac, pulmonary and peripheral artery diseases (Olshansky, Hayflick, & Carnes, 2002). Recent longitudinal studies (Fleg et al., 2005; Hollenberg, Yang, Haight, & Tager, 2006; Jackson, Sui, Hebert, Church, & Blair, 2009) have shown declines in the aerobic capacity of 20%–25% per decade in healthy individuals over 70 years in age. Although aerobic capacity decreases with decreased physical activity, similar rates of decline in aerobic capacity are observed in sedentary and highly active older adults (Katzel, Sorkin, & Fleg, 2001). However, the maximum aerobic capacity of extremely active people is substantially higher than that of their age sedentary peers (Fleg et al., 2005). When the energy requirement for an activity exceeds a person's aerobic capacity, the individual can no longer perform that activity. Thus, the ability to maintain a high aerobic capacity is a major determinant of an older adult's functional independence (Fleg & Strait, 2012).

Ageing is accompanied by a progressive loss of muscle mass, which has been associated with both lower muscle-force-production capacity and inability to perform the activities of daily living (Wallerstein et al., 2012; Menz et al., 2003). Cross-sectional data (Hunter, McCarthy, & Bamman, 2004) indicate that strength begins to decline slowly into the fifth decade of life, and subsequently declines more rapidly, at 12%–15% per decade. This decline appears to be greatest in the lower extremities (Aoyagi & Shepard, 1992; Judge, 2003) and is associated with a reduction in the size of muscle fibres and muscle fibre loss (Cadore et al.,

2011) as well as in maximum voluntary neural activation of muscle (Hakkinen, Alen, Kallinen, Newton, & Kraemer, 2000). This additionally results in a substantial impairment of sensorimotor information exchange, resulting in a decreased quality of intermuscular and intramuscular coordination. As a result, functional losses in strength and increasing gait uncertainties are experienced. Correspondingly, risk increases for acute problems arising from falls and injuries and chronic recurrent and degenerative illnesses (Faulkner, Larkin, Claflin, & Brooks, 2007).

Although aerobic endurance and lower body strength decrease with ageing, it is not clear how these aspects are related in older adults populations, i.e. whether aerobic endurance affects lower body strength or vice versa. Several studies report a significant correlation between aerobic endurance, gait velocity and mobility (i.e. Fiser et al., 2010; Rikli & Jones, 2013). Other studies determined relationships between lower body strength, gait velocity and mobility (Hicks et al., 2012; Protas & Tissier, 2009). However, to the best of our knowledge, no studies have investigated the relationship between aerobic endurance and lower body strength in the older adults in a longitudinal prospective. Knowledge about how these two variables influence each other over time can lead to the development of more specific and effective intervention strategies.

To understand the aging process, longitudinal studies provide many advantages relative to cross-sectional studies, as between-person age comparisons cannot provide a basis for disentangling changes due to ageing from stable individual characteristics, average between person trends, or decline effects, for example. In fact, longitudinal research could provide a framework for advancing aging theory and studies (Baltes 1979). Some issues motivate the emphasis for a longitudinal study to understand the ageing process. For example, physical and cognitive change reflects development and involves external influences that interact with both of these processes within individuals (Nilsson et al., 2004). Second, evidence for the

importance of the life span developmental perspective is provided in findings showing that early patterns of development are predictive of later changes (Hayward & Gorman, 2004). In fact, we expect that complex interactive effects are associated with multiple causal influences, with cumulative effects of risk factors, and perhaps with age-specific causal action (Rutter, 1988; Seeman, Singer, Rowe, & McEwen, 2001). Also, inferences regarding change and causal processes may be obscured if aging processes (time) is not taken into account (Vaupel & Yashin, 1985).

The goal of this study was to examine the relationship and determine any reciprocal influences between aerobic endurance and lower body strength in Italian sedentary older adults over time. Sedentary living is defined as a way of living or a lifestyle that requires minimal physical activity and that encourages inactivity through limited choices, disincentives, and/or structural or financial barriers (Chodzko-Zajko et al., 2009). However, it is well known that promoting the participation of sedentary elderly people in physical trainings implemented in places such as traditional gyms with specific facilities can be problematic, particularly in Italy (National Institute of Statistics, 2010). For this reason, it is important to adapt the physical training to the specific characteristic of the interest population.

The relationship was investigated using a longitudinal methodology and analysed by longitudinal cross-lagged modelling. Longitudinal modelling has three primary advantages that make its use particularly desirable (Menard, 2002; Burkholder & Harlow, 2003): First, it allows researchers to discover patterns of covariation among variables by observe their behaviour over time; Second, researchers can test models that include data collected at multiple time points and thus allow testing both directions of potential causality that are more difficult to test in a cross-sectional design. Finally, longitudinal data analysis provides estimates on relative construct stability by analysing the relation between subsequent measurements of the same variable. There are some studies of how cross-lagged analysis was

used to determine temporal relations among measures for example about: perceptual processing speed and intelligence (Deary, 1995,); physical and mental health (Hays, Marshall,Wang, & Sherbourne, 1994); reading and mathematics skills development (Onatsu-Arvilommi & Nurmi, 2000); emotional distress and cigarette smoking in adolescents (Orlando, Ellickson, & Jinnett, 2001). However, there are no studies that could be found that use the cross-lagged analysis to examine the relationship and determine any reciprocal influences between aerobic endurance and lower body strength in a longitudinal prospective.

In a cross-lagged design, information for each variable assessed at each time point is analysed. The figure 1 lists the four models that we analysed. The first model tested the stability of aerobic endurance and lower body strength at different times, without cross-lagged paths. The second model tested the effect of aerobic endurance on lower body strength over time. The third model tested the effects of lower body strength on aerobic endurance. The fourth model tested the reciprocal effects of aerobic endurance and lower body strength over time with a cross-lagged structural equation model.

These models were designed to answer the following questions:

1) How do aerobic endurance and lower body strength change with time and does a relationship exists between the two aspects?

2) What is the direction of influence between the two factors in Italian sedentary older adults over time?

As already suggested in the literature (Weineck, 2007), we expected that aerobic endurance is associated with lower body strength. Thus, we expected to find that sedentary older adults with good aerobic endurance are more likely to have better lower body strength than older adults with lower level of both variables and vice versa.

We expected that this study would facilitate the design of specific training that could be used to address one or more physical abilities to improve the physical status of the older

adults. To design an effective trial and training, it is necessary to understand how physical ability, as determined by aerobic endurance and lower body strength, of the older adults develop in a longitudinal perspective. This is particularly relevant for sedentary older adults who are not used to even moderate physical activity. Also, despite the relevance of this topic, we found no studies that investigated the relation between aerobic endurance and lower body strength in sedentary older adults over time.

Methods

A longitudinal research design was used in this study with three waves. All participants were tested three times in 1 year (6 months between tests) at Baseline, Time1 (T1) and Time2 (T2). This research is a part of the larger longitudinal 'Act on Ageing' project conducted in the Piedmont region, Italy.

Participants

Participant were 202 sedentary individuals over 65 years of age (mean = 73.92, SD = 5.84; 140 females) who live independently in the Piedmont region, Italy. Descriptive characteristics of participants are presented in Table 1. Participants were classified as having a sedentary lifestyle if they did not report participating in regular moderate or vigorous physical activity for the last 5 years. The eligibility criteria for participation were age over 65 years, ability to walk without assistance and a Mini Mental State Examination (MMSE) score higher than 26 (this score indicates the absence of cognitive impairment). Exclusion criteria were myocardial infarction and/or coronary artery bypass grafting valvular surgery within 1 year, uncontrolled diabetes or hypertension, orthopaedic impairment or upper or lower extremity fracture within past 6 months or participation in another study, even if the study was of a different kind. These criteria were selected to exclude impairments that could

negatively affect the test and to guarantee the health and safety of participants. Lists of older adults obtained from the Health Office of the Piedmont region and general practitioners were used to contact potential participants by telephone. After recruitment, individuals were required to obtain written approval from their primary-care physician to be eligible for the study. All participants were retired at the time of the study and were advised to maintain their normal daily routines. The Ethical Committee of the University of Torino approved the study, and all participants were informed that participation in the study was voluntary and confidential. All participants gave their written informed consent in accordance with Italian law.

Measures

Demographic data (age, gender, marital status and level of education) were self-reported. Each participant was assessed at the baseline time point for height, weight, and cognitive function (Folstein, Folstein, & McHugh, 1975).

We extracted the aerobic endurance and lower body strength tests from the Senior Fitness Test battery (SFT) (Rikli & Jones, 2013a). The SFT measures the underlying physical parameters associated with functional ability, and reflect usual age-related changes in physical performance. Also, the SFT is able to detect physical changes due to ageing process or training. The SFT meets scientific standards for validity and reliability (Rikli and Jones, 1999; Rikli & Jones, 2013a, 2013b). Moreover, these tests are easy, safe and quick to administer. As well, SFT test are feasible for use in common clinical, community and home settings meeting the concept of ecological perspective of research and health promotion (McLaren & Hawe, 2005).

Aerobic endurance and lower body strength tests were performed in the morning of the same day, with an hour of rest between the tests.

Aerobic endurance, defined as the capacity to perform large-muscle activity over a defined period of time (Weineck, 2007), was assessed with the 6-min walking test (Rikli & Jones, 2013a), i.e. the maximum distance that a person can walk in 6 min. Test- retest reliability of the measuring was .94 (Rikli & Jones, 2013b). A walkway was marked with cones to indicate the area of the test. The participants were instructed to walk as far as possible in 6 minutes, without running along a 60 metres walkway. The distance covered by each participant was measured in metres. Scores can be obtained for individuals of all ability levels—from borderline frail individuals, who can walk only a few feet in 6 min, to the highly fit, who can cover several hundred metres in the same time.

Lower body strength was assessed using the 30-s chair–stand test (Jones, Rikli, & Beam, 1999; Rikli & Jones, 2013a). Test- retest reliability was .89 (Rikli & Jones, 2013b). In this context, strength is the ability to generate force to overcome inertia or a load (Zatsiorsky, 2008). Lower body strength is an important aspect of fitness in older adults because of its role in daily activity. This test is effective for detecting normal age-related decline in strength (Bohannon, Shove, Barreca, Masters, & Sigouin, 2007) and the effect of physical training in older adults (Carvalho, Marques, & Mota, 2004). The test involves counting the number of times a person with their arms folded over their chest can come to a full stand from a seated position within 30 s. The armless chair was placed against a wall for support and safety and was adapted to improve or reduce the angle of 90° at the hips and knees (Rikli & Jones, 2013b).

Table 1

Statistical Analyses

We initially determined whether there was a statistical difference in the results obtained from the three waves by repeated measures analyses of variance (ANOVA). Also, in order to highlight the change over time, we computed the percentage of change by dividing the average gain by the baseline mean of our measures (Thomas, Nelson, Silverman, & Silverman, 2011).

To test the relations between aerobic endurance and lower body strength, we used a cross-lagged analysis using MPlus version 6 with a maximum likelihood method, which is recommended for small sample sizes (Olsson, Foss, Troye, & Howell, 2000). For missing data, we used full information maximum likelihood approach, which performs better than list-wise and pair-wise deletion methods (Schafer & Graham, 2002).

The models presented in Figure 1 were tested. Concerning the fit indices, we examined the chi-square, comparative fit index (CFI) and standardised root-mean-square residual (SRMR). A model is considered to fit well when the model chi-square is not significant. In addition, a CFI value of 0.95 or higher suggests good model fit (Hu & Bentler, 1998). The Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR) values of 0.08 or lower are expected for an adequate model fit (Brown & Cudeck, 1993; Hu & Bentler, 1998). Nested models were further compared using chi-square difference test.

Results

Aerobic endurance

As seen in Table 2, the means of aerobic endurance for the three waves are as follows: Baseline, mean = 416.7 meters, SD = 79.9; T1, mean = 392.7 meters, SD = 110.4; T2, mean = 377 meters, SD = 112.24. Repeated measure ANOVA suggested that aerobic endurance decrease significantly from Baseline to T1 and from T1 to T2 [F (1, 161) = 22.88, p <

0.0001]. Moreover, the results showed a relative decrease of 9.5% over time of aerobic endurance.

Lower body strength

Lower body strength also changed over time (Table 2). The means of lower body strength for the three waves are as follows: Baseline, mean = 10 times, SD = 3; T1, mean = 9 times, SD = 2; T2, mean = 8 times, SD = 2. Lower body strength decreased significantly from Baseline to T1 and from T1 to T2 [F (1, 161) = 60.36, $p < 0.0001$]. Also for lower body strength the results showed a relative decrease over time of 20%.

Cross-lagged analysis between aerobic endurance and lower body strength

First, we tested the four models presented in Figure 1. As seen from Table 3, only the reciprocal-effects model achieved a decent fit. The lower-body-strength-driven model had a significantly better fit compared to the stability model, and the aerobic-endurance-driven model revealed a marginally significantly better fit than the stability model. In addition, the reciprocal effects model fitted the data significantly better than the lower-body-strength-driven and aerobic-endurance-driven models. In conclusion, the findings suggest that the reciprocal-effects model represent the relationship between lower body strength and aerobic endurance over time relatively better than the alternative models. Figure 2 shows the structural part of the model (for the measurement part see Table 3). Overall, the relationship of both aerobic endurance and lower body strength were relatively stable from Baseline to T1 ($\beta = 0.54$, and $\beta = 0.70$, $p < 0.0001$, respectively) and T1 to T2 ($\beta = 0.94$, and $\beta = 0.62$, $p < 0.001$, respectively). For cross-lagged paths, there were three statistically significant effects. Aerobic endurance at Baseline positively predicted lower body strength at T1 ($\beta = 0.21$, $p < 0.0001$), suggesting that higher aerobic endurance at Baseline was associated with higher levels of lower body strength 6 months later. Furthermore, aerobic endurance at T1

significantly predicted lower body strength at T2 ($\beta = 0.37$, $p < 0.0001$), suggesting that higher aerobic endurance at T1 was associated with higher levels of lower body strength 6 months later. Regarding the effect of lower body strength, lower limb strength at Baseline significantly predicted aerobic endurance at T1 ($\beta = 0.17$, $p < 0.0001$), suggesting that higher lower body strength at Baseline was associated with higher aerobic endurance at T1, 6 months later. However, lower body strength at T1 did not significantly predict aerobic endurance at T2 ($\beta = 0.04$). In sum, the effect of aerobic endurance on lower limb strength was constant over time. In contrast, the effect of lower body strength was significant only for the first period.

Discussion

The present study aimed to examine the relationship between aerobic endurance and lower body strength in sedentary older adults. We tested four alternative models aimed at assessing the association between aerobic endurance and lower body strength. We found that the best way to represent this relationship was to have bidirectional links between aerobic endurance and lower body strength. The reciprocal-effects model best represented the complex relationship between aerobic endurance and lower body strength. Aerobic endurance and lower body strength affect each other in sedentary older adults.

Understanding the reciprocal associations between aerobic endurance and lower body strength is important for designing physical training specifically for the older adults, as well as for designing studies investigating physical intervention for the older adults.

Our longitudinal data show that, aerobic endurance and lower body strength are affected by time. Our findings are supported by studies from Chodzko-Zajko and colleagues (2009) and Hollman (2007), which indicated these aspects of physical functioning decrease over time. Furthermore, our results in accordance to those reported in previous longitudinal studies

(Hollenberg, Yang, Haight, & Tager, 2006; Hughes et al., 2001), confirm that there is a decline of aerobic endurance and lower body strength across the age span in healthy persons, and that this decline is related to life style habits. It is clear that a sedentary lifestyle, especially for the older adults, can be highly debilitating, resulting in the loss of self-sufficiency and health. In contrast, physical activity can be a protective factor for good physical and psychological conditions, even for individuals with frail physical or psychosocial states (Daley & Spinks, 2000). In general, physical functioning decreases with age (Shea, Park, & Braden, 2006; Voelck-er-Rehage & Alberts, 2005), and specific parameters, such as strength, endurance and balance, are predictors of dependence in the activities of daily living (Guralnik et al., 2000). The capacity of older adults to maintain muscle strength and power is an essential factor in maintaining independence (Rantanen, 2003). A threshold level of muscle strength is required to perform the basic activities of daily living and to participate in activities designed to maintain aerobic endurance.

Second, our model showed the relationship between aerobic endurance and lower body strength over time in sedentary older adults (Table 2) is very important because it shows how these fundamental elements of physical functioning influenced each other. As can be seen from the model, the level of aerobic endurance significantly affected lower body strength over time. In addition, lower body strength initially affected aerobic endurance significantly. In fact, we found that older adults who had high level of aerobic endurance also had a high level of lower limb strength, and this relationship was steady over time. Furthermore, the older adults who had a good level of aerobic endurance at the Baseline were more likely to maintain a good level of lower limb strength after 6 and 12 months. Aerobic–endurance activity is an effective form of exercise for increasing muscle strength and power in older individuals (Caserotti, Aagaard, & Puggaard, 2008; Latham, Bennett, Stretton, & Anderson, 2004; Macaluso & De Vito, 2004; Sayers, 2007). Specificity of training suggests that

endurance training has little effect on the development of muscle strength or power in healthy individuals (Nader, 2006). Moreover, the decreased physical functioning of the older adults allows greater initial gains in muscle function as a result of aerobic–endurance training because of a large adaptation potential (Fleck & Kraemer, 2004). Aerobic endurance training, e.g. cycle-ergometry or walking, is sufficient to increase lower body strength and power in older individuals as reported by a study of Lovell and colleagues (2010).

The relation between aerobic endurance and lower body strength has important practical consequences, because during the design of physical activity training for older adults is crucial to know how the physical variables influence each other. To design an effective training for the older adults, it is first necessary to know how aerobic endurance and lower body strength of the older adults develop over time. Our study suggests that combined training focusing on both aspects might be most effective than either form of training alone in counteracting the detrimental effects of a sedentary lifestyle on the health and physical functioning. However, training that focuses only on one of these aspects, aerobic endurance or lower limb strength, could indirectly result in improvement of the other

The small sample size of our study makes it difficult to generalise our results to larger contexts. For example, our sample size did not allow us to determine the relationship for subgroups based on age or gender. Furthermore, the present study examines only two time periods. Thus, a longer trial with more time points and a larger sample size might be more informative. Finally, it would be interesting to compare this relationship in groups of sedentary as well as physically active older adults.

Despite these limitations, our study highlights that the relation between aerobic endurance and lower body strength might not be represented properly without considering the reciprocal effects. Moreover, it extends the investigation of this relationship for sedentary older adults. These findings might be able to clarify the integrative mutual action over time of aerobic

endurance and lower limb strength in older adults. Indeed, setting realistic goals and designing activity protocols that take scientific evidence into consideration might lead to constructing and implementing interventions that are useful for improving and promoting active ageing for the Italian sedentary older adults.

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Table 1: Socio-demographic characteristics of study participants

		N	**%**
Gender (*N*)	Women	140	69
	Men	62	31
Level of education (*N*)	Low	134	66
	High	68	34
Family condition	Never married	19	9
	Married	102	51
	Widow/Widower	56	28
	Divorced	25	12
Past job	Manual labour	156	77
	Non–manual labour	46	23
Age		M = 73.92	SD = 5.84
BMI score		M = 29.6	SD = 5.3
MMSE (score 0–30)		M = 28.8	SD = 1.5

M = Mean; SD = standard deviation

Table 2: Intercorrelations among, and means (M) and standard deviations (SD) of aerobic endurance and lower limb strength variables

	1	**2**	**3**	**4**	**5**	**6**
1. Aerobic Endurance T1	--					
2. Lower body strength T1	.45***	--				
3. Aerobic Endurance T2	.65***	.48***	--			
4. Lower body strength T2	.50***	.76***	.60***	--		
5. Aerobic Endurance T3	.65***	.50***	.97***	.63***	--	
6. Lower body strength T3	.53***	.69***	.76***	.84***	.79***	--
M	416.7	10	392.7	9	377	8
SD	79.9	3	110.4	2	112.2	2

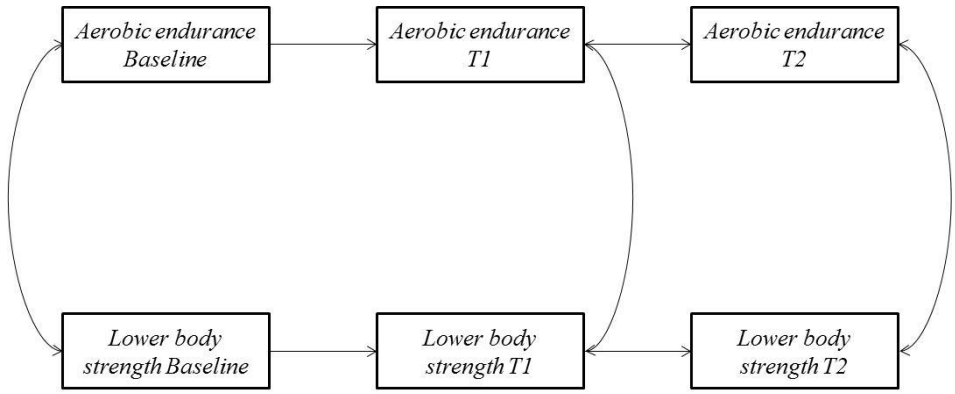
*$p < .05$; **$p < .01$; ***$p < .001$

Table 3: Model fit for competitive models

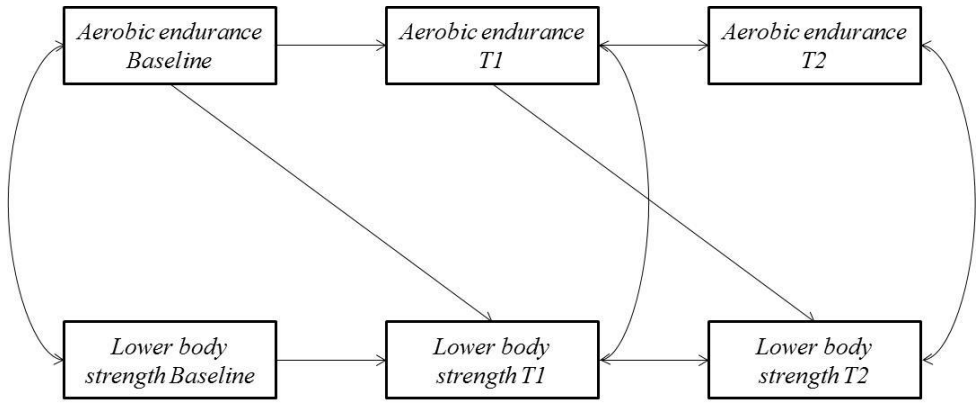
Model	χ^2	df	*p*	CFI	RMSEA	SRMR	Model Comparison	$\Delta\chi^2$	df	*p*
A) Stability model	98.343	8	.0001	.908	.236	.151	-			
B) Aerobic endurance driven	18.343	6	.0054	.987	.101	.067	A	80	2	.0001
C) Lower body strength driven	74.398	6	.0001	.931	.238	.099	A	23.945	2	.0001
D) Reciprocal effects model	5.788	4	.2156	.998	.047	.009	B-C	12.555/68.61	2	0.002/0001

Figure 1: Alternative models for the relationship between aerobic endurance and lower body strength

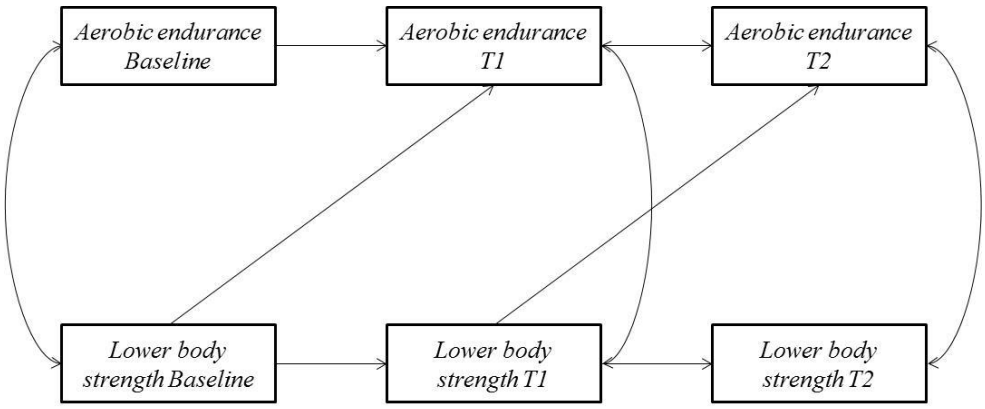
a) Stability model



b) Aerobic endurance driven model



c) Lower body strength driven model



d) Reciprocal effects model

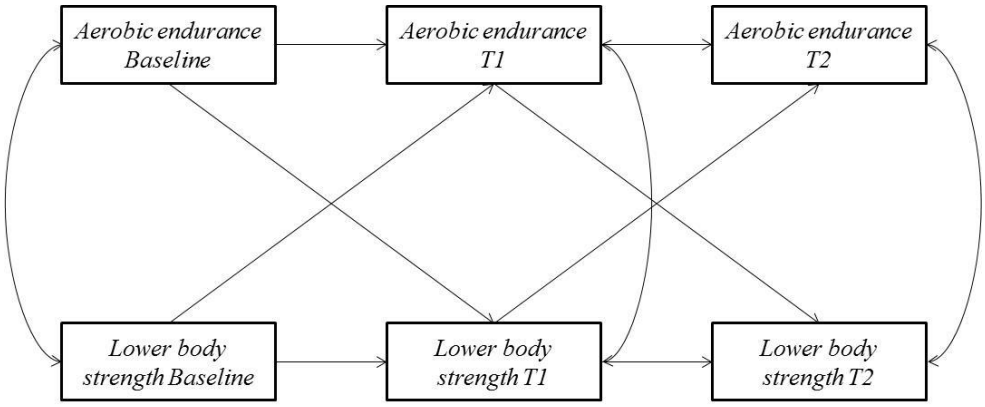
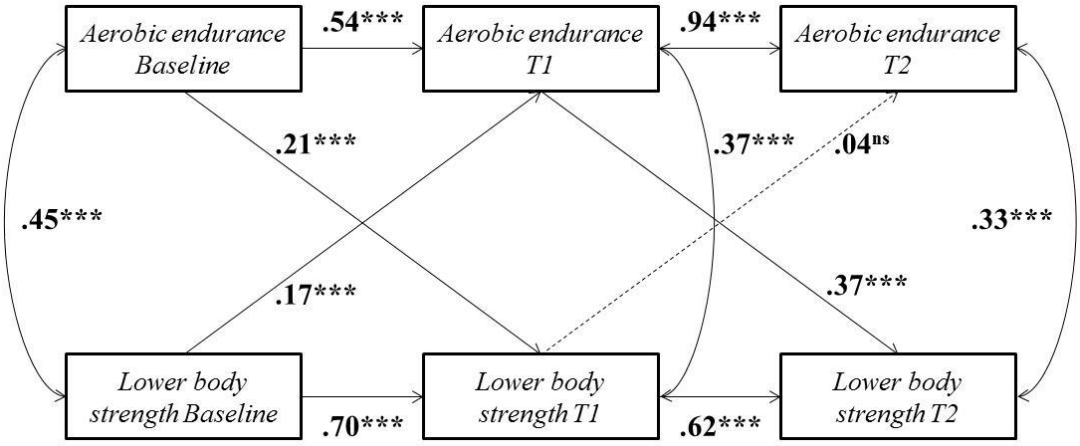


Figure 2: Structural model of the reciprocal effects between aerobic endurance and lower body strength


Aerobic endurance Baseline
Aerobic endurance T1
Aerobic endurance T2
Lower body strength Baseline
Lower body strength T1
Lower body strength T2
.54***
.94***
.21***
.37***
.04ns
.45***
.33***
.17***
.37***
.70***
.62***

*p < .05; ** p < .01; *** p < .001