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Flexibility is associated with motor competence in schoolchildren

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Available data on the associations between motor competence (MC) and flexibility are limited and result inconclusive. This study aims to examine the relationship between flexibility and MC in children. The sample comprised 596 Portuguese children (47.1% girls) aged 9.7 ± 0.6 years. Motor competence was evaluated with the body coordination test, Körperkoordination Test für Kinder. Cardiorespiratory fitness (20-m shuttle run), muscular strength (curl-up and push-up tests), and flexibility (back-saver sit and reach and trunk-lift tests) were evaluated using the Fitnessgram Test Battery. *Z*-scores by age and gender for the physical fitness tests were constructed. Analysis of variance and regression analysis were performed. Participants in the healthy zone groups of both flexibility tests exhibited significantly better scores of MC than the participants under the healthy zone ($P < 0.001$). Back-saver sit and reach and trunk-lift *Z*-scores, either individually or as a sum, were significant predictors of MC ($P < 0.05$ for all) after adjustments for the other physical fitness components, age, body mass index, and socioeconomic status, in both genders. Our findings highlight the importance of promoting and developing flexibility, as well as the other health-related physical fitness components in schoolchildren to reach adequate levels of MC.

There is evidence showing that children are currently less active, are less fit, and exhibit lower levels of motor competence (MC) (Centers for Disease Control and Prevention, 2000; Roth et al., 2010). Therefore, adequate levels of physical activity, physical fitness, and MC are desirable behaviors and outcomes that should be encouraged and developed from an early age to promote and maintain health and well-being (Lubans et al., 2010). Stodden et al. (2008) proposed a developmental recursive and reciprocal model explaining the relationships between MC, health-related physical fitness, perceived MC, physical activity, and risk of obesity. Regarding the relationship between MC and health-related physical fitness in this model, Stodden et al. (2008) suggest that this association will strengthen over time and that fitness can also act as a mediator between the association of MC and physical activity.

Poor MC has become a growing issue of interest because motor proficiency levels track from childhood into adolescence (Branta et al., 1984) and because MC is related to health outcomes such as adiposity (Lopes et al., 2012b), self-esteem (Ulrich, 1987), perceived physical competence (Lubans et al., 2010), cardiorespiratory fitness (Rodrigues et al., 2016), physical activity (Lopes et al., 2011), sedentary behavior (Lopes et al., 2012a), and academic achievement (Lopes et al., 2013).

Traditionally health-related physical fitness comprises body composition, cardiorespiratory fitness, muscular fitness, and flexibility (ACSM, 2000). Some studies have reported positive associations between MC and physical fitness in children and adolescents (Hands et al., 2009; Vandendriessche et al., 2011; Gisladottir et al., 2014) particularly for cardiorespiratory and muscular fitness (Lubans et al., 2010; Cattuzzo et al., 2016). However, available data on the associations between MC and flexibility are limited and result inconclusive (Ruiz et al., 2009; Robinson et al., 2015; Cattuzzo et al., 2016). Recently, a call has been made for further research on this subject (Malina, 2014; Robinson et al., 2015; Cattuzzo et al., 2016). Indeed, the few studies looking at the associations between MC and flexibility were conducted with small samples (Gisladottir et al., 2014), with wide age ranges (Schott et al., 2007), relied on only a single measure of flexibility (Hands et al., 2009) and presented contradictory results (Cattuzzo et al., 2016).

The benefits of flexibility include a better range of motion and function, prevention and reduction of postexercise soreness, reduced injury risk, lower risk of low back pain, neck tension, improved athletic performance, and improved coordination (Peck et al., 2014; Behm et al., 2016). The rationale for examining the relationship between flexibility and MC is that the range of motion is an important determinant of MC as it allows performing a movement with appropriate amplitude (Gandevia, 2010; De Ste Croix & Korff, 2013).

The aim of this study was to examine the relationships between flexibility and MC in a sample of Portuguese children. A secondary aim was to investigate the associations between body composition, cardiorespiratory fitness, muscular fitness, and MC.

Materials and methods

Study design and sampling

Data were derived from the Bracara Study, which aimed to evaluate the relationships between gross MC, physical activity, physical fitness, body composition, academic achievement, and health behaviors among elementary school children. The Bracara Study was conducted in a middle size city located in the north of Portugal during the 2009/2010 academic year. Study design, sampling, and measures are reported elsewhere (Lopes et al., 2012a).

Participants

All 21 public elementary schools in the city that was classified as urban (according to the Municipal Administration Registry) were identified and invited to participate in the study, corresponding to 846 children enrolled in the fourth grade; two schools decided not to take part in this study, corresponding to 90 children; six schools could not be assessed within the time frame to take part in this study, corresponding to 130 children; 30 children who failed the inclusion criteria (having a mental and/or physical disability or a health condition that did not allow them to participate in physical education classes) or had missing information on the variables of interest were excluded from the analyses. Therefore, the study included 13 urban public elementary schools, and 596 participants (281 girls) aged 9–12 years old.

The schools' directors and children's parents/guardians received verbal and written descriptions of the study and provided written informed consent. The protocol and procedures employed followed the Helsinki Declaration for Investigation in Human Subjects and were approved by the Portuguese Ministry of Education and by the University of Minho Ethics Committee.

All data were collected during regularly scheduled physical education classes by two assessors. Assessors were physical education teachers and received specific training and had already participated in previous anthropometry, MC, and aerobic fitness data collection. The assessors were helped by the physical education teachers of the schools enrolled in this study. The data were collected at the same time, and the agreement between these two assessors was tested in a previous data collection showing good results (data not published).

Measures

Motor competence

Motor competence was evaluated with the body coordination test, Körperkoordination Test für Kinder (KTK; Kiphard & Schiling, 1974). The KTK battery has four items: balance; jumping laterally; hopping on one leg over an obstacle; and shifting platforms. The tests were applied following the original protocols described elsewhere (Lopes et al., 2012a,b).

Physical fitness

Health-related components of physical fitness were evaluated using the Fitnessgram Test Battery, version 8.0. The FITNESSGRAM®, Dallas, TX, USA is included in the physical education curriculum, and the five tests recommended in the Portuguese National Program (curl-up, push-up, trunk lift, shuttle run, and the modified back-saver sit and reach) were used in this study. All tests were conducted according to the Fitnessgram measurement procedures (Welk & Meredith, 2008). A flexibility score (sum of the *z*-scores of best modified back-saver sit and reach and trunk lift) was computed by summing the *z*-scores for each of the flexibility test. In addition, using the two measures of flexibility (best modified back-saver sit and reach and trunk lift), participants were classified in two categories (Healthy Zone or under the Healthy Zone) according to the Fitnessgram categorizations for sex and age.

Anthropometry

Weight was measured to the nearest 0.1 kg using a regularly calibrated digital scale (Tanita TBF-300, Tokyo, Japan) with the children in light clothing and without shoes. Body fat percentage was estimated by a bioelectric impedance digital scale (Tanita TBF-300). Height was measured to the nearest millimeter in bare or stocking feet with the children standing upright against a stadiometer (Seca 220, Hamburg, Germany). Body mass index [body mass (kg)/height (m^2)] and waist-to-height ratio [waist (cm)/height (cm)] were calculated.

Sociodemographics

Each child's date of birth, gender, and socioeconomic status was extracted from the schools' administrative record systems. The socioeconomic status records used by the Portuguese Ministry of Education are based on annual family income: children may be eligible for benefit A, eligible for benefit B, or not eligible. These categories were used as a proxy measurement of family socioeconomic status. According to the Portuguese Ministry of Education, those eligible for benefit A receive books, school supplies, and meals for free; those eligible for benefit B receive 50% of the books required and a 50% discount on meals.

Statistical analysis

Descriptive data are presented as mean and standard deviations. Two-sided Student's *t*-tests were used to assess gender differences for continuous variables. To analyze the relationship between flexibility and MC, linear regression models were fitted to assess regression coefficients and 95% CI predicting MC (KTK motor quotient), after adjustments for cardiorespiratory fitness, push-up, curl-up, age, body mass index, and socioeconomic status, in both genders.

Data were analyzed using SPSS Statistics v.22 (SPSS, Inc. IBM Company, Chicago, Illinois, USA). A P value under 0.05 denoted statistical significance.

Results

Descriptive characteristics of the participants are shown in Table 1. Boys performed significantly better than girls in the cardiorespiratory fitness, MC, and push-up tests, while girls performed significantly better than boys for the modified back-saver sit and reach and trunk lift tests ($P < 0.001$ for all). A total of 61.6% of the participants (64.4% girls and 59% boys) were classified as belonging to the healthy zone or above on the back-saver sit and reach test according to the Fitnessgram criteria, corresponding figures for the trunk lift test were 75.9% (81.5% girls and 70.8% boys).

As illustrated in Fig. 1 and Fig. 2 participants in the healthy zone groups of the back-saver sit and reach and trunk lift tests exhibited significantly better scores of MC than the participants under the healthy zone ($P < 0.001$ for both).

As shown in Tables 2–4, Z-score for the back-saver sit and reach and the Z-score for trunk lift, either individually or as a sum, were significant predictors of MC ($P < 0.05$ for all) after adjustments for cardiorespiratory fitness, push-up, curl-up, age, body mass index, and socioeconomic status, in both genders. Cardiorespiratory fitness, push-up, and curl-up were also positively associated with MC, and body mass index was negatively associated with MC ($P < 0.05$ for all). When the Z-scores of the flexibility tests, either individuals or as a sum, were tested to predict each of the four subtests of MC, we observed positive associations between flexibility and shifting platforms in both genders ($P < 0.005$); the sum of the Z-scores of flexibility was also positively associated with balance and jumping laterally in both genders ($P < 0.005$); Z-score for the trunk lift was a significant predictor of jumping laterally in both genders, and of balance and hopping on one leg over an obstacle in boys ($P < 0.005$); Z-score for the back-saver sit and reach was positively associated with balance and jumping laterally only in boys ($P < 0.005$ for both) (see Supporting information).

Discussion

The main finding from this study suggests a positive association between flexibility and MC in children.

Although the few existent studies on this subject have analyzed this relationship considering MC as a predictor of flexibility, there is no biomechanical and/or physiological evidence or rationale indicating that MC may predict flexibility. In fact, according to Stodden et al.'s model, the relation between physical fitness and MC is reciprocal, and therefore, flexibility could be seen as a predictor or as an outcome of MC. PA promotes motor skill competence and physical fitness; and reciprocally, physically fit children are more likely to engage in physical activities and therefore develop their MC (Stodden et al., 2008).

From a biomechanical or/and physiological point of view, this reciprocal relationship between physical fitness and MC may seem sensible for some physical fitness components, such as muscular strength and cardiorespiratory fitness (Lubans et al., 2010; Cattuzzo et al., 2016). However, this may not be the case for flexibility. Indeed, flexibility may play an important role in range of motion and therefore in movement coordination. Range of motion depends on joint structure, soft-tissue mechanical proprieties, in particular the muscle-tendon unit compliance (degree of tissue deformation) and elasticity (ability to restore the tissue original shape after deformation).

Table 1. Participants' characteristics

	All (n = 596)	Girls (n = 281)	Boys (n = 315)	P*
Age (years)	9.7 ± 0.6	9.7 ± 0.5	9.7 ± 0.6	0.552
Cardiorespiratory fitness (no. of laps)	19.9 ± 11.3	16.6 ± 8.0	22.8 ± 13.0	< 0.001
Balance (motor quotient)	87.5 ± 13.8	88.7 ± 13.6	86.3 ± 13.9	0.032
Jumping laterally (motor quotient)	94.7 ± 17.8	87.3 ± 17.5	101.3 ± 15.1	< 0.001
Hopping on one leg over an obstacle (motor quotient)	88.5 ± 13.5	83.8 ± 13.4	92.6 ± 12.3	< 0.001
Shifting platforms	85.7 ± 12.9	84.2 ± 12.9	87.1 ± 12.9	0.006
Motor competence (motor quotient)	85.7 ± 14.4	81.7 ± 14.5	89.3 ± 13.4	< 0.001
Back-saver sit and reach† (cm)	22.62 ± 5.92	24.30 ± 5.17	21.12 ± 6.13	< 0.001
Trunk lift (cm)	25.18 ± 4.46	26.04 ± 4.04	24.41 ± 4.68	< 0.001
Body mass index (kg/m^2)	18.6 ± 3.3	18.6 ± 3.3	18.6 ± 3.3	< 0.001
Push-up (n)	4.37 ± 5.19	3.43 ± 3.9	5.21 ± 5.98	< 0.001
Curl-up (n)	6.74 ± 7.72	6.42 ± 7.45	7.03 ± 7.86	0.339

*t-test compared gender differences.

†Best of modified back-saver sit and reach.

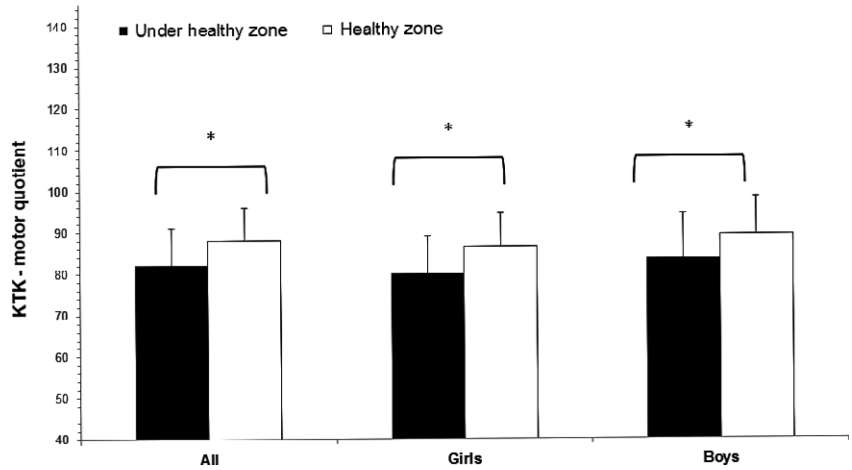

Fig. 1. Motor competence scores for the participants in the healthy zone and under the healthy zone groups of the trunk-lift test. *Significant differences between groups ($P < 0.001$).

Fig. 2. Motor competence scores for the participants in the healthy zone and under the healthy zone groups of the modified back-saver sit and reach test. *Significant differences between groups ($P < 0.001$).

Table 2. Regression coefficients and 95% confidence intervals from linear regression model predicting motor competence (*z*-score of the back-saver sit and reach)

	Motor competence					
	Adjusted model for girls			Adjusted model for boys		
	β	95% CI	*P*	β	95% CI	*P*
z-score sit and reach	1.887	0.463–3.290	0.009	1.706	0.507–2.905	0.005
z-score cardiorespiratory fitness	3.500	1.913–5.087	< 0.001	3.339	1.911 to −4.768	< 0.001
z-score curl-up	2.739	1.240–4.237	< 0.001	2.110	0.804–3.416	0.002
z-score push-up	2.636	1.037–4.235	0.001	2.788	1.413–4.163	< 0.001
Body mass index	−0.903	−1.355 to −0.451	< 0.001	−0.852	−1245 to −0.458	< 0.001
Socioeconomic status	1.237	−0.456 to −2.929	0.151	0.165	−1.372 to 1.701	0.833
Age	−1.884	−4.444 to 0.675	0.148	−1.402	−3.198 to 0.394	0.126

Elasticity is critical for muscle performance, as elastic structures can have a profound effect on muscle force, power, and work. The potential contribution of these elements can be accessed from their stiffness (Roberts, 2016) (i.e., the ability of the tissue to resist to deformation). This muscle-tendon mechanical property influences movement coordination by providing afferent feedback from receptors allocated in muscles and tendons about muscle lengths and their rate of range, which are important for detection of

Table 3. Regression coefficients and 95% confidence intervals from linear regression model predicting motor competence (*Z*-score of the trunk lift)

	Motor competence					
	Adjusted model for girls			Adjusted model for boys		
	β	95% CI	*P*	β	95% CI	*P*
z-score trunk lift	3.252	1.730–4.774	< 0.001	1.924	0.785–3.063	0.001
z-score cardiorespiratory fitness	3.335	1.775–4.895	< 0.001	3.237	1.812–4.662	< 0.001
z-score curl-up	2.698	1.228–4.168	< 0.001	1.949	0.645–3.253	0.004
z-score push-up	2.625	1.060–4.190	0.001	2.917	1.547–4.287	< 0.001
Body mass index	−0.983	−1.428 to −0.537	< 0.001	−0.951	−1.345 to −0.556	< 0.001
Socioeconomic status	1.334	−0.323–2.992	0.114	0.430	−1.089–1.949	0.578
Age	−2.507	−1.428 to −0.015	0.049	−1.463	−3.249–0.324	0.108

Table 4. Regression coefficients and 95% confidence intervals from linear regression model predicting motor competence (sum of the z-scores of best sit and reach and trunk lift)

	Motor competence					
	Adjusted model for girls			Adjusted model for boys		
	β	95% CI	*P*	β	95% CI	*P*
Sum of the *z*-scores of best back-saver sit and reach and trunk lift	1.961	1.054–2.867	< 0.001	1.452	0.721–2.182	< 0.001
z-score cardiorespiratory fitness	3.308	1.748–4.868	< 0.001	3.162	1.744–4.580	< 0.001
z-score curl-up	2.669	1.199–4.138	< 0.001	1.967	0.674–3.261	0.003
z-score push-up	2.494	0.925–4.063	0.002	2.885	1.525–4.245	< 0.001
Body mass index	−0.954	−1.398 to −0.510	< 0.001	−0.918	−1.307 to −0.528	< 0.001
Socioeconomic status	−0.69	−0.459–2.857	0.156	−0.214	−1.298–1.726	0.781
Age	−1.980	−4.473–0.514	0.119	−1.419	−3.194–0.356	0.117

limb position changes (Proske et al., 2000; Gandevia, 2010). Increased stiffness may be associated with increased isometric and concentric force generation, and muscle energy storage may be best manifested by closely matching muscle stiffness to the frequency of movement in stretch-shorten type contractions (Gleim & McHugh, 1997).

Elasticity is also required to explain the complex behavior of myofibril relaxation, and there is a range of compliances that allow the predominant rapid rate of cross-bridge detachment and relaxation (Regnier & Cheng, 2016). Hence, besides resisting to lengthening of the muscle, viscoelastic properties also aid in restoring the resting length of the muscle, and consequently may contribute to rapidly alternate between contraction and relaxation, an important characteristic of controlled movement (Ylinen et al., 2009; Regnier & Cheng, 2016).

In addition to stiffness, elasticity, and compliance properties of muscles and tendons, nervous system activity plays a role in flexibility trough proprioceptors, which provide feedback to the central nervous system. Muscle spindles positioned in the thick central portion of the muscle detect stretching and are essential for coordinated muscle activity (De Ste Croix & Korff, 2013).

The study of health benefits of physical fitness in youth is timely and even though some fitness test batteries for youth include measures of flexibility (i.e., FitnessGram, Eurofit), evidence regarding the health benefits of flexibility in youth is lacking (Ruiz et al., 2009). For this reason, the most recently standardized test battery proposed for health-related physical fitness screening for European youth (ALPHA) does not include a single measure of flexibility (Ruiz et al., 2011). Also, the most recent physical activity recommendations from World Health Organization specifically mention physical fitness; however, it is the importance of cardiorespiratory fitness and muscular fitness that is highlighted (WHO, 2010).

There is no single test to assess the overall flexibility of the body, as flexibility is joint specific (Hedrick, 2000). However, in epidemiological settings, assessing all anatomic joints of the body is not feasible, and therefore, most studies have relied on one single test —the sit and reach test—to measure general flexibility. In this study, we decided to measure flexibility using two tests (back-saver sit and reach and trunk lift tests) so that we could have a better picture of the participants' flexibility. Nevertheless, we acknowledge that the trunk lift test assesses both trunk extensor strength and flexibility (Welk & Meredith, 2008). Yet, our results show a positive relationship between both flexibility tests, as well as its composite score and MC.

Our results also show that children in the healthy zones in both flexibility tests achieve significantly higher motor quotient scores than the children under the healthy zones. In fact, participants attaining the healthy zones of the flexibility tests have on average a motor quotient indicative of normal motor coordination according to the KTK normative values (Kiphard & Schiling, 1974). These results support the assumption that to have proper MC, children needed to attain adequate levels of flexibility.

Regarding the secondary aim of this study, our results also show a positive association between cardiorespiratory and muscle fitness with MC and a negative relationship between body mass index and MC, findings that are consistent with previous studies (Lubans et al., 2010; Cattuzzo et al., 2016). Indeed, in a recent systematic review, Cattuzzo et al. (2016) found that 27 of 33 studies reported a negative relationship between MC and body composition; 100% (12 of 12 studies) reported positive associations between MC and cardiorespiratory fitness; and 64% (7 of 11 studies) reported a positive association between MC and musculo-skeletal fitness.

Physical fitness in children and adults is acknowledged as an important marker of current and future health (Ortega et al., 2008) that tracks moderately well through childhood to adulthood (Cleland et al., 2009). There is evidence from cross-sectional and longitudinal studies that low fitness levels (particularly cardiorespiratory and muscular strength) during childhood and adolescence are associated with other well-known health-related outcomes, such as increased risk for obesity (Ortega et al., 2011) and adult cardiovascular diseases (Ortega et al., 2012), impaired skeletal health (Moliner-Urdiales et al., 2010), reduced quality of life (Morales et al., 2013), and poor mental health (Ruiz et al., 2009).

Future research examining the association between health-related fitness, particularly flexibility and MC in children with longitudinal designs, are needed to increase the knowledge in this field and to allow generalization of these findings. Furthermore, experimental research is also needed to establish casual evidence.

This study has some limitations that should be acknowledged; the data have been derived from a cross-sectional study so the results do not indicate causality; our sample is not representative of the Portuguese population.

The strengths of this study comprise the inclusion of several confounders, a large sample with a narrow age range, as well as the use of two measures of flexibility, because flexibility tends to be joint specific.

This study extends previous investigations in children by showing positive associations between flexibility and the other components of physical fitness and MC. Taken together, our results advocate that to achieve proper MC levels, it is favorable to achieve optimal levels of health-related physical fitness.

Perspective

Flexibility is one of the health-related physical fitness components less studied. In fact, evidence regarding the health benefits of flexibility in youth is lacking (Ruiz et al., 2009). Regarding the associations between flexibility and MC, the results limited and uncertain (Robinson et al., 2015; Cattuzzo et al., 2016), and recently, a call have been made for further research (Malina, 2014; Robinson et al., 2015; Cattuzzo et al., 2016). This study found positive associations between flexibility and MC. Our findings highlight the importance of promoting and developing flexibility, as well as the other health-related physical fitness components in schoolchildren to reach adequate levels of MC.

Key words: Health-related physical fitness, motor coordination, trunk lift, back-saver sit and reach, children, KTK.

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Table S1. Regression coefficients and 95% confidence intervals from linear regression model predicting balance (z-score of the back-saver sit and reach).

Table S2. Regression coefficients and 95% confidence intervals from linear regression model predicting jumping laterally (z-score of the back-saver sit and reach).

Table S3. Regression coefficients and 95% confidence intervals from linear regression model predicting hopping on one leg over an obstacle (z-score of the back-saver sit and reach).

Table S4. Regression coefficients and 95% confidence intervals from linear regression model predicting shifting platforms (z-score of the back-saver sit and reach).

Table S5. Regression coefficients and 95% confidence intervals from linear regression model predicting balance (z-score of the trunk lift).

Table S6. Regression coefficients and 95% confidence intervals from linear regression model predicting jumping laterally (z-score of the trunk lift).

Table S7. Regression coefficients and 95% confidence intervals from linear regression model predicting hopping on one leg over an obstacle (z-score of the trunk lift).

Table S8. Regression coefficients and 95% confidence intervals from linear regression model predicting shifting platforms (z-score of the trunk lift).

Table S9. Regression coefficients and 95% confidence intervals from linear regression model predicting balance (sum of the z-scores of best sit and reach and trunk lift).

Table S10. Regression coefficients and 95% confidence intervals from linear regression model predicting jumping laterally (sum of the z-scores of best sit and reach and trunk lift).

Table S11. Regression coefficients and 95% confidence intervals from linear regression model predicting hopping on one leg over an obstacle (sum of the z-scores of best sit and reach and trunk lift).

Table S12. Regression coefficients and 95% confidence intervals from linear regression model predicting shifting platforms (sum of the z-scores of best sit and reach and trunk lift).

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