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Association Between Daily Steps Measured by Accelerometry and Diabetes in ELSA-Brasil Participants

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Abstract

Diabetes mellitus is a serious chronic disease whose main characteristic is hyperglycemia (increased blood glucose), accompanied by changes in lipid and protein metabolism. For individuals with diabetes mellitus, physical activity provides significant benefits and is an essential tool for metabolic management. Daily step counting, measured with AI support through wearable devices, can be an important metric of physical activity for the prevention and treatment of this disease if performed regularly and respecting a minimum daily amount. Objective: To investigate the association between daily steps and diabetes and to determine what minimum amount should be performed daily for a protective effect in participants of the Longitudinal Study of Adult Health. Methods: The study was cross-sectional and participants from the 2nd segment (2016-2018) were analyzed, with a sample of 12,636 participants. The dependent variable was diabetes, assessed by laboratory tests, and the independent variable was daily steps counting, assessed by accelerometry. The associations between the dependent and independent variables were analyzed using logistic regression. The odds ratio with 95% CI was estimated. Results: An association was found between daily steps and diabetes (OR = 0.76, CI = 0.70-0.83), in addition to the cutoff point of 6,880 with area under the ROC curve = 0.58 (CI = 0.57-0.59). Conclusion: Based on the results found in this study, we can conclude that the number of daily steps has a protective effect against diabetes, especially in men and women with abdominal obesity and in men with moderate/vigorous leisure-time physical activity.

Keywords: diabetes; daily steps; epidemiology

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1. Introduction

Physical activity can be defined as any movement of the human body produced by skeletal muscles that results in an increase in energy expenditure [1]. For individuals with Diabetes Mellitus (DM), physical activity provides significant benefits and is an essential tool for metabolic management [2]. Physical activity has shown consistent results in controlling and treating altered blood glucose levels and improving physical fitness, and is widely used in the treatment of DM [3].

Although physical activity is considered essential for the effective treatment of type 2 diabetes mellitus (T2DM), a considerable portion of this population is not physically active [4]. Encouraging an increase in habitual physical activities, such as walking to work or climbing stairs, may be an alternative to increase the daily energy expenditure of the general population [5].

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Wearable sensors based on artificial intelligence (AI) can collect, analyze, and transmit real-time health data to healthcare professionals, enabling them to make efficient decisions based on patient data. In this sense, wearable sensors have become increasingly popular due to their ability to provide a non-invasive and convenient means of monitoring patient health. These wearable sensors can track various health parameters, including physical activity levels measured by the number of daily steps, with AI support through wearable devices [6].

General population studies indicate an average frequency of 7,000 to 13,000 steps per day in adults aged 20 to 50 years who are apparently healthy. In the population with diabetes, studies have indicated an average of 6,291 steps/day [7]. This seems to indicate that diabetes tends to produce a reduction in habitual physical activity through daily walking. Therefore, it is important to evaluate and analyze the level of habitual physical activity of people with DM. Regular physical activity is a strategy recommended by several studies and guidelines for the control of DM2 and associated complications [7–12].

It is estimated that there are 382 million individuals in the world with DM, with a prospect of reaching 471 million people by the year 2035 [13]. In Brazilians, aged between 18 and 29 years, the prevalence of DM was 0.9%, increasing to 14.5% in the population aged between 60 and 64 years, reaching 19.9% in the population aged between 65 and 74 years [14]. In the ELSA-Brasil study, after a follow-up of 8.2 years, with data from the baseline (2008 - 2010) to the 2nd follow-up (2017 - 2019), Birck and collaborators (2022) [38] found that the incidence of diabetes was 14.3%. Patients with DM significantly influence public expenses. The average quarterly cost is approximately R$1,212.37 for each diabetic with vascular complications and R$931.88 for diabetics without complications. These values are significantly higher when patients are hospitalized [15]. In addition, there is a very important social issue when dealing with the population with DM. Individuals affected by this disease experience reduced quality of life, life expectancy, and mobility, thus causing psychological, physical, and metabolic disorders [16]. Therefore, the study becomes relevant because regular physical activity may possibly reduce the number of hospitalizations due to DM, providing a lower burden on the country's health system and a reduction in financial expenses with patients [16]. Thus, the objective of this study was to investigate whether there is an association between the number of daily steps and diabetes and what is the best cut-off point for the number of daily steps as a discriminator of the absence of diabetes.

2. Materials and Methods

2.1. Population and Sample

The study is cross-sectional and analyzed participants in the 2nd follow-up of the ELSA-Brazil (Longitudinal Study of Adult Health) cohort. Launched in 2008 by the Ministry of Health, ELSA-Brazil (Longitudinal Study of Adult Health) is the largest epidemiological study in Latin America, investigating chronic diseases such as diabetes and cardiovascular diseases and their risk factors in the Brazilian population. ELSA-Brazil is also the largest multicenter cohort study conducted by a country that is not among the developed countries and is composed of six teaching and research institutions in different Brazilian cities (Salvador, Porto Alegre, São Paulo, Rio de Janeiro, Belo Horizonte and Vitória). This study included 15,105 civil servants from the six institutions mentioned above, aged 35 to 74, in its baseline. Among other tasks, they used an accelerometer and a sleep diary to measure their physical activity levels and daily steps. To date, data have been collected at three time points: baseline between 2008 and 2010, 1st follow-up between 2012 and 2014, and 2nd follow-up between 2016 and 2018 (DECIT, 2009; EICKEMBERG et. al., 2020; PITANGA et. al., 2021) [17–19]. Data for the 3rd follow-up (2022 to 2024) are currently being collected. For the present study, all participants from the 2nd follow-up (2016-2018) who had data collected using the accelerometer will be selected.

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ELSA-Brasil was approved by the National Research Ethics Committee (CONEP MS 976/2006) and by all Research Ethics Committees of the six research centers involved. All participants signed the informed consent form, guaranteeing the confidentiality and secrecy of the data.

2.2. Data Production

The data was collected by a team of interviewers and measurers trained and certified by a quality control committee (SCHMIDT et. al., 2013) [20], qualified to execute the study protocol at any ELSA-Brasil Research Center.

Strict protocols were implemented for initiation and download of the accelerometers.

2.3. Diabetes Assessment

Diabetes data were collected after an overnight fast, biological material samples were collected from all participants and initially frozen and stored, being later transported to the central laboratory (University of São Paulo). All laboratory analyses were performed in a single research center for better standardization. The defining criteria for DM were: fasting plasma glucose (FPG) ≥ 126 mg/dl (7 mmol/L), 2-hour plasma glucose (2hPG) ≥ 200 mg/dl (11.1 mmol/L) in a standard oral glucose tolerance test (OGTT), and glycated hemoglobin (HbA1c) ≥ 6.5% (48 mmol/mol), according to the American Diabetes Association, (2014)11, and WHO, (2006) [21]. We considered a case prevalent at baseline when any of these criteria were present. Laboratory parameters were obtained by blood sampling after a 12-hour overnight fast. (FEDELI, et. al., 2013) [22].

2.4. Assessment of Daily Steps

For daily step assessment, participants wore an ActiGraph wGT3X-BT device (version 3.2.1, Actigraph Corp). We activated the devices in ActiLife software (version 6.13.4, ActiGraph) with a sampling frequency of 30 Hz, recording triaxial acceleration in raw format. Subjects wore the accelerometer attached with an elastic band above the right anterior superior iliac spine for 24 hours over 7 consecutive days, starting at 8:00 p.m. on the same day as the study clinic visit (day 1) and ending at 8:00 p.m. on day 8 (day 8). They were asked to wear the device at all times, but were instructed to remove it during water activities, such as swimming or bathing. Each subject's data was validated if all of the following criteria were met: (1) presence of data recorded at each epoch of the 24-hour cycle of the sample, even if combining different days; (2) a calibration error of less than 0.02 g after the post measurement self-calibration process; (3) at least 4 days with 16 or more hours of use; and (4) at least one of the 4 days being a Saturday or Sunday (DE PAULA, et al. 2023) [23]. Through the ROC curve, the cut-off point for the number of daily steps was determined, where sensitivity and specificity had the highest equilibrium point at 6,880 steps per day, for both men and women. The algorithm used was Troiano.

2.5. Data Analysis

Descriptive measures (proportions) will be calculated for all categorized variables. All analyses will be stratified by sex a priori. Associations between the dependent variable (diabetes) and the independent variable (number of daily steps) will be analyzed using logistic regression. The following variables will be considered as potential confounders or effect modifiers: age, sex, obesity, abdominal obesity, family income, education, and smoking. Effect modification analysis was performed by examining stratum-specific point measures and their confidence intervals. If the point measure of a factor in a specific stratum is not in the confidence interval of another factor in the same stratum, this will indicate effect modification. Confounding analysis was performed by comparing the odds ratio (OR) for the crude association with that for the association adjusted for potential confounders. The parameter used to identify the difference between the associations will be 10%. Next, a logistic regression analysis was performed. The analysis began with a full model, followed by a one-by-one removal of each potential confounding variable. Subsequently, the OR (odds ratio)

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was estimated for the association between the number of daily steps and diabetes, stratified and adjusted for the variables that were confirmed as effect modifiers and confounders, respectively. The covariates abdominal obesity and leisure-time physical activity were identified as effect modifiers. No covariates were identified as confounders. The confidence interval will be set at 95%.

The cutoff points for the number of daily steps for the absence of diabetes were identified using Receiver Operating Characteristic (ROC) curves, which are frequently used to determine cutoff points in diagnostic or screening tests (Erdreich & Lee, 1981)24. The statistical program STATA 17.0 was used.

3. Results

A total of 12,636 participants were included in the analysis, of which 5,623 (44.50%) were men and 7,013 (55.50%) were women, where men over 60 years old represent 56.21% while women over 60 years old represent 43.79%. An association was found between daily steps and diabetes (OR = 0.76, CI = 0.70-0.83), in addition to the cutoff point of 6,880 with area under the ROC curve = 0.58 (CI = 0.57-0.59). After the analysis of effect modification and confounding, it was found that, in men, there was an association with statistical significance for those with abdominal obesity (OR = 0.62, CI = 0.43-0.87) and who performed moderate/vigorous leisure-time physical activity (OR = 0.64, CI = 0.50-0.80). In women, an association was observed only in those with abdominal obesity (OR = 0.86, CI = 0.75-0.98). The sample characteristics are presented in Table 1. The prevalence of diabetes in females resulted in 23.3%, while in males, the prevalence was 29.0%. Men had greater obesity (60.79%) and abdominal obesity (66.69%) compared to women who had greater smoking (51.52%), moderate/vigorous leisure-time physical activity (51.38%), income (54.56%), presence of diabetes (50.08%) and greater number of daily steps (52.84%). Men are mostly black/mixed race (55.69%) and white (54.97%) compared to women, however, both men and women are mostly white.

Table 1. Sample characteristics in Wave 3. ELSA-Brazil (2018-2020).

	MEN	WOMEN	p- VALUE
YEARS OF AGE	*n*(%)	*n*(%)	
41 – 59	3,923 (54.95%)	3,216 (45.05%)	0.157
>60	3,090 (56.21%)	2,407 (43.79%)	
OBESITY			
No	4,823 (53.59%)	4,176 (46.41%)	0.000
Yes	2,105 (60.79%)	1,358 (39.21%)	
SMOKING			
Never smoked	4,578 (60.06%)	3,045 (39.94%)	0.000
Ex-smoker or smoker	2,403 (48.48%)	2,554 (51.52%)	
PHYSICAL ACTIVITY IN LEISURE TIME			
Light	5,043 (58.72%)	3,545 (41.28%)	0.000
Moderate and Vigorous	1,896 (48.62%)	2,004 (51.38%)	
INCOME			
<6558.5	1,882 (42.74%)	2,521 (57.26%)	0.004
>=6558.5	3,741 (45.44%)	4,492 (54.56%)	
ABDOMINAL OBESITY			
No	2,688 (44.09%)	3,408 (55.91%)	0.000
Yes	4,084 (66.69%)	2,040 (33.31%)	

RACE			
Black/Brown	3,047 (55.69%)	2,424 (44.31%)	0.427
White	3,600 (54.97%)	2,949 (45.03%)	
GLYCATED HEMOGLOBIN			
<6,5%	6,075 (56.55%)	4,667 (43.45%)	0.000
>=6,5%	938 (49.52%)	956 (50.48%)	
DIABETES			
Absence	3,891 (42.53%)	5,258 (57.47%)	0.000
Presence	1,592 (49.92%)	1,597 (50.08%)	
NUMBER OF DAILY STEPS			
<6880	1,895 (40.05%)	2,836 (59.95%)	0.000
>= 6880	3,728 (47.16%)	4,177 (52.84%)	

Notice:

Table 2 shows the association between the number of daily steps and diabetes adjusted for age and stratified by sex, abdominal obesity and leisure-time physical activity. When analyzing this combination, it was found that there was epidemiological relevance only in men with abdominal obesity who had more than 6,880 steps per day. In the other associations, there was no relevance.

Table 2. Association between daily steps and diabetes adjusted for age and stratified by sex, abdominal obesity and leisure-time physical activity.

	ABSENCE OF ABDOMINAL OBESITY		PRESENCE OF ABDOMINAL OBESITY	
NUMBER OF DAILY STEPS	Insufficient leisure-time physical activity	Leisure-time physical activity Moderate/ vigorous	Insufficient leisure-time physical activity	Leisure-time physical activity Moderate/ vigorous
Men				
No. of steps < 6.880	Ref (1,00)	Ref (1,00)	Ref (1,00)	Ref (1,00)
No. of steps > 6.880	1.02 (0.814-1.28)	0.86 (0.613-1.22)	1.04 (0.83-1.29)	0.62 (0.43-0.87)*
Women				
No. of steps < 6.880	Ref (1,00)	Ref (1,00)	Ref (1,00)	Ref (1,00)
No. of steps > 6.880	1.22 (0.90-1.65)	1.15 (0.69-1.92)	0.90 (0.77-1.06)	0.78 (0.57-1.06)

Note: Insufficient leisure-time physical activity (lowest level of physical activity). Moderate/vigorous leisure-time physical activity (3 or more days of moderate-intensity activity and/or walking for at least 30 minutes per day; 5 or more days of any combination of walking, moderate-intensity, or vigorous-intensity activity that achieved a minimum total of at least 600 MET-minutes/week; vigorous-intensity activity on at least 3 days that achieved a minimum total of physical activity of at least 1500 MET-minutes/week; 7 or more days of any combination of walking, moderate-intensity, or vigorous-intensity activity that achieved a minimum total of at least 3000 MET-minutes/week.

Table 3 shows the association between the number of daily steps and diabetes adjusted for age and stratified by sex and abdominal obesity. This combination showed epidemiological relevance only in women with abdominal obesity who had more than 6,880 daily steps. The other associations were not relevant.

Table 3. Association between daily steps and diabetes adjusted for age and stratified by sex and abdominal obesity.

	ABSENCE OF ABDOMINAL OBESITY		PRESENCE OF ABDOMINAL OBESITY	
Number of daily steps	*OR*	*95%IC*	*OR*	*95%IC*
Men				
No. of steps < 6.880	Ref (1,00)	Ref (1,00)	Ref (1,00)	Ref (1,00)
No. of steps > 6.880	0.94	(0.78-1.14)	0.87	(0.72-1.04)
Women				
No. of steps < 6.880	Ref (1,00)	Ref (1,00)	Ref (1,00)	Ref (1,00)
No. of steps > 6.880	1.18	(0.921-1.53)	(0.86) *	(0.75-0.98) *

Note: OR: Odds Ratio; CI: Confidence Interval.

Table 4 shows the association between the number of daily steps and diabetes adjusted for age and stratified by sex and leisure-time physical activity. A significant association was identified only in men who had more than 6,880 steps per day with moderate/vigorou physical activity during leisure time.

Table 4. Association between daily steps and diabetes adjusted for age and stratified by sex and leisure-time physical activity.

	Insufficient leisure-time physical activity		Leisure-time physical activity Moderate/ vigorous	
Number of daily steps	*OR*	*95%IC*	*OR*	*95%IC*
Men				
No. of steps < 6.880	Ref (1,00)	Ref (1,00)	Ref (1,00)	Ref (1,00)
No. of steps > 6.6880	0.89	(0.77-1.03)	0.64*	(0.50-0.80)
Women				
No. of steps < 6.880	Ref (1,00)	Ref (1,00)	Ref (1,00)	Ref (1,00)
No. of steps > 6.6880	0.91	(0.80-1.04)	0.78	(0.61-1.00)

4. Discussion

The present study sought to investigate whether there is an association between the number of daily steps and diabetes and what is the best cutoff point for the number of daily steps as a discriminator of the absence of diabetes. Abdominal obesity can be defined as excessive fat deposits in the abdominal region. It is a health condition that is positively related to non-communicable diseases [25]. In addition, it is considered an adverse form of obesity with serious implications. Therefore, it has been strongly associated with certain common chronic non communicable diseases, in particular: cardiovascular diseases, diabetes, hypertension, cancer, kidney diseases and fatty liver diseases.

Although training can increase the proportion of type 1 and 2A fibers, physical inactivity promotes a shift towards type 2A and 2X fibers [26]. This has implications not only for performance but also for metabolic diseases such as DM2, as different fibers also differ in their glucose handling capacity [27]. Chronic energy imbalance and physical inactivity lead to myocellular maladaptation.

Skeletal muscle of individuals with DM2 exhibits impaired insulin stimulated glucose transport and consequent lower glycogen synthesis, reflecting insulin resistance [28].

Decreased mitochondrial function and therefore decreased lipid oxidation capacity are other features of insulin resistant individuals. This, in combination with increased systemic lipid influx, facilitates ectopic lipid accumulation in skeletal muscle. Regular exercise can improve myocellular mitochondrial function and increase fatty acid oxidation capacity [29]. Importantly, even a single bout of exercise is a potent stimulus to increase glucose disposal by activating 5′-AMP-activated protein kinase (AMPK), leading to translocation of the insulin-independent glucose transporter (GLUT4) and increasing glucose uptake and glycogen storage, thereby rapidly reducing the abnormalities associated with DM2 [30]. Regular exercise with repeated muscle contractions therefore provides the basis for metabolic health and the prevention and treatment of DM2. Therefore, there is a possible correlation between the number of daily steps and diabetes prevention, since we can consider the number of steps per day as regular physical activity. Therefore, through similar physiological mechanisms, the number of daily steps can be considered a protective factor against diabetes, especially for individuals with abdominal obesity.

Cavero-Redondo [31], conducted a meta-analysis and confirmed the beneficial effects of physical activity interventions on glycemic control measured by glycohemoglobin in non-diabetic populations. In addition, Zhao [32] concluded that higher levels of physical activity were associated with a lower prevalence of DM, with a more pronounced reduction when daily activity levels were lower. Physical activity reduces the risk of DM through long- and short-term improvements in insulin action for better glucose control [33].

A similar result was identified in a study carried out in Japan [34], in 2023, which sought to analyze the associations between glycemic variability, assessed by continuous glucose monitoring, sleep quality and daily steps using wearable devices in healthy individuals. The results showed that glycemic variability, in both sexes, on days of higher daily steps was decreased compared to days of lower daily steps in each participant. Since positive correlations have been reported between glycemic variability assessed by continuous glucose monitoring and a marker of oxidative stress [35] or coronary plaque rupture [36], it is suggested that glycemic variability increases the development of cardiovascular complications [37]. In addition, glycemic variability has also been associated with sleep quality and physical activity. Poor sleep quality has been reported to be related to increased glycemic variability in patients with type 1 diabetes [38] and type 2 diabetes [39].

Similar to our results, Kim et al. [40] published a 12-week, randomized, open-label, controlled, single-center extension study involving individuals with type 2 diabetes who had HbA1c <8.5% and BMI ≥23 kg/m2, where all participants used a smartphone application called PHR. Regarding glycemic outcomes, in the intervention group, HbA1c at week 12 was significantly lower than in the control group, and significant differences between the groups were found in changes in fasting glucose levels from baseline to week 12.

A systematic review by Hall et al. [41] showed robust results in two large studies with 5-year follow-up that examined the association between daily step counts and incident dysglycemia or DM2. The results demonstrate similarity with our study in finding a significantly reduced risk with higher daily step counts. Corroborating these results, the authors concluded that taking less than 10,000 steps per day is sufficient to generate health benefits.

This study has some limitations, such as: the accelerometer records the total daily step count without differing in step speed, i.e., it was not possible to identify whether the individual took the steps quickly or slowly, and this may make it difficult to interpret the results. Furthermore, although the sample contained 15,105 individuals at baseline and 12,636 in this study, coming from three important regions of the country, namely the northeast, southeast and south, presenting regional and social diversity, the ELSA-Brasil population may not be representative of the Brazilian population, as it is a sample of public employees, the majority with a high level of education and income.

Based on the results found in this study, we can conclude that: exceeding the number of steps per day may mean a lower risk of developing diabetes. For individuals with abdominal obesity, a higher daily step count becomes even more important as a protective factor against chronic diseases. Furthermore, as it was not possible to identify the levels of intensity of daily steps, leisure-time physical activity performed at moderate/vigorous intensity appears to be a key factor in combating diabetes. In other words, given the limitations of the study, we can conclude that leisure-time physical activity performed at moderate and vigorous intensity is more likely to be more relevant than daily step count as a protective factor for diabetes, in both sexes.

The results of this study can help public health managers by informing them of the importance of physical activity as a tool to help prevent chronic diseases such as type 2 diabetes. Furthermore, by suggesting a target for the number of daily steps, it would be easier to define public policies to encourage walking by suggesting distances that cover the minimum number of steps per day. However, although the present study showed robust results, more research on the subject is needed in order to find better outcomes with daily step interventions.

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Institutional Review Board Statement: The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) at the beginning of the study and at each stage of ELSA-Brasil follow-up by all Research Ethics Committees of the investigation centers involved.

Informed Consent Statement: All participants signed the informed consent form, guaranteeing the confidentiality and secrecy of the data.

Conflicts of Interest: The authors declare no conflict of interest.

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