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Relationship between ambulatory physical activity assessed by activity trackers and physical frailty among nursing home residents

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ABSTRACT

Backgrounds: The aim of this study was to assess the relationship between the level of ambulatory physical activity, measured by physical activity tracker, and the clinical components of physical frailty, among nursing home residents.
Methods: We proceeded in 3 steps: (1) Validation of the physical activity tracker (i.e. the Pebble): 24 volunteer adults walked on a treadmill. The number of steps recorded by the Pebble worn by the subjects was compared with the number of steps counted by the investigators, by means of the Intra-class correlation coefficients (ICC). (2) Measurement of ambulatory physical activity, using the Pebble trackers, over a 7-day period. (3) Relationship between the results obtained with the Pebble trackers (step 2) and subjects' clinical characteristics, linked to physical frailty.
Results: ICC data, showed that the reliability of the Pebble was better when it was worn at the foot level (ICC ranged from 0.60 to 0.93 depending on the tested speed). Gait speed is also an important determinant of the reliability, which is better for low gait speed. On average, the 27 nursing home residents included in the second step of this study walked 1678.4 ± 1621 (median = 1300) steps per day. Most physical components of frailty measured in this study were significantly different between subjects who walked less than 1300 steps per day and those who were more active.
Conclusion: This study showed that nursing home residents have a poor ambulatory physical activity, assessed using a physical activity tracker, which is associated with poorer physical performances and higher disability.

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1. Introduction

Aging is accompanied by a steady decline in physical activity [1]. This is an important public health concern because sedentary behavior is a strong risk for chronic diseases, disability, physical frailty and even death [2,3]. It has been recognized that physical activity can have a positive impact on these adverse health outcomes [1]. Therefore, many scientific societies recommend reaching a minimum level of physical activity per week. Physical activity consists not only of sport activities but includes also activities of daily living and movement. Although physicians recognize the importance of physical activity for elderly people, few have incorporated physical activity counseling into routine clinic visits [4]. One barrier has been the paucity of means to objectively assess physical activity pattern [5]. Nevertheless, activity trackers are becoming increasingly more widespread, affordable [6] and used by clinicians and patients to measure physical activity. These tools have evolved over time from relatively simple mechanical pedometers to more complex accelerometers [7]. Pedometer accuracy is compromised in recording slow walking speed [8,9] and may be a serious limitation when monitoring activity in specific population, such as frail elderly. To ensure the applicability of this kind of activity tracker across age groups, it is critical to assess the validity of the device at multiple speeds and positions of wear prior to use [2]. Thus, the first objective of this study was to assess the validity and reliability of a new activity tracker, in a population of young and elderly

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adults, during a treadmill walking at multiple speeds (corresponding to slow, median and fast gait speed in elderly) and positions of wear. After the validation of the activity tracker, the second objective of the study was to measure precisely ambulatory physical activity of elderly, in nursing home settings. The third objective of this study was to assess the relationship between the measured level of ambulatory physical activity and the clinical components of physical frailty, among nursing home residents. The data presented and discussed in this article could fill a gap in the literature where few precise data exist on the extent of physical activity in nursing home.

2. Methods

2.1. Step 1: validation of the physical activity tracker (i.e. the pebble)

2.1.1. Study design

This is a cross sectional study performed among volunteer adults in order to validate the Peeble in the general population, so that this accelerometer could be used in different populations. A convenience sample of 24 volunteers was recruited, respecting equity between men and women (50% of women) and between young (12 subjects aged below 65 years) and older adults (12 subjects aged 65 years or older). Volunteers with the ability to ambulate continuously on a treadmill unaided for 30–45 min were included. Exclusion criteria consisted of any neurological disorder, cognitive disorder, recent musculoskeletal injury or surgery that would impair motor function. Informed consent was obtained from all participants. Ethics approval was obtained from the Medical Ethics Committee of the University of Liège under the number 2013/178.

2.1.2. The pebble

The Pebble+ (FitLinxx Global Headquarters, Shelton CT 06484, US) is an all-day activity monitor. It clips to an individual's shoe or waistband, blending seamlessly into daily life. The Pebble activity tracker utilizes a 3-axis accelerometer and patented technology to measure patterns of motion, producing a unique waveform signature. It uses this signature in a series of intelligent algorithms that dynamically adjust based on the type of motion detected, providing accurate, verifiable activity data for users of all ages and activity levels. The device determines total steps, activity time and individual's speed, which can be used to calculate distance and caloric burn.

2.1.3. Treadmill walking protocol

Participants were instructed in the use of the treadmill prior to the beginning of the protocol. Then, participants walked on the treadmill at predetermined speeds (set on the treadmill 2.5 km/h (0.7m/s); 4 km/h (1.1m/s) and 5.5 km/h (1.5m/s)) for 15 min at each speed. According to Mondero-Odasso, these gait speeds correspond to slow gait speed, average gait speed and fast gait speed, respectively, among the elderly [10]. These results are consistent with our previous study performed in nursing home (i.e. the SENIOR cohort) in which we showed that pre-frail subjects had a gait speed of 0.75 m/s and robust subjects had a gait speed of 1.04 m/s on average [11]. Moreover, the speeds of 4 km/h and 5.5 km/h are often used in validation studies performed in the adult population [2,12]. In the present study, persons under 30 years realized the test at the 3 speeds while people over 65 years old only realized the tests at the first 2 speeds because all these people were not able to walk at the fastest speed. Meanwhile, an observer manually counted the participants' steps. The walking test was also filmed by a camera to ensure that the number of steps counted was appropriate. A rest of approximately 1 min between two periods of walking was observed. For the test, two Pebbles were positioned according to the manufacturer's recommendation on both right ankle and right hip. In practice, the devices were attached to the subject's shoe and waistband. After each session of 15 min, the treadmill was stopped and the Pebbles removed.

2.1.4. Statistical analysis

All descriptive data are presented as mean and standard deviation. To investigate the device validity, we assessed the level of agreement, between the number of steps estimated by the Pebble and counted by the investigator, using Intra-class Correlation coefficients (ICC). The relative reliability of the Pebble, compared to the reference (counted steps), was assessed by means of the ICC. The closer the coefficient is to 1, the higher is the reliability. We considered an ICC over 0.90 as very high, between 0.70 and 0.89 as high and between 0.50 and 0.69 as moderate [13]. All calculations were performed using SAS statistical package (version 9.3 for windows) and R statistical packages.

2.2. Step 2: measurement of ambulatory physical activity, using the pebble trackers, over a 7-day period, among nursing home residents

2.2.1. Study design

This is a cross sectional study performed in a nursing home in the area of Liège. The study population consisted of nursing home residents from "les cheveux d'Argent". Inclusion criteria were (1) to be aged 65 or over, (2) to be able to stand up and to walk (technical assistance authorized), (3) and to have given written informed consent. Disoriented patients were excluded from the study. Patient with an occasional and temporary dysfunction were also excluded. Specify that no subject included in this step had participated to the first step (validation of the pebble).

2.2.2. Data collected

Subjects were asked to wear the Pebble for 7 consecutive days. It was attached on the residents' shoe and recorded the number of steps. Demographic characteristics of the subjects were also collected: age, sex, need of care, Body mass Index (BMI), walking assistance and physiotherapy. The period of 7 days was chosen to be representative of the physical activity of the residents. Indeed, in nursing home, daily activities are similar from a week to another. Moreover, it was important to take into account the week and the week-end.

2.2.3. Statistical analysis

The data recorded by the pebble were transferred to the « Actihealth » platform using wireless. Actihealth presents the data in table form (per patient, per day, per week, per hour, . . .). The number of steps walked by each resident was expressed as mean and standard deviation. Subjects were then divided into two groups based on the median number of steps in the study population.

2.3. Step 3: relationship between results obtained with the pebble trackers (in step 2) and subjects' clinical characteristics, linked to physical frailty

2.3.1. Study design

This is a cross sectional study performed in a nursing home in the area of Liège. The study population consisted of the residents who wore the Pebble in step 2.

2.3.2. Data collected

In addition to the number of steps taken by the residents recorded by the Pebble, a large number of variables related to physical frailty were collected:

- Body mass index (BMI), was calculated from weight and height, measured at the nearest 0.1 kg/cm.
- Energy expenditure was assessed using the Minnesota questionnaire [14].
- Cognitive skills were assessed with the Mini Mental State Examination [15].
- Nutritional status was estimated by the Mini Nutritional Assessment [16].
- Quality of life was assessed with the EQ-5D questionnaire [17].
- The level of autonomy for activities of Daily Living was estimated by the Katz scale [18].
- Functional and motors skills (i.e. gait and body balance) were assessed using the Tinetti test [19], the "Timed Up and Go" test [20] and the "Short Physical Performance Battery" test [21].
- Peak expiratory flow was measured using a Mini-Wright meter.
- Grip strength was assessed by means of a hydraulic dynamometer (Saehan Corporation, MSD Europe Bvba, Belgium, an isometric hydraulic hand dynamometer) [22].
- Maximal isometric voluntary contraction of 8 muscle groups (i.e.: knee extensors, knee flexors, ankle extensors, ankle flexors, hip abductors, hip extensors, elbow flexors, elbow extensors) was measured with a MicroFet 2 hand-held dynamometer (Hogan Health Industries, West Jordan, USA) [23].
- Frailty status was assessed using the 5 criteria of Fried [24].
- Body composition was assessed by means of bioelectrical impedance analysis (InBody S10 Biospace device) [25].

These data were collected during a face-to-face meeting with the patient which lasted about 40 min. The same observer conducted all the tests. The data were completed using the medical record.

2.3.3. Statistical analysis

A Shapiro-Wilk test verified the normal distribution for all parameters. Quantitative variables were expressed as mean ± standard deviation (SD), or as median and interquartile range (P25-P75) for asymmetric distributions. Qualitative variables were expressed as number and percentage. To compare the clinical characteristics of the subjects according to their ambulatory activity, the student *t*-test (or the Mann-Whitney non parametric test) was used for continuous variables while Chi-squared test was used for categorical variables. Significant variables in the univariate analysis were included in a multivariate logistic regression to compare low and high ambulatory activity groups. All calculations were performed using Statistica 10 software, SAS statistical package (version 9.3 for windows) and R statistical packages. Results were considered to be statistically significant at the 5% critical level ($p < 0.05$).

3. Results

3.1. Step 1: validation of the physical activity tracker (i.e. the pebble)

A total of 24 subjects were included: 12 young adults aged between 21 and 30 years (24.8 ± 4.06 years, 58.8% of men) and 12 adults aged over 65 years (67.9 ± 3.20 years, 41% of men).

The results of the validation process of the Pebble are presented in Table 1 below. They are given according to the 3 walking speeds (i.e.: 2.5 km/h, 4 km/h or 5.5 km/h) and for the 2 positions of wear of the Pebble (i.e.: hip and foot).

As shown in Table 1, the ICC values varied from 0.14 (rapid speed) to 0.64 (low speed) when the Pebble was worn on the hip, and from 0.60 (medium speed) to 0.93 (low speed) when worn on the foot. Which means that, when worn on the foot, in our study conditions, the Pebble seemed moderately reliable at the medium and rapid speeds and highly reliable at the low speed. For steps 2 and 3 of our study, the activity trackers were worn on the foot.

Table 1
Validation data of the Pebble at 3 different speeds and 2 different positions.

Walking speed	n	Hip ICC (95% CI)	Foot ICC (95% CI)
2.5 km/h	24	0.64 (0.29–0.84)	0.93 (0.85–0.97)
4 km/h	24	0.42 (−0.027–0.72)	0.60 (0.24–0.82)
5.5 km/h	12	0.14 (−0.43–0.64)	0.62 (0.0014–0.89)

3.2. Step 2: measurement of ambulatory physical activity, using the pebble trackers, over a 7-day period, among nursing home residents

In this second step, 27 nursing home residents were included. They were aged 86.7 ± 7.8 years on average (ranged 67–98 years) and 21 (75%) were women. The main characteristics of the population are presented in Table 2.

According to the activity trackers, these residents walked, on average, 1678.4 ± 1621 steps per day (median = 1300 (P25-P75: 449.9–2141.3). Women walked 1534 ± 1721 steps per day whereas men walked 2182 ± 1194 steps pr day.

3.3. Step 3: relationship between results obtained with the pebble trackers (in step 2) and subjects' clinical characteristics, linked to physical frailty

The 27 patients included in step 2 of the present study were divided into 2 groups according to the level of ambulatory activity: those who walked less than 1300 steps per day (i.e. the median value) (n = 14) and those who walked at least 1300 steps per day (n = 13). Clinical characteristics, linked to physical frailty, were compared between these two groups, as shown in Table 3.

As it could be expected, the energy expenditure, estimated by the Minnesota questionnaire, was significantly higher ($p = 0.003$) among people who walked more than 1300 steps per day than in those who walked less than 1300 steps a day. These subjects had also a significantly higher MMSE score ($p = 0.004$), Katz level ($p = 0.04$), Tinetti score ($p = 0.0003$), SPBB score ($p < 0.001$), peak flow ($p = 0.001$), isometric strength of the 8 muscle groups tested (*p*-value ranged from 0.0003 to 0.01) and grip strength ($p = 0.005$) as well as a significantly lower time required to perform the Timed up and Go test (0.0004) than subjects who walked less than 1300 steps per day. Moreover, subjects more active (i.e. >1300 steps/day) were significantly less frail (i.e. Fried score) than less active subjects ($p = 0.0005$) and were requiring less frequently nursing or medical care ($p = 0.03$). Finally, these subjects had also a better nutritional status and less at risk of malnutrition ($p = 0.04$). No other significant difference was observed between the two groups.

After adjustment for potential confounding variables, the results of the logistic regression highlighted that Katz index was

Table 2
Characteristics of the population (n = 27).

Characteristics	Mean ± SD	Number (%)
Age (years)	86.7 ± 7.8	
Gender (Women)		21 (75)
Residents requiring nursing care		11 (40.7)
BMI (kg/m^2)	24.7 ± 5.2	
Walking assistance (Yes)		17 (62.9)
Physiotherapy (Yes)		12 (44.4)

Table 3
Relationship between ambulatory activity and clinical characteristics, linked to physical frailty.

Clinical characteristics	< 1300 steps per day (n = 14)		≥ 1300 steps per day (n = 13)		p-value
	Mean ± SD Or number (%)	Median (P25-P75)	Mean ± SD	Median (P25-P75)	
Age (years)	88.4 ± 6.8		84.2 ± 8.5		0.17
Gender (women)	13 (92.9)		8 (61.5)		0.06
Residents requiring nursing care	9 (64.3)		3 (23.1)		0.03
BMI (kg/m^2)	25.6 ± 6.3		24.8 ± 6.3		0.95
Walking assistance (Yes)	11 (78.5)		6 (46.1)		0.16
Physiotherapy (Yes)	7 (50)		5 (38.5)		0.54
Number of drugs	9.4 ± 2.9	10 (7–10)	8.5 ± 4.4	7 (6–9.5)	0.14
Number of comorbidities	6.9 ± 5.4	6 (4–9)	3.6 ± 2.2	3 (2–5)	0.06
Energy expenditure (kcal/d)	832 ± 529	711.3 (367.5–1102.5)	1656 ± 774	365.7 (1275–1890)	0.003
MMSE score (/30)	18 ± 6.7	19 (14–25)	24.8 ± 4.4	26 (23–28)	0.004
Normal nutritional status (MNA)	6 (42.9)		11 (84.6)		0.04
At risk of malnutrition (MNA)	7 (50)		2 (15.4)		0.04
EQ-5D score	0.5 ± 0.2	0.66 (0.56–0.73)	0.6 ± 0.2	0.63 (0.47–0.75)	0.91
EQ-vas (%)	74.6 ± 14.5		68.8 ± 14.9		0.33
Katz score (6–24 points)	14.5 ± 5.1	13 (11–16)	10.8 ± 3.5	9 (8–12)	0.04
Tinetti score (/28)	17.9 ± 6.1	19 (16–21)	25.5 ± 2.7	27 (24–28)	< 0.001
SPPB Score (/12)	1.9 ± 1.23	2 (1–2)	8.2 ± 2.6	9 (6–10)	< 0.001
Timed Up and Go test (sec)	45.4 ± 24.8	43.6 (29.6–58.6)	16.3 ± 8.3	15.1 (13–16.3)	< 0.001
Peak flow (ml/min)	82.5 ± 29.3	70 (60–100)	173.1 ± 85.9	150 (120–200)	0.001
Grip strength (kg)	10.6 ± 4.2	11.8 (8–12.2)	20.1 ± 10.7	15 (12–24.1)	0.005
Strength of the knee extensors (N)	62.5 ± 27.8	60.2 (40.9–81.8)	124.3 ± 59.2	96.9 (80.9–153)	0.002
Strength of the knee flexors (N)	48.6 ± 13.4	44 (36.4–62.7)	95.4 ± 37.6	82.7 (72.5–112.5)	0.003
Strength of the ankle flexors (N)	44.2 ± 22.2	41.8 (35.5–52)	82.4 ± 33.2	76 (63.6–108.5)	0.002
Strength of the ankle extensors (N)	62.7 ± 29.5	61 (47.6–77.4)	113.3 ± 51.1	102.7 (79.1–153)	0.005
Strength of the hip abductors (N)	28.8 ± 22.7	30.6 (0–49)	83.1 ± 40.9	76.5 (57.3–106.7)	0.0002
Strength of the hip extensors (N)	29.0 ± 26.8	29.1 (0–52)	87.9 ± 41.9	80.5 (58.7–120.7)	0.0002
Strength of the elbow flexors (N)	43.6 ± 26.2	34.6 (31.5–63.9)	100.2 ± 56.1	88.5 (68.9–113.9)	0.002
Strength of the elbow extensors (N)	39.8 ± 20.4	38.9 (29.3–52.5)	81.2 ± 51.8	66.5 (59.1–100.5)	0.01
Fried criteria (5 points)	2.2 ± 0.9	2 (2–3)	0.8 ± 0.9	1 (0–1)	0.0005
Appendicular lean mass divided by height squared (kg/m^2)	7.8 ± 1.6	7.4 (7.1–7.94)	8.1 ± 1.6	7.88 (7.09–9.33)	0.64
% fat	26.7 ± 15.7	25.8 (15.8–36.2)	21.6 ± 10.1	20.9 (18.7–27)	0.33

*Data adjusted on age, sex and BMI

the only variable associated with the ambulatory activity of the subjects ($\beta = -0.13$; $p = 0.02$).

When comparing subjects below the first quartile (i.e. 449 steps per day) and subjects above 3rd quartile (i.e. 2141 steps per day), the same characteristics appear significantly different between the two groups.

4. Discussion

This study fulfilled 3 objectives.

In the first step, our findings indicated that the Pebble is a valid and reliable device for monitoring step counts, at the population level, when worn on the foot, for all tested treadmill walking speeds, both in young and older adults. These results are in line with the validity and reliability of other activity trackers: A recent study demonstrated an excellent reliability of the FitBit activity monitor device [2]. This validation was performed on 30 young adults, at 5 different walking speeds and the device was worn at the hip level (ICC > 0.95 for each walking speed). Ryan also demonstrated the validity of the ActivPAL activity monitor [26]. This study enrolled 20 young adults and 5 walking speeds were tested. The ActivPAL was worn on the anterior mid-thigh. The Tracmor triaxial accelerometer was also validated among 11 young adults at 3 different speeds [12]. Giannakidou suggest that the Omron pedometers are accurate in the measurement of step-count. This study was conducted on 42 young adults, at five different speeds [27]. Very few studies have validated the tracker activity among older people. However, older adults usually walk more slowly than young adults. Because the validity of pedometers is generally admitted to be lower at low gait speeds [8,9], it is important to assess the accuracy of the activity trackers in this population. This is why we decided to validate the pebble among young adult and elderly. The study of Davis 2007 provides evidence that accelerometry offers a feasible tool for the assessment of several aspects of PA in older people [1]. Moreover, our study is the first to test the validity of the Pebble. This device has the advantages of being cheap, small and easy to use. Nevertheless, data must be downloaded on a computer to see the results.

In the second step, we showed that elderly nursing home residents walked, on average, 1678.4 ± 1621 (median = 1300) steps per day, which is far below the 10.000 steps recommended by the WHO. To assess the number of steps performed by the elderly, we used a cheap and easy to use physical activity tracker (i.e. The Pebble). Although other authors have already evaluated the level of physical activity in elderly populations, this is the first time that this kind of tool is used in nursing home setting. Indeed, in most studies, physical activity among elderly is measured using questionnaires (i.e. PASE [28], PAQ [29], Minnesota [30]). Moreover, to be enrolled in the study, residents needed to be able to stand and to perform different tests (TUG, Tinetti, . . .) which means that the frailest subjects were probably excluded from this study and the average daily number of steps has probably been overestimated. The multiple benefits of physical activity are well known. Indeed, a recent review confirmed that greater physical activity was associated with reduced risk of functional limitations and disability with age [31]. Nevertheless, there is no evidence to inform an absolutely defined number of steps per day specific to older adults. This is probably due to the very broad ranges of habitual activity among older person, which reflect the natural diversity of physical capacity [32]. The only current public health recommendation about the number of steps to be taken per day is aimed at healthy adults and should probably be adapted for older subjects [33].

Finally, the third step of the present study highlighted a positive relationship between lower ambulatory physical activity and poorer muscular and physical performances. This is consistent with a recent study which shown that low levels of physical activity are common and are associated with poor levels of lower limb function in older adults [34]. This is also in line with another performed among elderly women which shown that the median level of daytime activity was most strongly, negatively, related to impairments of function, of activities of daily living, and of social interaction [35]. Moreover, Katz index was the most predictive variable of the ambulatory activity of our institutionalized subjects. This was not surprising because physical impairment is an important component of disability. Others studies showed that higher level of physical activity was associated with lower risk of Activity of Daily Living (ADL) disability [36,37]. However, to our knowledge, very few studies have objectified the relationship between ambulatory activity (i.e. number of steps) and disability. In addition, these data have rarely been obtained in nursing home settings. The prevalence of functional limitations and Activity Daily Living in older persons is estimated at 20–30%, and this percentage increases with age [38]. This figure is consistent with the important physical inactivity prevalence among seniors and confirms the need for further research in the field of disability among older persons. From a clinical point of view, this study highlights the need to assess and improve muscle and physical performances among seniors in order to increase their physical activity. Indeed, assessing the level of physical activity in elderly as well as their physical status (i.e. robust, pre-frail or frail) allows to identify those individuals who although have the ability to be active, are not. From a clinical and Public Health point of view, this is very important in order to implement action to encourage people to move more.

Our study has both strengths and limitation. The main strengths of this study were its rigorous methodology and its originality. Indeed, to the best of our knowledge, this is the first scientific study that has validated and used an activity tracker in institutionalized elderly. Another strength of this study concerns the large number of data collected, by means of different evaluations, at baseline. So, many confounding factors are considered. Then, to ensure a good compliance, the investigators have attached the devices to the shoes of the patients themselves, every morning. They also withdrew the pebble every night. Consequently, there are no missing data in this research. Our study has also some weaknesses. The first limitation concerns the first step of this study. Indeed, it is acknowledged that treadmill walking is not representative of normal walking. However, treadmills are very useful, thanks to their controlled walking speed, to evaluate the accuracy of activity trackers at various speeds. The walking speeds tested were varied and took into account the heterogeneity of walking in the general population. Another limitation concerned the selection criteria of the nursing home residents. To be enrolled in the study, residents needed to be able to stand and to perform different tests (TUG, Tinetti, . . .). Therefore, the frailest subjects were probably excluded from this study and the average daily number of steps has probably been overestimated. Finally, the population included in the validation step isn't fully representative of nursing home residents included in the second and third steps of this study. Nevertheless, one of the walking speeds tested in the first step corresponds to the usual walking speed of elderly.

In conclusion, the Pebble activity tracker is a valid and reliable tool for measuring step counts in young and old adults. Our results also showed that lower ambulatory physical activity is associated with poor physical performances and disability among nursing home residents. From a clinical point of view, a special attention should be given to these subjects with poor physical performances and disability in order to slow down the spiral of the dependency. From a public health point of view, it is urgent to edit recommendations (e.g. number of steps a day) for ambulatory activity adapted to the older persons.

Conflict of interest

None.

Contributors

FB, AM, JYR, JLC, CB, GA and OB conceived the study and the protocol. FB, EL, and JN were in charge of patients' recruitment and collected all data. ND and GA helped in the management of data and FB performed statistical analyses. FB wrote the paper and is primarily responsible for the final content. All authors read and approved the final manuscript.

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