INTRODUCTION

Type 2 diabetes (T2DM) is a global health problem and the prevalence of diabetes is almost 20% in the age group of 65-69 years. Physical activity (PA) based on recommendations can reduce the incidence of T2DM by almost 30%.

According to previous PA profiling, the risk of cardiovascular diseases and high body mass index (BMI) has been shown to be higher in the most sedentary subjects. Accelerometers are feasible and reliable for quantifying habitual PA. Nearly, a third of adults do not meet PA recommendations, and the lack of PA is more common in older adults.

The aim was to analyze the relationship of accelerometry measured physical activity (PA) and sedentary time (SED) profiles to glucose metabolism in 660 people aged 67-69 years. In this cross-sectional study, four different PA profiles were identified (couch potatoes, light movers, sedentary actives, actives) based on moderate to vigorous physical activity (MVPA) and SED. Glucose metabolism was determined by an oral glucose tolerance test. The prevalence of any glucose metabolism disorder was lower in more active PA profiles than in less active profiles (couch potatoes 50%, actives 33%). According to multivariable linear regression, insulin resistance, 120-min glucose, and insulin values were lower among the actives compared with the couch potatoes (HOMA-IR: β = −0.239, 95% CI = −0.456 to −0.022, P = .031; 120-min glucose: β = −0.459, 95% CI = −0.900 to −0.019, P = .041; 120-min insulin: β = −0.210, 95% CI = −0.372 to −0.049, P = .011). Prevalence of glucose metabolism disorders were lower and insulin sensitivity was better among the actives compared with the couch potatoes. Active lifestyle with daily MVPA and low SED seems to improve glucose metabolism even in older age and should be recommended for older adults.

KEYWORDS
exercise, health, physical activity
Knowledge about accelerometry measured PA and sedentary time (SED) and their association with health outcomes in older adults is limited.\(^8\) Older adults spend over half of their waking hours in a sedentary state.\(^4,8,9\) and prolonged SED has been found to be an independent risk factor for T2DM.\(^9,11\)

The benefits of moderate to vigorous physical activity (MVPA)\(^12\) and light physical activity (LPA) on glucose metabolism are acknowledged.\(^12,13\) In older adults, more time spent in MVPA has been associated with lower fasting glucose\(^8,14\) and insulin values.\(^15\) LPA was also associated with lower fasting glucose values\(^14\) and homeostatic model assessment for insulin resistance (HOMA-IR) values,\(^16\) but in other studies, no association between LPA and fasting glucose was found.\(^8\) Some studies have found no connection between SED and fasting glucose\(^8\) in older adults, while others show a positive association between SED and fasting glucose\(^17\) and insulin\(^15\) but not between SED and glycated hemoglobin (HbA1c).\(^17\) Using oral glucose tolerance test (OGTT), instead of only fasting glucose values, can find subject with high risk for T2DM without increasing PA and weight loss.\(^18\)

Physical activity profiles based on PA and SED, the relationships between these and health outcomes can be examined to find high-risk subjects and tailor PA prescriptions.\(^3\) Some studies have evaluated the association between PA profiles and metabolic health among adults.\(^3,4,19,20\) LPA time exceeding SED time has been associated with lower fasting insulin values despite the amount of MVPA\(^19\) and a positive LPA–SED ratio not to be associated with HbA1c, but HbA1c being lower among those who achieved PA recommendations.\(^20\) No studies have been made on the associations between PA profiles and glucose metabolism in older adults. The aim of this study was to reveal how PA profiles based on accelerometry measured PA and SED are related to glucose metabolism in a population-based sample of older people.

## 2 | MATERIALS AND METHODS

### 2.1 | Participants

Originally, all 1332 people born in 1945 living in Oulu, Finland, in 2001 (Oulu45 cohort) were invited to the baseline clinical examination, and 993 participated. In this follow-up study,\(^21\) those who had participated in the baseline visit and who had been alive in 2013 (n = 887) were invited. The final study population (n = 660) of this cross-sectional study consisted of all men (n = 277) and women (n = 383) who had participated in the follow-up data collection and from whom valid accelerometry data were available. For analyzing glucose and insulin parameters, participants with previously diagnosed diabetes were excluded.

The follow-up study was approved by the Ethical Committee of the Northern Ostrobothnia Hospital District in Oulu, Finland (EETTMK 12/2013) and was performed in accordance with the Declaration of Helsinki.

### 2.2 | Questionnaires

The participants perceived health, functional ability, cognition, and economic situation were investigated by questions with categorical answers (very good, pretty good, moderate, pretty poor, very poor). Smoking status (non-smoker, current smoker, and former smoker) was inquired. The total AUDIT scores were calculated for those subjects who had answered to all questions and risky alcohol use defined as ≥8 points.\(^22\) For diseases, the question “Do you currently have any of the following conditions as diagnosed by a medical professional?” was used with answer options “yes” or “no”. The 32 diagnoses inquired included heart, respiratory, endocrinology, neurology, musculoskeletal, mental, and eye diseases.

### 2.3 | Clinical examinations

Weight (to the nearest 0.1 kg), height, and waist circumference (WC) (to the nearest 0.5 cm) were measured. Blood pressure was measured twice on the upper left arm (Omron M3, Omron Healthcare Europe BV) after the participant had been sitting for 5 minutes. WC was measured three times in horizontal lines around the midpoint of the lowest rib and the iliac crest.\(^23\) The mean of the blood pressure and WC measurements was used in the analyses. Body composition was measured using bioelectrical impedance device (InBody 720, InBody).

### 2.4 | Oral glucose tolerance test

A 75-g OGTT was performed after overnight fasting by participants who had not been previously diagnosed with diabetes and did not have diabetes medication, and their glucose levels, measured using a blood glucose meter (Bauer Contour, Bayer Consumer Care AG), were <8.0 mmol·L\(^{-1}\). Plasma glucose and serum insulin values were measured during fasting, at 30 minutes, 60 minutes, and 120 minutes after glucose intake. HbA1C was analyzed on whole blood.

Glucose metabolism disorders were defined as impaired fasting glucose (IFG) (fasting glucose between 6.1 and 6.9 mmol·L\(^{-1}\)), impaired glucose tolerance (IGT) (120-min glucose in OGTT between 7.8 and 11.0 mmol·L\(^{-1}\)), and T2DM (120-min glucose ≥11.1 mmol·L\(^{-1}\) or fasting glucose ≥7.0 mmol·L\(^{-1}\) or HbA1c ≥6.5%).

Homeostatic model assessment for insulin resistance was derived from fasting plasma glucose and insulin concentrations. The original formulas have been modified for more complex computed-based programs.\(^24\) The Matsuda...
index was calculated, as follows: \(10000 \times \frac{\text{fasting glucose level} \times \text{fasting insulin level}}{\text{mean glucose level} \times \text{mean insulin level during the OGTT}}\).\(^{25}\)

### 2.5 Accelerometry measured physical activity

Physical activity was measured with a wrist-worn accelerometry-based monitor (Polar Active, Polar Electro Ltd.) that provides metabolic equivalent (MET) values every 30 seconds.\(^{26}\) Polar Active has been shown to have a strong correlation \((r = 0.987)\) with energy expenditure measured with indirect calorimetry\(^{27}\) and double-labeled water \((r = 0.86)\).\(^{28}\) The participants were advised to use the monitor on their non-dominant wrist for 2 weeks 24 h/day. Age, height, weight, and sex were used as pre-defined inputs to the monitor. The monitor gave no feedback to the participants.

Measured PA was classified into activity levels: very light \((1.00-1.99\text{ MET})\), light \((2.00-3.49\text{ MET})\), moderate \((3.50-4.99\text{ MET})\), vigorous \((5.00-7.99\text{ MET})\), and very vigorous \((\geq 8.00\text{ MET})\), using the limits by the manufacturer. Activity with intensity 3.50 MET or higher was classified as MVPA and activity between 1.00 and 1.99 MET as SED. Participants with at least four valid days of wear time \((\geq 600\text{ min/day})\) were included in the analyses. The monitor wear time was calculated as the sum of all activity over 1 MET. On average, the participants had 13 valid measurement days.

### 2.6 Physical activity profiles

Knowledge-driven PA profiles were created as suggested previously.\(^3\) Based on medians for MVPA \((35\text{ min/day})\) and SED \((708\text{ min/day})\), participants were classified into four groups:

1. Couch potatoes (MVPA <35 min/day; SED \(\geq 708\text{ min/day}\))
2. Light movers (MVPA <35 min/day; SED <708 min/day)
3. Sedentary actives (MVPA \(\geq 35\text{ min/day}\); SED \(\geq 708\text{ min/day}\))
4. Actives (MVPA \(\geq 35\text{ min/day}\); SED <708 min/day)

### 2.7 Statistics

The results were analyzed with IBM SPSS Statistics software (SPSS 24 for Windows, SPSS Inc). The statistical significance was set to \(P < .05\). One-way ANOVA for continuous variables with normal distribution (Tukey’s post-hoc test for pairwise comparison), the Kruskal-Wallis test for continuous variables with non-normal distribution (the Dunn-Bonferroni method for pairwise comparison), and the chi-square test for categorical variables were used to examine the statistical significance of the differences among the PA profiles. The Mantel-Haenszel test for trends was used when the \(P\)-value for the chi-square test was not statistically significant. Participants who had previously diagnosed diabetes were excluded when analyzing glucose and insulin variables, and also, those who had study visit diagnosed diabetes were excluded for IFG and IGT analyses.

The multivariable linear regression model was used to reveal associations among the PA profiles, other confounding factors, and glucose metabolism variables. The PA profiles were entered into the model, and the couch potatoes were used as the reference group. The models were adjusted for WC, sex, diagnosed high blood pressure (yes or no), smoking habits (yes or no), alcohol consumption (AUDIT \(\geq 8\) or <8 points), number of diagnoses, and satisfaction with economic situation (satisfied or not satisfied). Collinearity was tested in multivariable linear regression model. VIF <5 was used for value of non-collinearity. Insulin variables were natural log transformed because of non-normal distribution.

### 3 RESULTS

Most of the participants reported good perceived health, well-being, and functional ability (Table 1). Almost half of the participants reported diagnosed hypertension and over tenth with formerly diagnosed diabetes (type 1 diabetes or T2DM).

The mean time spent on MVPA, LPA, and SED were 41, 254, and 703 min/day, respectively. BMI, WC, visceral fat area, and fat percentage were higher in less active PA profiles. The mean muscle mass percentage was the lowest among the couch potatoes. (Table 1). Previously, undiagnosed T2DM was found in 7%, IFG in 20%, and IGT in 25% of the participants (Figure 1). Both IFG and IGT was found in 9% of the participants.

The prevalence of IGT was the highest among the light movers (30%), followed by the couch potatoes. (29%) and was the lowest among the actives (19%) \((P\) for trend = .009). IFG was found in 23% of the couch potatoes, 22% of the light movers, 25% of the sedentary actives, and 12% of the actives \((P =.021)\). The prevalence of previously undiagnosed T2DM was the highest among the couch potatoes (12%) and the lowest among the sedentary actives (4%) \((P =.034)\). 50% of the couch potatoes and 33% of the actives had some glucose metabolism disorder \((P =.005)\) (Figure 1). 13% of the couch potatoes, 8% of the light movers, 12% of the sedentary actives, and 5% of the actives had both IFG and IGT \((P =.042)\). Previously or study visit diagnosed diabetes was found 19% of the participants, prevalence being 28% for the couch potatoes, 17% for the light movers, 12% for the sedentary actives, and 14% for the actives \((P <.001)\).
The glucose (Table 2, Figure 2) and insulin values (Table 2, Figure 3) were systematically lower during OGTT in more active PA profiles. The HOMA-IR and Matsuda index values were favorable for more physically active profiles (Table 2). In the linear multivariable regression model, the PA profiles were associated with 120-min glucose, 120-min insulin, and HOMA-IR after adjusting for other potential confounding factors. Compared with the couch potatoes, the actives had significantly lower 120-min glucose (β = −0.459, 95% CI = −0.900 to −0.019, P = .041), 120-min insulin values (β = −0.210, 95% CI = −0.372 to −0.049, P = .011), and HOMA-IR values (β = −0.239, 95% CI = −0.456 to −0.022, P = .031). When the models were adjusted also for monitor wear time, the results remained similar. When the PA and SED were treated as continuous variables, the results remained the same, but total physical activity was also associated with Matsuda index and fasting insulin. (Data not shown).

Predictors for fasting glucose (Model R² = 0.158; P < .001) were WC, economic situation, diagnosed hypertension, and number of diagnoses. WC, sex, risky alcohol use, and PA profile were significant predictors for 120-min glucose (Model R² = 0.140; P < .001).

Waist circumference, sex, and risky alcohol use were significantly associated with fasting insulin (Model R² = 0.305; P < .001). Statistically significant predictors for 120-min insulin values (Model R² = 0.237; P < .001) were WC, sex, diagnosed hypertension, and PA profile.

Homeostatic model assessment for insulin resistance (Model R² = 0.277; P < .001) was associated with WC, sex, diagnosed hypertension, and PA profile. WC, sex, and risky alcohol use were statistically significantly associated with the Matsuda index (Model R² = 0.277; P < .001).

4 | DISCUSSION

This population-based study showed an association among PA profiles based on the accelerometry measured MVPA and SED to glucose metabolism in older adults. Four profiles...
couch potatoes, light movers, sedentary actives, and actives — were identified. Prevalence of glucose metabolism disorders was lower in more active PA profiles compared with less active profiles. According to multivariable linear regression analysis, insulin resistance and 120-min glucose and insulin values were lower among the actives compared with the couch potatoes.

Type 2 diabetes has been shown to be twice as common in most sedentary compared with most active older adults, and the findings of this study are similar. IGT was lower among more active PA profiles, and IFG and combination of IFG and IGT were most common in PA profiles where SED was over the median.

Increased PA and decreased SED might be more beneficial for those with IGT than with IFG because of different pathophysiolgies. The decreased prevalence of IFG and combination of IFG and IGT among the light movers compared with the sedentary actives might be that the energy expenditure of PA for the light movers may be higher than for the sedentary actives. The risk for developing T2DM is approximately twice as high for individuals with both IFG and IGT compared with those with either IFG or IGT.

During the OGTT, glucose curve peaked in 30 minutes among the actives and in 60 minutes among the other PA profiles. A previous study in young adults, based on self-reported PA showed glucose curve peaking earlier in more active subjects. Delayed peak of glucose curve has been associated with a higher prevalence of pre-diabetes and T2DM and lower insulin sensitivity.

**FIGURE 1** Glucose metabolism disorders in OGTT or HbA1c by physical activity profiles in previously non-diabetic participants aged 67-69 y. OGTT: Oral glucose tolerance test; IFG: Impaired fasting glucose; IGT: Impaired glucose tolerance; T2DM: Type 2 diabetes. Differences among PA profiles were analyzed with the chi-square test (Pearson chi-square) at significance levels *P <.05 and **P <.01

**TABLE 2** Glucose and insulin values in oral glucose tolerance test and insulin indexes for previously non-diabetic participants according to physical activity profiles based on accelerometry measurement

|                | Couch potatoes | Light movers | Sedentary actives | Actives | All n = 564 |
|----------------|----------------|--------------|-------------------|---------|-------------|
| Fasting glucose| 5.7 (0.6)      | 5.6 (0.5)    | 5.7 (0.6)         | 5.6 (0.5)* | 5.7 (0.5)   |
| 30-min glucose | 8.8 (1.7)      | 9.0 (1.4)    | 8.7 (1.6)         | 8.7 (1.6) | 8.8 (1.6)   |
| 60-min glucose | 9.2 (2.9)*     | 9.2 (2.3)    | 8.8 (2.8)         | 8.4 (2.5)* | 8.8 (2.7)   |
| 120-min glucose| 7.4 (2.2)ab    | 7.1 (1.9)c   | 6.7 (1.7)         | 6.4 (1.8)*** | 6.9 (2.0)   |
| Fasting insulin| 13.7 (9.3-19.9)* | 12.3 (9.0-15.5)c | 12.0 (8.3-16.3) | 9.6 (7.3-14.3)*** | 11.6 (8.3-15.8) |
| 30-min insulin | 71 (48-112)c   | 67 (47-115)  | 59 (42-98)        | 57 (40-86)*  | 62 (43-104) |
| 60-min insulin | 103 (59-163)d  | 93 (54-158)  | 80 (50-146)       | 74 (51-123)** | 81 (53-149) |
| 120-min insulin| 74 (49-148)ab  | 70 (52-142)cd | 52 (39-112)       | 50 (35-80)*** | 60 (41-120) |
| HbA1c (%)      | 5.9 (0.6)      | 5.8 (0.4)    | 5.7 (0.3)         | 5.8 (0.4)  | 5.8 (0.4)   |
| HOMA-IR        | 2.2 (1.4)ab    | 1.9 (1.1)c   | 1.7 (0.8)         | 1.5 (0.8)*** | 1.8 (1.1)   |
| Matsuda index  | 58.0 (35.9)    | 63.4 (43.2)c | 67.9 (33.4)       | 78.4 (38.4)*** | 67.6 (38.6) |

Note: Abbreviations: HOMA-IR, homeostasis model assessment of insulin resistance; SD, standard deviation. Values are mean (SD) or median (25th-75th percentile). Differences among PA profiles are analyzed with one-way ANOVA for variables with normal distribution and the Kruskal-Wallis test for variables with non-normal distribution. Pairwise comparisons were made if the overall P-value was significant at significance levels *P <.05, **P <.01, and ***P <.001. Only significant (P <.05) pairwise comparison P-values are reported: * coach potatoes compared with actives, * coach potatoes compared with sedentary actives, light movers compared with actives, and ** light movers compared with sedentary actives. Values are calculated for the number of participants having data on the variable in question.
Glycated hemoglobin values did not differ between activity profiles. In previous studies, PA levels have not been associated with reversion to normoglycemia in individuals with HbA1c defined pre-diabetes but higher levels of total PA were associated with reversion to normoglycemia for older women whose pre-diabetes was diagnosed by OGTT. Previous days’ PA and diet could effect on results of OGTT in a short period, while HbA1c reflects the glucose control for past 8-12 weeks.\(^3\)

In this study, the insulin curves decreased at the same rate after 60 minutes among the PA profiles. Previously, it has been shown that insulin values during the OGTT decreased after 60 minutes in older adults with normal glucose tolerance and after 90 minutes in those with IFG, but the insulin values of older adults with IGT increased during the whole OGTT.\(^3\)

Lower insulin values during the OGTT may be explained by better muscle insulin sensitivity for more active PA profiles. Based on exercise interventions, PA following recommendations is associated with better insulin sensitivity for older adults.\(^3\) The mean of muscle mass was over 3% higher for actives and sedentary actives than for more sedentary PA profiles. Previously, higher skeletal muscle mass compared to body weight was shown to be associated with better insulin sensitivity.\(^3\)

After the adjustment of confounding factors, the actives differed from the couch potatoes in HOMA-IR and 120-min glucose and insulin values. A previous study found an independent association between LPA and HOMA-IR in older adults but no association between MVPA and HOMA-IR.\(^1\)

In this study, the mean of SED was 703, the mean of LPA was 254, and the mean of MVPA was 41 min/day. In previous studies of older adults, SED varied between 533 and 630, the LPA between 203 and 322, and MVPA between 14 and 36 min/day.\(^4\) We used a wrist-worn accelerometer, while other studies used hip-worn accelerometers. The time spent in MVPA has been shown to be higher and SED has been shown to be lower, measured by Polar Active than hip-worn accelerometers.\(^4\)

Self-reported health, functional ability, and body composition were better, and the number of diagnoses was lower in more active PA profiles. It is important to notice that there might be a reverse causality between diagnoses and PA, which may lead to biased estimate of the association between exposure and outcome. Possibly, the multiple diagnoses of the most sedentary group (couch potatoes) preclude physical activity and they may not have chosen deliberately their sedentary lifestyle.

The strength of this study is accelerometry measured PA and SED in a population-based study of older adults.

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**FIGURE 2** Mean of the plasma glucose values (mmol·L\(^{-1}\)) during the oral glucose tolerance test by physical activity profiles in previously non-diabetic participants aged 67-69 y. Differences among PA profiles were analyzed with one-way ANOVA. Pairwise comparisons were made if the overall P-value was significant at significance levels \(*P < .05\), \(**P < .01\), and \(***P < .001\). Only significant \((P < .05)\) pairwise comparison P-values are reported: \(a\) coach potatoes compared with actives, \(b\) coach potatoes compared with sedentary actives, and \(c\) light movers compared with actives.

**FIGURE 3** Median of the serum insulin values (mU·L\(^{-1}\)) during the oral glucose tolerance test by physical activity profiles in previously non-diabetic participants aged 67-69 y. Differences among PA profiles were analyzed with the Kruskal-Wallis test. Pairwise comparisons were made if the overall P-value was significant at significance levels \(*P < .05\), \(**P < .01\), and \(***P < .001\). Only significant \((P < .05)\) pairwise comparison P-values are reported: \(a\) coach potatoes compared with actives, \(b\) coach potatoes compared with sedentary actives, \(c\) light movers compared with actives, and \(d\) light movers compared with sedentary actives.
accelerometry-based measurements are more accurate than the self-reported method, which is important when examining the association between PA and health variables.

Some limitations to measuring PA with accelerometers must be noted. The accelerometer underestimates energy expenditure in some activities such as carrying and lifting. The slower movements of older adults and the cut-points of MET values, which are the same for younger adults, can affect measurement reliability. Wrist-worn accelerometers generally show less precise estimates of PA intensity and time being sedentary than hip monitors. However, wrist-worn accelerometers have been shown to be easy to use and highly acceptable by older participants and, therefore, the data of wrist-worn accelerometers are considered to have high quality and completeness. Recently, wrist-worn accelerometers were encouraged to be used among older people especially when the participants do not need to have access to feedback from the devices.

Another strength of this study is the PA profiles, which allows to examine the combination of PA and SED with glucose metabolism. In this study, the measurement period of PA includes approximately 13 days instead of the usual 1 week representing better real-life conditions.

In the linear regression model, a strong association was found between WC and glucose metabolism. Association between the PA profile and WC was also found, which can partly explain results of the multivariable linear regression model. Future studies should cover PA profiles’ associations with glucose metabolism in different WC classes.

5  |  PERSPECTIVE
In this population-based study, significant associations were found between accelerometer measured PA profiles and glucose metabolism in older adults. Increasing PA and decreasing SED are important to prevent T2DM. Older adults whose PA statuses are low and who may have physical limitations should be encouraged to increase any intensity of PA instead of SED to improve glucose metabolism, even though the PA levels do not meet the PA recommendations.

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DATA AVAILABILITY STATEMENT
Oulu45 data are available from the University of Oulu, Infrastructure for Population Studies. Permission to use the data can be applied for research purposes via electronic material request portal. In the use of data, we follow the EU general data protection regulation (679/2016) and Finnish Data Protection Act. The use of personal data is based on cohort participant’s written informed consent at his/her latest follow-up study, which may cause limitations to its use. Please, contact NFBC project center (NFBCprojectcenter@oulu.fi) and visit the cohort website (www.oulu.fi/nfbco) for more information.

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