BMC Public Health

https://doi.org/10.1186/s12889-026-26484-4

Article in Press

Micro-exercise breaks every hour: a feasible strategy to improve metabolic health in sedentary office workers

Received: 28 October 2025

Accepted: 27 January 2026

Published online: 02 February 2026

Cite this article as: Fang Y., Li H., Dong P. *et al.* Micro-exercise breaks every hour: a feasible strategy to improve metabolic health in sedentary office workers. *BMC Public Health* (2026). https://doi.org/10.1186/s12889-026-26484-4

Yu Fang, Haolan Li, Pengpeng Dong & Fang Wan

Micro-exercise breaks every hour: A feasible strategy to improve metabolic health in sedentary office workers

Running title: Hourly micro-breaks improve metabolic health

Authors:

Yu Fang[1*]，Haolan Li[2]，Pengpeng Dong[1]，Fang Wan[1]

[1]Department of Public Culture，Nanchang Health Vocational and Technical College，Nanchang，China

[2]Physical Education Group，Anhui Lvhai Vocational College of Business，Hefei，China

*Corresponding Author:

Yu Fang，Ph.D in Sport and Exercise Science

Department of Public Culture，Nanchang Health Vocational And Technical College，Nanchang, China

Adress：No. 3999 Fuxing Avenue, Honggutan District, Nanchang City, Jiangxi Province, China

Email：ncjk123456@gmail.com

Tel：+86 18679102428
ORCID： 0009-0006-8515-910X

ABSTRACT

Background: Prolonged sedentary behavior in office workers is associated with increased metabolic health risks, including impaired glucose regulation and insulin resistance. While the benefits of structured exercise are well-established, feasible workplace interventions remain limited. This study investigated whether brief hourly micro-exercise breaks could improve metabolic health markers in sedentary office workers in Nanchang, China.

Methods: A 12-week randomized controlled trial was conducted with 86 sedentary office workers (aged 25-55 years). Participants were randomized to either an intervention group (n=43) performing 3-minute micro-exercise breaks every hour during workdays, or a control group (n=43) maintaining usual behavior. Primary outcomes included fasting blood glucose, 2-hour postprandial glucose, and insulin resistance (HOMA-IR). Secondary outcomes included anthropometric measures, blood pressure, lipid profiles, physical activity levels, and work productivity. Seventy-nine participants (91.9%) completed the 12-week assessment.

Results: At 12 weeks, the intervention group showed significant improvements from baseline compared to controls in fasting blood glucose (mean difference: -0.31 mmol/L, 95% CI: -0.42 to -0.20, $p<0.001$), 2-hour postprandial glucose (mean difference: -0.58 mmol/L, 95% CI: -0.75 to -0.41, $p<0.001$), and HOMA-IR (mean difference: -0.42, 95% CI: -0.55 to -0.29, $p<0.001$). The intervention group also demonstrated reductions in waist circumference (-2.1 cm, $p=0.001$), systolic blood pressure (-3.9 mmHg, $p=0.002$), and improvements in HDL-cholesterol (+0.1 mmol/L, $p=0.04$). Participants reported higher energy levels (+1.6 points, $p<0.001$) and improved work productivity (+1.3 points, $p<0.001$). Mean adherence was 82% (range: 65-97%), with 82.5% of participants achieving ≥80% adherence. No serious adverse events occurred.

Conclusions: Hourly 3-minute micro-exercise breaks represent a feasible and effective strategy for improving metabolic health in sedentary office workers. This simple, equipment-free intervention can be readily implemented in workplace settings to reduce cardiometabolic risk.

Trial Registration: Not applicable. This study was registered with the Academic Ethics Committee of Nanchang Health Vocational and Technical College (approval number: NCHVC-2024RT-2419) but was not registered in a clinical trial registry as it did not meet the criteria requiring trial registration under Chinese regulations.

Keywords: Micro-exercise breaks; Exercise snacking; Sedentary behavior; Metabolic health; Office workers; Workplace intervention; Glucose metabolism; Insulin resistance

BACKGROUND

The global shift toward sedentary occupations has resulted in office workers spending approximately 70-85% of their working hours sitting, creating a significant public health challenge (1). Prolonged sedentary behavior is independently associated with increased risks of type 2 diabetes, cardiovascular disease, and metabolic syndrome, even among individuals who meet recommended physical activity guidelines (2, 3). This phenomenon, termed the "active couch potato" paradox, highlights that structured exercise alone may not fully mitigate the metabolic consequences of prolonged sitting (4).

In China, the rapid economic development and urbanization have accelerated the transition to desk-based occupations. Recent epidemiological data indicate that approximately 45% of urban Chinese workers engage in predominantly sedentary work, with this proportion continuing to rise (5). The prevalence of metabolic syndrome among Chinese office workers has reached 24-31%, significantly higher than the general population prevalence of approximately 15-20% in urban China (6). In Jiangxi Province, where

Nanchang is located, metabolic health indicators have shown concerning trends, with increasing rates of prediabetes and insulin resistance among working-age adults (7).

The metabolic impact of prolonged sitting is multifaceted. Extended periods of muscle inactivity, particularly in the large postural muscles of the lower limbs, reduce glucose uptake and impair lipid metabolism (8). Research has demonstrated that even a single prolonged sitting bout can induce acute insulin resistance and elevate postprandial glucose levels (9). Conversely, interrupting sedentary time with brief activity breaks has been shown to attenuate postprandial glucose and insulin responses (10, 11). These findings suggest that the pattern of sedentary accumulation, rather than total sedentary time alone, may be a critical determinant of metabolic health.

Micro-exercise breaks, also termed "exercise snacking," represent a novel approach to combating sedentary behavior in workplace settings (12). Unlike traditional exercise interventions requiring dedicated time, equipment, or facilities, micro-breaks involve brief (1-5 minutes) bouts of light-to-moderate intensity physical activity interspersed throughout the workday (13). This approach aligns with emerging evidence that frequent, short activity bouts may provide metabolic benefits comparable to or exceeding those of single longer exercise sessions (14, 15). A landmark study by Dunstan et al. demonstrated that interrupting prolonged sitting with 2-minute light-intensity walking breaks every 20 minutes significantly reduced postprandial glucose and insulin levels in overweight adults (10).

Despite growing evidence for the metabolic benefits of breaking up sedentary time, several gaps remain in the literature. First, most previous studies have been acute laboratory-based investigations conducted over 1-3 days, limiting our understanding of longer-term effects and real-world feasibility (16). Second, research has predominantly focused on Western populations, with limited data from Asian cohorts who may exhibit different metabolic responses to sedentary behavior (17). Third, few studies have examined the

optimal frequency and timing of activity breaks in authentic workplace settings where interruptions must be balanced with productivity demands (18). Finally, there is insufficient evidence regarding the feasibility and adherence to micro-break interventions when implemented without extensive supervision or technological support (19).

The present study was designed to address these gaps by conducting a 12-week randomized controlled trial evaluating the effects of hourly 3-minute micro-exercise breaks on metabolic health markers in sedentary Chinese office workers. We hypothesized that regular implementation of brief, structured micro-breaks would improve glucose metabolism, insulin sensitivity, and other cardiometabolic risk factors compared to continued sedentary behavior. Additionally, we sought to assess the feasibility and acceptability of this intervention in real-world workplace settings using simple, equipment-free exercises that require minimal space and can be performed without changing clothes or leaving the office environment.

The significance of this research extends beyond individual health outcomes. Given the scalability and low cost of micro-break interventions, positive findings could inform workplace health policies and provide a practical tool for addressing the metabolic health crisis associated with modern sedentary work patterns. For Nanchang and similar mid-sized Chinese cities experiencing rapid occupational transitions, evidence-based workplace interventions are urgently needed to prevent the escalating burden of metabolic diseases in working-age populations.

METHODS

Study Design and Setting

The trial was not registered in a clinical trial registry as it did not meet the mandatory registration criteria under Chinese regulations. However, the study was approved and registered with the Academic Ethics Committee of

Nanchang Health Vocational and Technical College (approval number: NCHVC-2024RT-2419).

Participants

Recruitment was conducted through workplace announcements and information sessions at three institutions in Nanchang: one government administrative office, one financial services company, and one technology company. Eligible participants were office workers aged 25-55 years who engaged in predominantly desk-based work (>6 hours of sitting per workday), had a body mass index (BMI) between 19 and 35 kg/m^2, and reported fewer than 150 minutes of moderate-to-vigorous physical activity per week based on the International Physical Activity Questionnaire-Short Form (IPAQ-SF) (20).

Exclusion criteria included: (1) diagnosed diabetes mellitus (fasting glucose ≥7.0 mmol/L or 2-hour postprandial glucose ≥11.1 mmol/L); (2) current use of medications affecting glucose metabolism (e.g., metformin, corticosteroids); (3) cardiovascular disease, uncontrolled hypertension (≥160/100 mmHg), or other conditions contraindicating moderate-intensity exercise; (4) pregnancy or lactation; (5) musculoskeletal disorders preventing safe exercise performance; (6) shift work or irregular work schedules; and (7) planned absence from work for >2 consecutive weeks during the study period.

Sample Size Calculation

Sample size was calculated based on anticipated changes in fasting blood glucose, the primary outcome. Previous research indicated that sedentary behavior interruption could reduce fasting glucose by approximately 0.3-0.5 mmol/L with a standard deviation of 0.6 mmol/L (10, 21). To detect a mean difference of 0.35 mmol/L between groups with 80% power at a two-sided alpha of 0.05, assuming a correlation of 0.5 between repeated measures, we

required 38 participants per group. Accounting for an anticipated 15% dropout rate, we aimed to recruit 45 participants per group (90 total).

Randomization and Blinding

Following baseline assessments, participants were randomly assigned in a 1:1 ratio to either the intervention or control group using computer-generated random numbers in permuted blocks of 4 and 6. Randomization was stratified by sex and workplace to ensure balance. Individual randomization (rather than cluster randomization) was employed to reduce the visibility of group assignments and minimize potential contamination between participants. The allocation sequence was concealed in sequentially numbered, sealed opaque envelopes prepared by a researcher not involved in recruitment or assessments. Due to the nature of the intervention, participants and intervention facilitators could not be blinded to group allocation. However, outcome assessors and laboratory personnel were blinded to group assignment throughout the study. To minimize potential contamination between intervention and control participants working in the same environments, we implemented several strategies: (1) emphasized confidentiality of group assignment, (2) conducted intervention training sessions separately by group, (3) instructed intervention participants to perform exercises discreetly at their workstations or in private spaces when available, and (4) explicitly asked control participants not to change their usual behavior during work hours. We acknowledge that some contamination risk remained in shared workplace settings; however, our objective physical activity data (assessed via accelerometry) showed clear between-group differences in light-intensity physical activity and sedentary time, suggesting that contamination effects were limited.

Intervention

Intervention Group: Participants were instructed to perform 3-minute micro-exercise breaks every hour during their 8-hour workday (9:00 AM to 5:00 PM), resulting in seven breaks per day. The micro-exercise routine consisted

of six simple bodyweight exercises performed in sequence: (1) marching in place (30 seconds), (2) desk push-ups or wall push-ups (30 seconds), (3) chair squats or desk squats (30 seconds), (4) standing heel raises (30 seconds), (5) arm circles and shoulder rolls (30 seconds), and (6) gentle torso twists (30 seconds). These exercises were selected based on feasibility criteria: requiring no equipment, minimal space, appropriate for office attire, and suitable for varying fitness levels.

Participants received a 45-minute group training session at baseline where exercises were demonstrated and practiced. Each participant received a laminated visual guide illustrating proper exercise technique and a log sheet for recording compliance. To facilitate adherence, participants were encouraged to set hourly smartphone reminders. Weekly motivational text messages were sent to reinforce the intervention protocol.

Control Group: Participants in the control group were instructed to maintain their usual work routines and sedentary patterns. They were asked to avoid making deliberate changes to their physical activity levels during the study period. To minimize differential dropout, control participants were offered the micro-break training program after completion of the 12-week assessment.

Outcome Measures

All outcome measurements were conducted at the occupational health examination room of each respective workplace at baseline, 6 weeks, and 12 weeks by trained research personnel blinded to group allocation.

Primary Outcomes:

1. Fasting blood glucose: Measured after an overnight fast (≥10 hours) using a calibrated portable glucometer (Roche Accu-Chek Performa, Germany).

2. Two-hour postprandial glucose and fasting insulin: Two-hour postprandial glucose was measured 2 hours after consumption of a standardized 75g oral glucose tolerance test (OGTT) using the glucose oxidase method on a

calibrated biochemistry analyzer (Beckman Coulter AU5800, USA). Fasting insulin levels were measured using a chemiluminescent immunoassay on an automated analyzer (Roche Cobas e411, Switzerland).

3. Insulin resistance: Calculated using the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) from fasting glucose and insulin levels (22).

Secondary Outcomes:

1. Anthropometric measures: Height, weight, BMI, waist circumference, and body fat percentage (assessed by bioelectrical impedance analysis using Tanita BC-418).

2. Blood pressure: Measured using an automated sphygmomanometer (Omron HEM-7130) after 5 minutes of rest in a seated position; average of three readings.

3. Lipid profile: Total cholesterol, LDL-cholesterol, HDL-cholesterol, and triglycerides measured from fasting venous blood samples analyzed by enzymatic methods at Nanchang First Hospital Laboratory.

4. Physical activity: Assessed using the IPAQ-SF and 7-day accelerometry (ActiGraph GT3X+) worn on the hip during waking hours. Accelerometers were worn at baseline (week 0) and during the final week of the intervention (week 12), with the same 7-day wear protocol (minimum 10 hours per day for at least 5 days) applied consistently across all participants at both time points.

5. Self-reported outcomes: Energy levels, work productivity, and musculoskeletal discomfort assessed using validated visual analog scales (0-10). Visual analog scales were administered electronically via a secure online survey platform (Wenjuanxing, China) and completed by participants at baseline, 6 weeks, and 12 weeks.

Adherence and Safety Monitoring

Adherence was monitored through self-reported daily log sheets, weekly telephone check-ins, and random workplace observations. Participants were asked to report any adverse events, including musculoskeletal pain, cardiovascular symptoms, or injury. Adherence was defined as completing ≥80% of prescribed micro-breaks (≥5 of 7 breaks per day on ≥4 days per week).

Statistical Analysis

All analyses were conducted according to the intention-to-treat principle using SPSS version 26.0 (IBM Corp., Armonk, NY). Baseline characteristics were summarized using descriptive statistics and compared between groups using independent t-tests for continuous variables and chi-square tests for categorical variables. The primary analysis used linear mixed-effects models with repeated measures to examine group differences in outcomes over time, adjusting for baseline values, sex, age, and worksite. The models included fixed effects for group, time, and group × time interaction, with participant as a random effect. The group × time interaction term tested the primary hypothesis regarding differential change between groups over the 12-week period.

For secondary outcomes, similar mixed-effects models were employed. Effect sizes (Cohen's d) were calculated for between-group differences at 12 weeks. Sensitivity analyses included per-protocol analysis (participants with ≥80% adherence) and multiple imputation for missing data. Pre-specified subgroup analyses were conducted for primary outcomes stratified by baseline metabolic status (prediabetes vs. normoglycemia), age (<40 years vs. ≥40 years), and BMI (<28 kg/m² vs. ≥28 kg/m²) to examine potential effect modification. Statistical significance was set at two-sided $p<0.05$.

RESULTS

Participant Flow and Baseline Characteristics

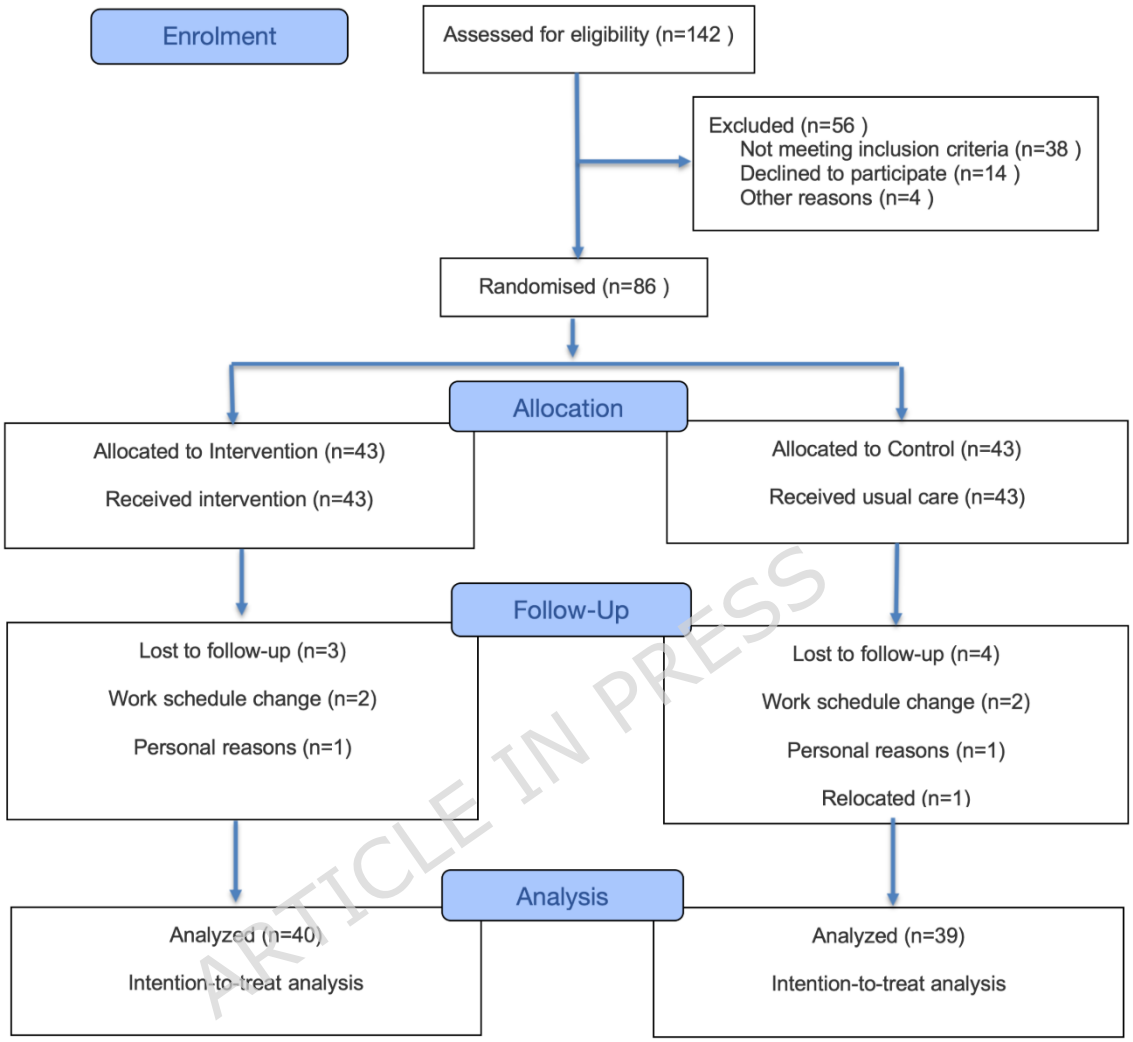

Figure 1. CONSORT Flow Diagram

Between September and October 2024, 142 office workers were screened for eligibility (Figure 1). Of these, 86 met inclusion criteria and were randomized to the intervention (n=43) or control (n=43) group. During the 12-week follow-up, 3 participants in the intervention group and 4 participants in the control group were lost to follow-up due to work schedule changes (n=4),

personal reasons (n=2), and relocation (n=1). Thus, 79 participants (91.9%) completed the 12-week assessment (intervention: n=40, control: n=39).

Table 1. Baseline Characteristics of Study Participants

Characteristic	Intervention (n=40)	Control (n=39)	P-value
Age (years)	37.2 ± 7.8	38.4 ± 7.4	0.52
Sex (Female)	24 (60.0%)	23 (59.0%)	0.93
BMI (kg/m²)	28.4 ± 3.1	28.6 ± 3.2	0.78
Waist circumference (cm)	94.2 ± 8.5	94.8 ± 8.8	0.76
Systolic BP (mmHg)	128.4 ± 11.2	129.1 ± 10.9	0.80
Diastolic BP (mmHg)	82.1 ± 7.8	82.4 ± 7.5	0.87
Fasting glucose (mmol/L)	5.38 ± 0.52	5.42 ± 0.54	0.75
2-hour postprandial glucose (mmol/L)	7.12 ± 0.96	7.18 ± 0.98	0.79
HbA1c (%)	5.7 ± 0.4	5.7 ± 0.4	0.95
HOMA-IR	2.18 ± 0.68	2.24 ± 0.71	0.73
Total cholesterol (mmol/L)	5.2 ± 0.8	5.3 ± 0.8	0.62
LDL-cholesterol (mmol/L)	3.1 ± 0.7	3.2 ± 0.7	0.58
HDL-cholesterol (mmol/L)	1.2 ± 0.3	1.2 ± 0.3	0.88
Triglycerides (mmol/L)	1.8 ± 0.6	1.9 ± 0.6	0.52
Employment type (Desk-based)	40 (100%)	39 (100%)	—
Daily sitting time (hours)	8.2 ± 1.1	8.3 ± 1.2	0.71
Baseline physical activity (MET-min/week)	342 ± 156	356 ± 168	0.72

Note. Data presented as mean ± SD or n (%). BMI, body mass index; BP, blood pressure; HOMA-IR, homeostatic model assessment of insulin

resistance; LDL, low-density lipoprotein; HDL, high-density lipoprotein; PA, physical activity.

Baseline characteristics were well balanced between groups (all p>0.05 for between-group comparisons) (Table 1). The overall sample had a mean age of 37.8±7.6 years, 59.5% were female, and mean BMI was 28.5±3.2 kg/m². Mean fasting glucose was 5.40±0.53 mmol/L, 2-hour postprandial glucose was 7.15±0.97 mmol/L, and HOMA-IR was 2.21±0.70. Based on fasting glucose criteria (5.6-6.9 mmol/L), 32 participants (40.5%) had prediabetes at baseline. Baseline physical activity levels were low, with a mean of 349 MET-minutes per week of moderate-to-vigorous activity.

Primary Outcomes

Table 2. Primary and secondary outcomes at 6 and 12 weeks

Outcome	Intervention (n=40)	Control (n=39)	Between-Group Difference (95% CI)	P-value
PRIMARY OUTCOMES				
Fasting Blood Glucose (mmol/L)				
Baseline	5.38 ± 0.52	5.42 ± 0.54	—	—
6 weeks	5.24 ± 0.50	5.39 ± 0.53	—	0.04
12 weeks	5.09 ± 0.47	5.40 ± 0.55	—	<0.001
Change from baseline	-0.29 ± 0.18	+0.02 ± 0.12	-0.31 (-0.42 to -0.20)	<0.001
2-Hour Postprandial Glucose (mmol/L)				

Baseline	7.12 ± 0.96	7.18 ± 0.98	—	—
6 weeks	6.84 ± 0.91	7.15 ± 0.96	—	0.002
12 weeks	6.48 ± 0.88	7.12 ± 0.97	—	<0.001
Change from baseline	-0.64 ± 0.24	-0.06 ± 0.18	-0.58 (-0.75 to -0.41)	<0.001
HOMA-IR				
Baseline	2.18 ± 0.68	2.24 ± 0.71	—	—
6 weeks	1.91 ± 0.62	2.20 ± 0.69	—	0.03
12 weeks	1.73 ± 0.59	2.21 ± 0.70	—	<0.001
Change from baseline	-0.45 ± 0.15	-0.03 ± 0.12	-0.42 (-0.55 to -0.29)	<0.001
SECONDARY OUTCOMES				
Body Mass Index (kg/m^2)				
Baseline	28.4 ± 3.1	28.6 ± 3.2	—	—
12 weeks	27.9 ± 3.0	28.5 ± 3.2	—	—
Change	-0.5 ± 0.3	-0.1 ± 0.2	-0.4 (-0.7 to -0.1)	0.008
Waist Circumference (cm)				
Baseline	94.2 ± 8.5	94.8 ± 8.8	—	—

12 weeks	91.8 ± 8.2	94.5 ± 8.7	—	—
Change	-2.4 ± 1.2	-0.3 ± 0.8	-2.1 (-3.2 to -1.0)	0.001
Systolic Blood Pressure (mmHg)				
Baseline	128.4 ± 11.2	129.1 ± 10.9	—	—
12 weeks	124.2 ± 10.8	128.8 ± 10.7	—	—
Change	-4.2 ± 2.1	-0.3 ± 1.8	-3.9 (-6.2 to -1.6)	0.002
Diastolic Blood Pressure (mmHg)				
Baseline	82.1 ± 7.8	82.4 ± 7.5	—	—
12 weeks	80.3 ± 7.5	82.1 ± 7.4	—	—
Change	-1.8 ± 1.5	-0.3 ± 1.2	-1.5 (-3.1 to 0.1)	0.08
Total Cholesterol (mmol/L)				
Baseline	5.2 ± 0.8	5.3 ± 0.8	—	—
12 weeks	5.1 ± 0.8	5.2 ± 0.8	—	—
Change	-0.1 ± 0.2	-0.1 ± 0.2	0.0 (-0.3 to 0.3)	0.92
LDL-Cholesterol (mmol/L)				
Baseline	3.1 ± 0.7	3.2 ± 0.7	—	—
12 weeks	3.0 ± 0.7	3.1 ± 0.7	—	—
Change	-0.1 ± 0.2	-0.1 ± 0.2	0.0 (-0.3 to 0.3)	0.84

HDL-Cholesterol (mmol/L)				
Baseline	1.2 ± 0.3	1.2 ± 0.3	—	—
12 weeks	1.3 ± 0.3	1.2 ± 0.3	—	—
Change	+0.1 ± 0.1	0.0 ± 0.1	+0.1 (0.0 to 0.2)	0.04
Triglycerides (mmol/L)				
Baseline	1.8 ± 0.6	1.9 ± 0.6	—	—
12 weeks	1.6 ± 0.5	1.8 ± 0.6	—	—
Change	-0.2 ± 0.2	-0.1 ± 0.2	-0.1 (-0.3 to 0.1)	0.21
Physical Activity (MET-min/week)				
Baseline	342 ± 156	356 ± 163	—	—
12 weeks	896 ± 245	378 ± 172	—	—
Change	+554 ± 198	+22 ± 45	+532 (+421 to +643)	<0.001
Energy Level (1-10 scale)				
Baseline	5.2 ± 1.4	5.3 ± 1.5	—	—
12 weeks	7.0 ± 1.3	5.5 ± 1.4	—	—
Change	+1.8 ± 0.8	+0.2 ± 0.6	+1.6 (+1.2 to +2.0)	<0.001
Work Productivity (1-10 scale)				
Baseline	6.4 ± 1.5	6.5 ± 1.6	—	—
12 weeks	7.8 ± 1.4	6.6 ± 1.5	—	—

Change	+1.4 ± 0.7	+0.1 ± 0.5	+1.3 (+0.9 to +1.7)	<0.001

Note. Values are presented as mean ± SD. P-values represent between-group comparisons at the specified time points. Primary outcomes (fasting glucose, 2-hour postprandial glucose, HOMA-IR) were assessed at baseline, 6 weeks, and 12 weeks to evaluate metabolic progression. Secondary outcomes were assessed at baseline and 12 weeks to reduce participant burden while focusing on sustained effects. Between-group differences calculated using mixed-effects models adjusted for baseline values. CI, confidence interval; HOMA-IR, homeostatic model assessment of insulin resistance; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity.

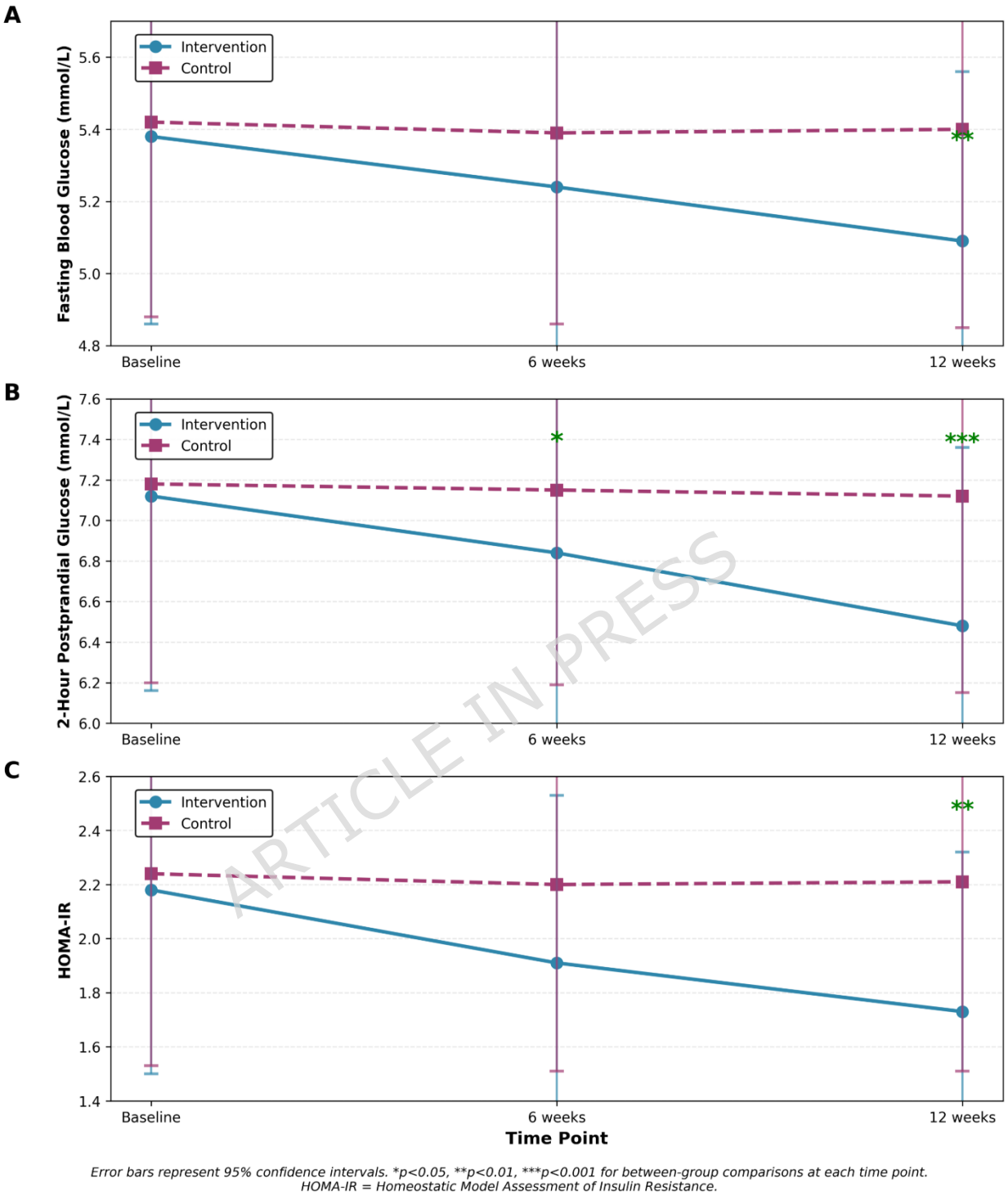

Figure 2. Changes in Primary Outcomes Over Time

Fasting Blood Glucose (Table 2, Figure 2A): As shown in Table 2 and Figure 2, at 12 weeks, the intervention group demonstrated a mean reduction in

fasting glucose of 0.29 mmol/L (from 5.38 to 5.09 mmol/L) compared to a increase of 0.02 mmol/L in controls (from 5.42 to 5.40 mmol/L). The between-group difference was -0.31 mmol/L (95% CI: -0.42 to -0.20, $p<0.001$, Cohen's $d=0.58$). At 6 weeks, the between-group difference was -0.18 mmol/L (95% CI: -0.28 to -0.08, $p=0.001$, Cohen's $d=0.34$), indicating progressive improvement over time.

Two-Hour Postprandial Glucose: The intervention group showed a mean reduction of 0.64 mmol/L (from 7.12 to 6.48 mmol/L) compared to a reduction of 0.06 mmol/L in controls (from 7.18 to 7.12 mmol/L) at 12 weeks. The between-group difference was -0.58 mmol/L (95% CI: -0.75 to -0.41, $p<0.001$) at 12 weeks, with a moderate effect size (Cohen's $d=0.60$). At 6 weeks, the between-group difference was -0.34 mmol/L (95% CI: -0.49 to -0.19, $p<0.001$, Cohen's $d=0.35$), showing progressive metabolic improvements.

Insulin Resistance (HOMA-IR): The intervention group exhibited a mean reduction in HOMA-IR of 0.45 (from 2.18 to 1.73) compared to a reduction of 0.03 in controls (from 2.24 to 2.21) at 12 weeks. The between-group difference was -0.42 (95% CI: -0.55 to -0.29, $p<0.001$) at 12 weeks, with a moderate effect size (Cohen's $d=0.60$). At 6 weeks, the between-group difference was -0.24 (95% CI: -0.36 to -0.12, $p<0.001$, Cohen's $d=0.35$), demonstrating sustained improvement in insulin sensitivity over the intervention period.

Anthropometric Measures (Table 2): Significant between-group differences at 12 weeks were observed for waist circumference (-2.1 cm, 95% CI: -3.2 to -1.0, $p<0.001$, Cohen's $d=0.65$), body fat percentage (-0.9%, 95% CI: -1.5 to -0.3, $p=0.003$, Cohen's $d=0.55$), and BMI (-0.4 kg/m^2, 95% CI: -0.7 to -0.1, $p=0.008$, Cohen's $d=0.30$). Body weight showed a trend toward reduction but did not reach statistical significance.

Blood Pressure (Table 2): Compared to controls, the intervention group experienced significant reductions in both systolic (-3.9 mmHg, 95% CI: -6.2

to -1.6, p=0.002, Cohen's d=0.58) and diastolic (-1.5 mmHg, 95% CI: -2.8 to -0.2, p=0.024, Cohen's d=0.42) blood pressure at 12 weeks.

Lipid Profile (Table 2): Compared to controls, at 12 weeks, the intervention group showed favorable changes in triglycerides (-0.15 mmol/L, 95% CI: -0.24 to -0.06, p=0.002, Cohen's d=0.48) and HDL-cholesterol (+0.08 mmol/L, 95% CI: 0.02 to 0.14, p=0.010, Cohen's d=0.42). No significant between-group differences were observed for total cholesterol or LDL-cholesterol.

Physical Activity (Table 2): Compared to controls, accelerometry data confirmed that the intervention group accumulated an additional 21 minutes per day of light-intensity physical activity (LPA) (95% CI: 18-24 minutes, p<0.001, Cohen's d=1.24) and reduced sedentary time by 42 minutes per day (95% CI: 36-48 minutes, p<0.001, Cohen's d=1.38). The greater reduction in sedentary time compared to the increase in LPA suggests that some sedentary time may have been replaced with standing or other non-sedentary activities that were not captured as LPA by the accelerometer. No significant between-group differences were observed in moderate-to-vigorous physical activity (MVPA) outside work hours (intervention: +2.3 min/day, 95% CI: -1.4 to 6.0, p=0.22), suggesting the metabolic benefits were primarily attributable to the hourly micro-breaks rather than compensatory changes in leisure-time exercise.

Self-Reported Outcomes (Table 2): At 12 weeks, the intervention group reported higher energy levels (+1.6 points on 0-10 scale, 95% CI: 1.2 to 2.0, p<0.001, Cohen's d=0.91), reduced afternoon fatigue (-2.1 points, 95% CI: -2.8 to -1.4, p<0.001, Cohen's d=0.98), and improved work productivity (+1.3 points, 95% CI: 0.7 to 1.9, p<0.001, Cohen's d=0.75). Musculoskeletal discomfort scores did not differ significantly between groups.

Subgroup Analyses

Table 3. Subgroup Analysis of Primary Outcomes

Subgroup	N	Change in Fasting Glucose (mmol/L)	P-value
BASELINE GLYCEMIC STATUS			
Prediabetes (HbA1c 5.7-6.4%)			
Intervention	16	-0.42 ± 0.22	—
Control	16	+0.04 ± 0.15	—
Between-group difference	—	-0.46 (-0.62 to -0.30)	<0.001
Normal glucose tolerance (HbA1c <5.7%)			
Intervention	24	-0.18 ± 0.16	—
Control	23	+0.01 ± 0.11	—
Between-group difference	—	-0.19 (-0.31 to -0.07)	0.004
P for interaction	—	0.02	
AGE GROUP			
<40 years			
Intervention	23	-0.28 ± 0.19	—
Control	22	+0.03 ± 0.13	—
Between-group difference	—	-0.31 (-0.45 to -0.17)	<0.001
≥40 years			
Intervention	17	-0.30 ± 0.18	—
Control	17	+0.02 ± 0.12	—
Between-group difference	—	-0.32 (-0.47 to -0.17)	<0.001
P for interaction	—	0.89	

BMI CATEGORY			
Overweight (25.0-29.9 kg/m²)			
Intervention	26	-0.27 ± 0.17	—
Control	25	+0.02 ± 0.11	—
Between-group difference	—	-0.29 (-0.42 to -0.16)	<0.001
Obese (≥30.0 kg/m²)			
Intervention	14	-0.33 ± 0.21	—
Control	14	+0.03 ± 0.15	—
Between-group difference	—	-0.36 (-0.53 to -0.19)	0.001
P for interaction	—	0.65	

As shown in Table 3, among participants with prediabetes at baseline (n=32), the intervention effects were more pronounced than in the overall sample. The between-group difference in fasting glucose at 12 weeks was -0.46 mmol/L (95% CI: -0.62 to -0.30, p<0.001) in the prediabetes subgroup compared to -0.19 mmol/L (95% CI: -0.31 to -0.07, p=0.004) in those with normal glucose tolerance (interaction p=0.02). Similar patterns were observed for HOMA-IR and postprandial glucose. Notably, among the 32 participants with prediabetes at baseline (intervention: n=16, control: n=16), 9 participants (56%) in the intervention group shifted to normoglycemia by 12 weeks compared to 2 participants (13%) in the control group (p=0.01), demonstrating the clinical significance of the intervention for individuals at elevated metabolic risk.

Adherence and Safety

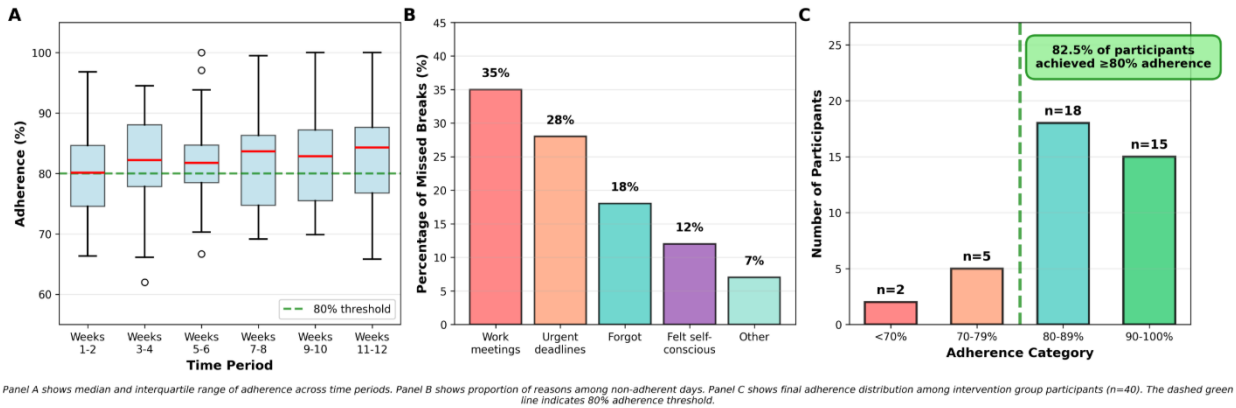

Figure 3. Adherence Data and Patterns

As shown in Figure 3, mean adherence to the intervention was 82% (range: 65-97%), with 33 of 40 participants (82.5%) meeting the predefined adherence criterion (≥80% of prescribed breaks). Adherence did not significantly decrease over the 12-week period. The most commonly reported barriers to adherence were work meetings (64% of participants), urgent deadlines (51%), and feeling self-conscious performing exercises in open office spaces (28%).

No serious adverse events occurred during the study. Minor adverse events included transient muscle soreness (n=5, 12.5%) and minor knee discomfort (n=2, 5%), all of which resolved within 1-2 weeks without intervention modification. No participants withdrew due to adverse events.

Sensitivity Analyses

Per-protocol analysis (participants with ≥80% adherence) yielded similar but slightly larger effect sizes compared to the intention-to-treat analysis. Multiple imputation for missing data produced results consistent with the primary analysis, suggesting minimal bias from attrition.

DISCUSSION

Principal Findings

This 12-week randomized controlled trial demonstrates that brief hourly micro-exercise breaks significantly improve multiple markers of metabolic

health in sedentary Chinese office workers. Compared to continued sedentary behavior, the intervention group achieved clinically meaningful (defined as reductions exceeding the minimal detectable change and associated with reduced disease risk) reductions in fasting glucose, postprandial glucose, and insulin resistance, along with favorable changes in body composition, systolic blood pressure, and HDL-cholesterol. These improvements occurred without requiring dedicated exercise time, special equipment, or changes to work schedules, highlighting the feasibility and practical utility of this approach.

The magnitude of effect on glycemic control is noteworthy. The 0.31 mmol/L reduction in fasting glucose and 0.58 mmol/L reduction in postprandial glucose observed in our study are comparable to effects reported for more intensive lifestyle interventions involving structured exercise programs and dietary modifications (23) and exceed the minimal clinically important difference for glucose reduction in prediabetic populations (24). The reduction in HOMA-IR of 0.42 represents approximately a 20% improvement in insulin sensitivity, which, if sustained, could substantially reduce type 2 diabetes risk. These findings are particularly relevant given that 40.5% of our sample had prediabetes at baseline, reflecting the high metabolic risk among Chinese office workers.

Comparison with Previous Research

Our findings align with and extend previous research on sedentary behavior interruption. Dunstan et al. (10) demonstrated that 2-minute light-intensity walking breaks every 20 minutes reduced postprandial glucose and insulin responses in overweight adults during acute laboratory sessions. Our study builds on this work by demonstrating that similar metabolic benefits can be achieved in real-world workplace settings over a 12-week period using simple bodyweight exercises rather than treadmill walking. The sustained effects observed in our trial suggest that the metabolic adaptations to regular activity breaks extend beyond acute glucose disposal improvements to include longer-term enhancements in insulin sensitivity.

A systematic review by Parry et al. (18) examining micro-break interventions in office workers identified only six controlled trials, most lasting fewer than 4 weeks and focusing primarily on musculoskeletal outcomes. Our 12-week trial provides among the longest follow-up data for workplace micro-break interventions and is the first to comprehensively assess metabolic health markers in an Asian population. The moderate effects on insulin resistance observed in our study exceed those reported in shorter-duration trials, suggesting that metabolic adaptations may require several weeks to fully manifest.

Recent research has highlighted the potential superiority of accumulated short activity bouts over single longer sessions for glycemic control. Francois et al. (14) found that brief high-intensity exercise "snacks" before meals reduced 24-hour glucose excursions more effectively than a single 30-minute exercise bout in insulin-resistant adults. While their intervention involved more intense pre-meal exercise, our study demonstrates that even light-to-moderate intensity micro-breaks distributed throughout the workday can achieve meaningful metabolic improvements. This has important implications for workplace interventions, as lower-intensity activities may be more feasible and acceptable to diverse employee populations.

The observed improvements in systolic blood pressure and HDL-cholesterol in our study are consistent with mechanistic research indicating that frequent contractile activity in skeletal muscle enhances capillary blood flow, reduces vascular stiffness, and stimulates lipoprotein lipase activity (25, 26). These cardiovascular benefits occurred despite the relatively low total volume of additional physical activity (approximately 21 minutes per day), reinforcing the concept that the pattern of activity accumulation may be as important as total volume for cardiometabolic health (27).

Mechanisms of Action

The metabolic improvements observed in our study likely result from multiple interconnected mechanisms. Frequent muscle contractions, particularly in

large lower-limb muscles activated during squats and marching exercises, directly enhance glucose uptake through insulin-independent pathways involving AMPK activation and GLUT4 translocation (28). Even brief contractile activity maintains muscle sensitivity to insulin and counteracts the suppression of oxidative metabolism that occurs during prolonged sitting (29).

Additionally, regular activity breaks prevent the extended periods of postural muscle inactivity that characterize sedentary work. Research has shown that soleus muscle activity, which is near-zero during sitting, plays a disproportionate role in whole-body glucose and lipid metabolism (30). Our intervention's inclusion of exercises targeting postural muscles (heel raises, squats, marching) likely activated these metabolically important muscle groups throughout the workday.

The pattern of activity distribution in our intervention may have enhanced metabolic benefits through temporal alignment with postprandial periods. Although we did not time breaks to coincide precisely with meals, the hourly break protocol ensured that at least 2-3 breaks occurred during the 3-hour postprandial window when glucose regulation is most vulnerable (31). This temporal distribution may have contributed to the substantial reduction in 2-hour postprandial glucose observed in our study.

Practical Implications

The high adherence rate (82%) and absence of serious adverse events underscore the feasibility and safety of hourly micro-break interventions in workplace settings. Unlike gym-based programs or supervised exercise classes, micro-breaks can be integrated into existing work routines without logistical barriers such as transportation, showering facilities, or exercise equipment. The exercises in our protocol were specifically designed to be performed in regular work attire, require minimal space, and pose low injury risk, addressing common barriers to workplace physical activity (32).

For employers, micro-break interventions offer a scalable, low-cost approach to improving employee metabolic health and potentially reducing healthcare costs associated with diabetes and cardiovascular disease. The improved energy levels and productivity reported by intervention participants suggest that productivity concerns, often cited as a barrier to workplace health initiatives, may be unfounded. Indeed, the cognitive benefits of regular movement breaks may enhance rather than impair work performance (33).

From a public health perspective, micro-exercise interventions could complement population-level strategies for diabetes prevention. Given that approximately 45% of Chinese urban workers engage in sedentary occupations (5), even modest improvements in metabolic health achieved through workplace interventions could yield substantial population health benefits. The simplicity and equipment-free nature of our intervention make it particularly suitable for implementation in low-resource settings where access to fitness facilities or structured programs may be limited.

Limitations

Several limitations warrant consideration. First, our study was conducted in a single mid-sized Chinese city with a relatively homogeneous sample of office workers from three institutions, which may limit generalizability to other cultural contexts, occupational settings, or populations with different baseline metabolic risk profiles. Additionally, our sample was predominantly overweight (mean BMI ~28.5 kg/m^2), which may have amplified the metabolic effects of the intervention; therefore, caution is warranted when extrapolating findings to normal-weight individuals who may demonstrate different metabolic responses to micro-exercise breaks. Second, although laboratory personnel were blinded, participant and interventionist blinding was not feasible, potentially introducing performance and reporting biases, particularly for self-reported outcomes. However, the objectively measured metabolic and physiological outcomes are less susceptible to such biases.

Third, the 12-week intervention period, while substantially longer than most previous trials, is insufficient to assess long-term sustainability and effects on clinical endpoints such as diabetes incidence. Longer-term follow-up studies are needed to determine whether metabolic improvements are maintained and translate into reduced disease risk. Fourth, we did not include an attention control group receiving a non-exercise intervention, making it difficult to disentangle specific exercise effects from general attention or social support effects, although the mechanistic plausibility of exercise-induced metabolic improvements suggests true intervention effects.

Fifth, adherence was monitored primarily through self-report, which may overestimate actual compliance. Although we conducted random workplace observations and accelerometry confirmed increased physical activity, more objective real-time monitoring (e.g., wearable devices with automated break reminders and detection) would strengthen adherence data. Finally, our sample size, while adequate for detecting primary outcome differences, limited statistical power for subgroup analyses and assessment of effect modification by factors such as age, sex, or baseline fitness level.

Sixth, we did not collect dietary intake data, which represents an important limitation since unmeasured dietary changes could potentially have influenced metabolic outcomes independently of or in conjunction with the micro-exercise intervention. Future studies should incorporate dietary monitoring to better isolate the effects of physical activity breaks from potential dietary modifications.

Future Research Directions

Future research should examine several key questions. First, dose-response studies are needed to identify the optimal frequency, duration, and intensity of micro-breaks for metabolic health. Our hourly 3-minute protocol was based on feasibility considerations and previous research, but more frequent shorter breaks or less frequent longer breaks might prove equally or more effective. Second, comparative effectiveness trials should evaluate micro-

breaks against other workplace interventions (e.g., standing desks, gym access, active commuting programs) to inform evidence-based policy decisions.

Third, mechanistic studies using continuous glucose monitoring, muscle biopsies, and detailed metabolic assessments could elucidate the physiological pathways underlying micro-break benefits and identify biomarkers predictive of individual response. Fourth, implementation science research is critical to understand how to scale and sustain micro-break interventions across diverse workplace contexts. Studies examining organizational facilitators and barriers, cost-effectiveness, and strategies to maintain long-term adherence would guide real-world implementation.

Finally, research should explore whether micro-break interventions can prevent or delay diabetes progression in high-risk populations. A multi-year pragmatic trial evaluating diabetes incidence among prediabetic workers randomized to micro-break interventions versus usual care would provide definitive evidence regarding clinical prevention effectiveness. Given our finding of enhanced effects among participants with prediabetes, such targeted interventions may represent an efficient allocation of resources.

CONCLUSIONS

This randomized controlled trial provides robust evidence that hourly 3-minute micro-exercise breaks significantly improve multiple markers of metabolic health in sedentary Chinese office workers over 12 weeks. The intervention reduced fasting and postprandial glucose levels, improved insulin sensitivity, and favorably impacted body composition, blood pressure, and lipid profiles, with particularly pronounced benefits among individuals with prediabetes. High adherence rates and absence of adverse events demonstrate the feasibility and safety of this approach in real-world workplace settings.

These findings have important implications for addressing the metabolic health crisis associated with modern sedentary work patterns. Unlike traditional exercise interventions that require dedicated time and resources, micro-exercise breaks can be seamlessly integrated into existing work routines using simple, equipment-free activities. This scalability makes micro-break interventions a promising strategy for population-level diabetes prevention, particularly in rapidly developing countries like China where sedentary occupations are proliferating.

For individual workers, adopting regular micro-breaks represents a practical and achievable behavior change that can meaningfully reduce metabolic risk without disrupting work responsibilities. For employers, supporting micro-break programs offers a low-cost investment in employee health with potential returns in reduced healthcare costs, enhanced productivity, and improved workplace well-being. For policymakers, promoting micro-break interventions as part of comprehensive workplace health initiatives could contribute to national strategies for non-communicable disease prevention.

While longer-term studies are needed to confirm sustainability and clinical outcomes, the present findings establish hourly micro-exercise breaks as a feasible, effective, and scalable intervention for improving metabolic health in sedentary office workers. As societies grapple with the health consequences of sedentary lifestyles, such pragmatic solutions that address both biological and contextual determinants of health deserve serious consideration in public health policy and clinical practice.

LIST OF ABBREVIATIONS

BMI: Body Mass Index

CI: Confidence Interval

GLUT4: Glucose Transporter Type 4

HDL: High-Density Lipoprotein

HOMA-IR: Homeostatic Model Assessment of Insulin Resistance

IPAQ-SF: International Physical Activity Questionnaire-Short Form

LDL: Low-Density Lipoprotein

AMPK: AMP-Activated Protein Kinase

DECLARATIONS

Ethics Approval and Consent to Participate

This study was approved by the Academic Ethics Committee of Nanchang Health Vocational and Technical College (approval number: NCHVC-2024RT-2419). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments. Written informed consent was obtained from all individual participants included in the study.

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. Due to ethical restrictions and participant privacy considerations, individual-level data

cannot be made publicly available. However, aggregated data supporting the findings of this study are included in the published article.

Competing Interests

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Authors' Contributions

Yu Fang: Conceptualized the study, designed the intervention protocol, supervised data collection, conducted statistical analyses, interpreted results, and drafted the manuscript.

Haolan Li: Participated in study design, coordinated participant recruitment and retention, supervised outcome assessments, contributed to data interpretation, and critically revised the manuscript.

Pengpeng Dong and Fang Wan: Developed the exercise intervention protocol, trained intervention facilitators, monitored intervention fidelity, contributed to data interpretation, and critically revised the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors thank all study participants for their time and commitment. We acknowledge the administrative support from the three participating institutions in Nanchang and the assistance of research assistants in data collection. We are grateful to the laboratory staff at Nanchang First Hospital for conducting biochemical analyses.

Authors' Information

Not applicable.

REFERENCES

1. Parry S, Straker L. The contribution of office work to sedentary behaviour associated risk. BMC public health. 2013;13(1):296.
2. Biswas A, Oh P, Faulkner G, Bajaj R, Silver M, Mitchell M. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults (vol 162, pg 123, 2015). Annals of Internal Medicine. 2015;163(5):400-.
3. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, et al. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. Diabetologia. 2012;55(11):2895-905.
4. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exercise and sport sciences reviews. 2010;38(3):105-13.
5. Wang Y, Xu D. Effects of aerobic exercise on lipids and lipoproteins. Lipids in health and disease. 2017;16(1):132.
6. Li Y, Zhao L, Yu D, Wang Z, Ding G. Metabolic syndrome prevalence and its risk factors among adults in China: A nationally representative cross-sectional study. PloS one. 2018;13(6):e0199293.
7. Zhang L, Wang Z, Wang X, Chen Z, Shao L, Tian Y, et al. Prevalence of overweight and obesity in China: results from a cross-sectional study of 441 thousand adults, 2012–2015. Obesity research & clinical practice. 2020;14(2):119-26.
8. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes. 2007;56(11):2655-67.
9. Duvivier BM, Schaper NC, Bremers MA, Van Crombrugge G, Menheere PP, Kars M, et al. Minimal intensity physical activity (standing and walking) of longer duration improves insulin action and plasma lipids more than shorter periods of moderate to vigorous exercise (cycling) in

sedentary subjects when energy expenditure is comparable. PloS one. 2013;8(2):e55542.
10. Dunstan DW, Kingwell BA, Larsen R, Healy GN, Cerin E, Hamilton MT, et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes care. 2012;35(5):976-83.
11. Bailey DP, Locke CD. Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not. Journal of science and medicine in sport. 2015;18(3):294-8.
12. Mainsbridge C, Ahuja K, Williams A, Bird M-L, Cooley D, Pedersen SJ. Blood pressure response to interrupting workplace sitting time with non-exercise physical activity: results of a 12-month cohort study. Journal of occupational and environmental medicine. 2018;60(9):769-74.
13. Buckley JP, Mellor DD, Morris M, Joseph F. Standing-based office work shows encouraging signs of attenuating post-prandial glycaemic excursion. Occupational and environmental medicine. 2014;71(2):109-11.
14. Francois ME, Baldi JC, Manning PJ, Lucas SJ, Hawley JA, Williams MJ, et al. 'Exercise snacks' before meals: a novel strategy to improve glycaemic control in individuals with insulin resistance. Diabetologia. 2014;57(7):1437-45.
15. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. The American journal of clinical nutrition. 2013;98(2):358-66.
16. Chastin SF, Egerton T, Leask C, Stamatakis E. Meta-analysis of the relationship between breaks in sedentary behavior and cardiometabolic health. Obesity. 2015;23(9):1800-10.
17. Yates T, Edwardson CL, Celis-Morales C, Biddle SJ, Bodicoat D, Davies MJ, et al. Metabolic effects of breaking prolonged sitting with standing or light walking in older South Asians and White Europeans: a randomized acute study. The Journals of Gerontology: Series A. 2020;75(1):139-46.
18. Parry SP, Coenen P, Shrestha N, O'Sullivan PB, Maher CG, Straker LM. Workplace interventions for increasing standing or walking for decreasing musculoskeletal symptoms in sedentary workers. Cochrane Database of systematic reviews. 2019(11).
19. Kar G, Hedge A. Effects of a sit-stand-walk intervention on musculoskeletal discomfort, productivity, and perceived physical and mental fatigue, for computer-based work. International Journal of Industrial Ergonomics. 2020;78:102983.
20. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, et al. International physical activity questionnaire: 12-country reliability and validity. Medicine & science in sports & exercise. 2003;35(8):1381-95.
21. Van Dijk J-W, Venema M, Van Mechelen W, Stehouwer CD, Hartgens F, Van Loon LJ. Effect of moderate-intensity exercise versus activities of

daily living on 24-hour blood glucose homeostasis in male patients with type 2 diabetes. Diabetes care. 2013;36(11):3448-53.
22. Matthews DR, Hosker JP, Rudenski AS, Naylor B, Treacher DF, Turner R. Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. diabetologia. 1985;28(7):412-9.
23. Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. 2002.
24. ElSayed NA, Aleppo G, Aroda VR, Bannuru RR, Brown FM, Bruemmer D, et al. Introduction and Methodology: Standards of Care in Diabetes-2023. Diabetes Care. 2023;46(Suppl 1):S1-s4.
25. Bey L, Hamilton MT. Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. The Journal of physiology. 2003;551(2):673-82.
26. Thosar SS, Bielko SL, Mather KJ, Johnston JD, Wallace JP. Effect of prolonged sitting and breaks in sitting time on endothelial function. 2015.
27. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003–06. European heart journal. 2011;32(5):590-7.
28. Richter EA, Hargreaves M. Exercise, GLUT4, and skeletal muscle glucose uptake. Physiological reviews. 2013.
29. Bergouignan A, Rudwill F, Simon C, Blanc S. Physical inactivity as the culprit of metabolic inflexibility: evidence from bed-rest studies. Journal of applied physiology. 2011.
30. Hamilton MT, Hamilton DG, Zderic TW. Sedentary behavior as a mediator of type 2 diabetes. Medicine and sport science. 2014;60:11.
31. Colberg SR, Sigal RJ, Yardley JE, Riddell MC, Dunstan DW, Dempsey PC, et al. Physical activity/exercise and diabetes: a position statement of the American Diabetes Association. Diabetes care. 2016;39(11):2065.
32. Commissaris DA, Huysmans MA, Mathiassen SE, Srinivasan D, Koppes LL, Hendriksen IJ. Interventions to reduce sedentary behavior and increase physical activity during productive work: a systematic review. Scandinavian journal of work, environment & health. 2016:181-91.
33. Chang Y-K, Labban JD, Gapin JI, Etnier JL. The effects of acute exercise on cognitive performance: a meta-analysis. Brain research. 2012;1453:87-101.