Importance of Overall Activity and Intensity of Activity for Cardiometabolic Risk in Those with and Without a Chronic Disease

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ABSTRACT

DAWKINS, N. P., T. YATES, C. L. EDWARDSON, B. MAYLOR, J. HENSON, A. P. HALL, M. J. DAVIES, D. W. DUNSTAN, P. J. HIGHTON, L. Y. HERRING, K. KHUNTI, and A. V. ROWLANDS. Importance of Overall Activity and Intensity of Activity for Cardiometabolic Risk in Those with and Without a Chronic Disease. *Med. Sci. Sports Exerc.*, Vol. 54, No. 9, pp. 1582–1590, 2022. **Introduction:** Higher levels of physical activity are associated with lower cardiometabolic risk. However, the relative contribution of overall activity and the intensity of activity are unclear. Our aim was to determine the relative contribution of overall activity and intensity distribution of activity to cardiometabolic risk in a cross-sectional analysis of apparently healthy office workers and in people with one or more chronic disease. **Methods:** Clustered cardiometabolic risk score was calculated from mean arterial pressure, high-density lipoprotein cholesterol, triglycerides and HbA1c. Open-source software (GGIR) was used to generate average acceleration and intensity gradient from wrist-worn accelerometer data for two data sets: office-workers who did not have a self-reported medical condition (n = 399, 70% women) and adults with one or more chronic disease (n = 1137, 34% women). Multiple linear regression analyses were used to assess the relative contribution of overall activity and intensity of activity to cardiometabolic risk. **Results:** When mutually adjusted, both overall activity and intensity of activity were independently associated with cardiometabolic risk in the healthy group ($P < 0.05$). However, for the CD group, although mutually adjusted associations for average acceleration were significantly associated with cardiometabolic risk ($P < 0.001$), intensity was not. In healthy individuals, cardiometabolic risk was lower in those with high overall activity and/or intensity of activity, and who also undertook at least 10 min brisk walking. In those with a chronic disease, risk was lower in those who undertook at least 60 min slow walking. **Conclusions:** These findings suggest interventions aiming to optimize cardiometabolic health in healthy adults could focus on increasing both intensity and amount of physical activity. However, in those with chronic disease, increasing the amount of activity undertaken, regardless of intensity, may be more appropriate. **Key Words:** ACCELEROMETRY, GGIR, CARDIOMETABOLIC RISK, CHRONIC DISEASE, INTENSITY GRADIENT

Noncommunicable diseases, such as cancers, cardiovascular diseases, diabetes, and noninfectious respiratory disorders, are responsible for approximately 70% of deaths globally (1). This indicates a shift in the causes of mortality from communicable to noncommunicable disease (2), contiguous with the increase in aging populations globally (3). Consequently, understanding the mechanisms behind these conditions is important. Physical activity is widely accepted as being beneficial for health and has been shown to reduce the risk of cardiovascular disease, diabetes, hypertension, dyslipidemia, and multimorbidity (4–6), with cardiometabolic disease outcomes inversely associated with level of physical activity (7,8). Even a modest increase from a low activity level over time has been shown to reduce the incidence of cardiometabolic risk factors (9). Consequently, it is increasingly recognized that physical activity of all intensities across the 24 $h \cdot d^{-1}$ should be considered for population health benefits, not only time spent in moderate-to-vigorous physical activity (10).

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Two metrics that facilitate analysis of the 24-h activity profile from raw accelerometer data are average acceleration and intensity gradient (11). The average acceleration reflects the overall physical activity or the total amount of physical activity; the intensity gradient reflects the distribution of activity intensity across the day, with a higher value reflecting a greater proportion of activity at higher intensities. Crucially, these two metrics are only moderately correlated (12), thus can be used to glean insights into the relative importance of the amount of activity or the intensity for health (12). For example, application of these methods has suggested that the intensity of activity is key for bone mineral density in adults (13), adiposity in children (11), cardiovascular risk in children (14), and physical function in adults (11). However, both amount and intensity of activity are additively associated with adiposity in adults (11), and high amounts of lower-intensity activity during adolescence may be beneficial for hip structural geometry in young adults (13).

To our knowledge, these metrics have not been used to investigate associations between physical activity and cardiometabolic risk in adults. An understanding of the relative importance of the amount of activity and the intensity of activity for cardiometabolic risk could provide insight into mechanisms underlying associations and inform the development of interventions tailored to different populations. This stems from the most recent World Health Organization physical activity guidelines which for the first time provided guidance specific to those with a chronic disease (15). As such, it is important to assess health outcomes in relation to physical activity in a similar manner to meet the needs of specific populations.

Thus, this study aims to determine the relative contribution of the overall activity and intensity of physical activity to cardiometabolic risk in apparently healthy office workers and people with one or more chronic disease.

MATERIALS AND METHODS

Data Source and Study Populations

Data were taken from four cross-sectional studies, within the Leicester Diabetes Centre, all of which assessed physical activity using wrist-worn accelerometers: healthy office workers (healthy); adults with multimorbidity, adults with type 2 diabetes, and adults 12 to 24 months postcardiac event diagnosis. All extracted measures were collected in line with the published protocols for each of the studies (16–18). Methodologies used in these studies were all very similar.

The Stand More at (SMART) Work and Life data (healthy) has been previously described by Edwardson et al. (16). In brief, participants were adult office workers 18 yr or older within local Councils in the Leicester, Manchester, and Liverpool areas (n = 723). For the current study, participants who had a self-reported medical condition (n = 275) were excluded to form an ostensibly healthy sample.

Chronotype of patients with type 2 diabetes and effect on glycemic control (CODEC) has been previously described by Brady et al. (19). In brief, it is an ongoing study at the involving people with type 2 diabetes aiming to recruit approximately 2000 participants. Data were obtained from adult participants age 18 to 75 yr (n = 712) currently enrolled in the study.

Movement through Active Personalized engagement (MAP) has been previously described by Dalosso et al. (17). In brief, it is a study involving people with two or more long term conditions age 40 to 85 yr recruited from primary care as. Data were extracted for those with accelerometer data available at baseline (n = 346).

Physical Activity after Cardiac EventS (PACES) has been previously described by Herring et al. (18). In brief, it is a study involving adults age ≥18 yr, 12 to 48 months postdiagnosis of a coronary heart disease related cardiac event as. Data were extracted for those with accelerometer data available at baseline (n = 285).

All studies received ethical approval from the local NHS research ethics committee and participants provided written informed consent. Where a study had multiple timepoints, baseline data were used.

For this study, the three CD groups (CODEC, MAP, and PACES) were combined into a single chronic disease (CD) group. These three groups contained people with similar characteristics as well as the chronic conditions sharing common mechanisms. This newly merged group pooled data from participants with one or more chronic disease (n = 1343). Descriptive characteristics for each of these groups is presented in Supplemental Table S1 (see Supplemental Digital Content, Descriptive characteristics and physical activity by CD subgroups, http://links.lww.com/MSS/C573).

Demographics

The following data were extracted from the relevant cohorts: age, sex, ethnicity, socioeconomic status, smoking status and whether lipid lowering, or blood pressure medications were prescribed. Self-reported ethnicity was collapsed into categories of white, South Asian, or other, in view of the small number of people from other ethnic groups. Socioeconomic status was estimated from the index of multiple deprivation (IMD) which was determined from self-reported postcode (20). Smoking status was categorized as never smoked, former smoker and current smoker.

Anthropometric and Biomedical Characteristics

Height, body mass, waist circumference, blood pressure, resting heart rate, and body fat percentage (assessed using bioelectrical impedance [Tanita SC-330ST; Tanita Europe BV, Middlesex, UK]), and biomedical markers (HbA1c, fasted blood glucose, and lipid profile), were extracted from each dataset. Body mass index was calculated as body mass (kg)/height $(m)^2$. A clustered cardiometabolic risk score was calculated from mean arterial pressure, high-density lipoprotein (HDL) cholesterol, triglycerides and HbA1c, as has previously been used to assess associations between physical activity and cardiometabolic risk in healthy and at risk populations (21,22,23). Triglycerides, HDL cholesterol, and HbA1c were not normally distributed and were log transformed. Variables were standardized within

group, and the standardized score for HDL cholesterol were inverted. The individual *z*-scores were summed, and the cardiometabolic risk score was calculated as the mean of the standardized scores. Thus, the cardiometabolic risk scores were group specific, which is appropriate for investigation of associations within each of the groups (23). An additional cardiometabolic risk score was calculated, including waist circumference, a measure of adiposity.

Physical Activity

Participants were requested to wear accelerometers on their nondominant wrist 24 $h \cdot d^{-1}$ for up to 8 d. In the CD groups, the participants wore the GENEActiv (ActivInsights Ltd, Cambridgeshire, UK), whereas the healthy group wore the Axivity AX3 (Axivity, Newcastle, UK). Accelerometers were initialized to record accelerations at 100 Hz with a dynamic range of ±8*g*. Available evidence suggests that physical activity outcomes from the GENEActiv and Axivity devices worn on the nondominant wrist can be considered largely equivalent (24).

Accelerometer data processing. All devices were initialized and downloaded using their specific software prior to receipt into this study. GENEActivs were initialized and data downloaded in binary format using GENEActiv PC (version 3.1). Axivity devices were initialized and data downloaded in .cwa format using OmGui open-source software (OmGui Version 1.0.0.30, Open Movement, Newcastle, UK).

All accelerometer files were processed and analyzed identically with R-package GGIR version 1.9–0 (http://cran.r-project.org) (25). Signal processing in GGIR included autocalibration using local gravity as a reference (26), detection of sustained abnormally high values, detection of nonwear, calculation of the average magnitude of dynamic acceleration (i.e., the vector magnitude of acceleration corrected for gravity [Euclidean Norm minus 1*g*]) in milli-gravitational units (mg) averaged over 5-s epochs. Participants were excluded if their accelerometer files showed: postcalibration error greater than 0.01*g* (10 mg), fewer than 3 d of valid wear (defined as >16 $h \cdot d^{-1}$) (27), or wear data not present for each 15 min period of the 24-h cycle. The default setting was used for the detection of nonwear as described previously (26).

The following outcomes were generated and averaged across all valid days ("AD" variables in GGIR): average acceleration (mg) (overall activity); intensity gradient (intensity); acceleration (intensity) above which a person's most active X minutes (MX metrics, where X is the number of minutes) are accumulated (mg): $M1/3_{DAY}$; M120; M60; M30, M15; M10; M5; M2. These metrics have been described in full previously (28) and are detailed in the supplemental material (Table S2, see Supplemental Digital Content, Physical activity metrics, http://links.lww.com/MSS/C573).

Analysis

Pearson's correlation coefficients were used to investigate the correlations between the average acceleration and the intensity gradient within each sample to confirm they contained independent information on the physical activity profile.

A series of multiple linear regression analyses were used to explore the relative contributions of overall activity and intensity of activity on cardiometabolic risk score and for each of the risk factors individually (waist circumference, mean arterial pressure, HbA1c, triglycerides and HDL cholesterol). In each case, model 1 was unadjusted, and model 2 was adjusted for the potential covariates (age, sex, ethnicity, smoking status, IMD, and lipid lowering or blood pressure medication). Models 1 and 2 were run for average acceleration and the intensity gradient. Model 3 was also adjusted for potential covariates, but both average acceleration and the intensity gradient were entered together to test whether associations were independent, and the product term of average acceleration and the intensity gradient entered to determine whether there was an interactive effect of the amount and intensity of physical activity. Results were deemed significant at $P < 0.05$. Continuous variables were centered before entry into the analyses. Centering involves subtracting the mean from each individual score; therefore, the mean of the centered variable was zero. The product term of average acceleration and the intensity gradient was calculated from the centered scores. The variance inflation factor (VIF) was calculated to check for multicollinearity with a value greater than 5 indicating the effects of the predictors could not be reliably estimated (29).

To elucidate the form of significant independent, additive, and interactive effects, the relationship between overall activity and cardiometabolic risk when the intensity gradient was medium (at its mean), high (1 standard deviation [SD] above the mean), and low (1 SD below the mean) were graphed, as described elsewhere (30). These illustrate the predicted cardiometabolic risk for a male participant with mean values for all the covariates. By entering both overall activity and intensity of activity metrics and their product term into regression analyses (as described above), it is possible to determine whether only intensity or overall activity is important (main effect of one independent of the other, but no additive or interactive effect); there are additive effects of overall activity and intensity (main effects of intensity and overall activity independent of each other, but no interaction); or the effect of overall activity differs by intensity, e.g., at high intensities, there is little added benefit from increasing overall activity, but at low intensities adding activity is beneficial (interactive effect) (11).

As the overall activity and intensity metrics may not be immediately interpretable to visualize the physical activity profiles in relation to typical activities, group means for the MX values were plotted on radar plots as previously described (31). Dotted/dashed circles show approximate values for slow walking (100 mg), brisk walking (250 mg) and vigorous physical activity (400 mg) taken from laboratory calibration studies (32) as previously described (28,33). Walking values are included in the translation of the data to provide a user friendly measure of physical activity. To clearly illustrate relative differences between groups for each of the MX metrics, a standardized plot is also presented. The MX metrics were standardized within the metric relative to the mean and SD of the healthy reference group. The *z* scores were plotted on the standardized radar plot,

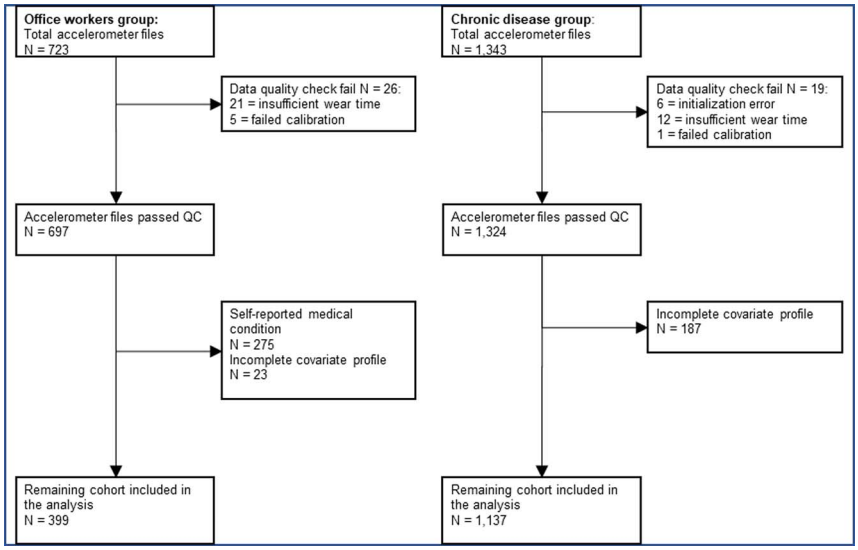

FIGURE 1—Participant flowchart.

illustrating how each metric differs from the healthy group in terms of SD. These plots illustrate the intensity profile across, which the amount of activity is accumulated.

Linear regressions were run using Stata 16 (StataCorp LP, College Station, TX) and the radar plots were generated using a ggplot2 in R. Alpha was set at 0.05. Interactions were considered significant at $P < 0.1$.

RESULTS

Data were available for 2066 participants, of which 530 were excluded from this study (detailed in Fig. 1), resulting in 1536 participants being included in the final analysis. Descriptive statistics are presented in Table 1. Mean (SD) age for participants in the healthy group was 43 yr (10.5 yr), approximately 20 yr younger than the CD group. The healthy group had better markers for health than the CD group. Proportionally more people had never smoked in the healthy group (67.9%) compared with the CD group (48.7%) and the healthy group had a higher proportion of women in its sample (70.4%) compared with the CD group (33.5%). White participants made up the largest proportion of both groups, but the proportion was higher in the CD group (90.2%) compared with the healthy group (74.4%). Healthy office workers who were excluded based on an incomplete covariate profile were similar to those included, but less likely to have never smoked. Those excluded from the CD group did not differ on demographics but were less likely to be on blood pressure medication, had more favorable HbA1c and triglycerides, and poorer overall activity and HDL cholesterol (Supplemental Table S3, see Supplemental Digital Content, Participant characteristics by inclusion/exclusion, http://links.lww.com/MSS/C573).

The correlations between the average acceleration and the intensity gradient were moderate at 0.56 and 0.63, shared variance 31% and 40%, for the healthy group and CD group, respectively, indicating that the two metrics provided complementary information. The R^2 for the intensity gradient was >91% in both groups, indicating that it was a good fit for the intensity distribution (12).

Association between Physical Activity and Cardiometabolic Risk

The results of the analyses of all models are presented in Table 2. The modeled cardiometabolic risk associated with ±1 SD difference in average acceleration and/or intensity gradient of a male participant with mean values for all the covariates is illustrated in Figures 2A and 3A, and the physical activity profiles associated with different levels of risk are illustrated in Figures 2B and 3B.

TABLE 1. Descriptive characteristics and physical activity by group.

	Healthy Office Workers (n = 399)	Chronic Disease (n = 1137)
Continuous variables		
Age (yr)	43.0 (10.5)	65.2 (9.2)
Height (cm)	166.9 (9.3)	168.9 (9.3)
Mass (kg)	71.0 (15.5)	86.6 (17.3)
BMI (kg·m^{-2})	25.4 (4.8)	30.3 (5.1)
Mean arterial pressure	90.7 (10.9)	98.0 (12.3)
HbA1c (mmol·mol^{-1})	33.0 (3.5)	49.5 (13.9)
HbA1c (%)	5.2 (0.3)	6.68 (1.27)
Triglycerides (mmol)	1.17 (0.62)	1.72 (0.97)
HDL cholesterol (mmol)	1.45 (0.42)	1.34 (0.41)
Waist circumference (cm)	85.7 (13.7)	104.6 (14.3)
IMD rank	18,308.0 (9290.4)	20,546.2 (8744.7)
IMD decile	6.08 (2.81)	6.75 (2.67)
Categoric variables		
Ethnicity (White)	297 [74.4]	1,024 [90.2]
Sex (female)	281 [70.4]	381 [33.5]
Smoking (never)	271 [67.9]	554 [48.7]
Lipid medication (no)	397 [99.5]	331 [29.1]
Blood pressure medication (no)	397 [99.5]	285 [25.1]
Physical activity variables		
Average acceleration (mg)	27.9 (7.3)	22.4 (7.0)
Intensity gradient	−2.53 (0.20)	−2.73 (0.21)

BMI, body mass index.
Values are presented as mean (standard deviation) or n [%].

TABLE 2. Associations between physical activity (average acceleration and intensity gradient) and cardiometabolic risk and the individual variables in office workers and people with one or more chronic disease(s).

		Model 1		Model 2			Model 3		
		Coefficient	95% CI	R^2 (%)	Coefficient	95% CI	R^2 change with intensity (%)	Coefficient	95% CI
Healthy group (office workers without a self-reported medical condition)									
Cardiometabolic risk	Average acceleration (*mg*)	**–0.015**	**–0.022 to –0.007**	**24.3**	**–0.013**	**–0.019 to –0.007**	**+1.0**	**–0.009**	**–0.017 to –0.001**
	Intensity gradient	**–0.486**	**–0.743 to –0.229**	**24.5**	**–0.524**	**–0.779 to –0.270**		**–0.382**	**–0.708 to –0.057**
Cardiometabolic risk (with WC)	Average acceleration (*mg*)	**–0.016**	**–0.023 to –0.008**	**28.0**	**–0.014**	**–0.020 to –0.008**	**+1.5**	**–0.009**	**–0.017 to –0.000**
	Intensity gradient	**–0.551**	**–0.810 to –0.292**	**28.9**	**–0.604**	**–0.852 to –0.356**		**–0.475**	**–0.793 to –0.156**
Waist circumference	Average acceleration (*mg*)	**–0.296**	**–0.478 to –0.114**	**21.9**	**–0.258**	**–0.421 to –0.094**	**+2.0**	–0.099	–0.307 to 0.110
	Intensity gradient	**–12.064**	**–18.205 to –5.922**	**23.7**	**–13.848**	**–19.738 to –7.959**		**–12.572**	**–19.836 to –5.309**
Mean arterial pressure	Average acceleration (*mg*)	–0.085	–0.222 to 0.052	11.7	–0.063	–0.196 to 0.070	**+0.9**	0.020	–0.148 to 0.188
	Intensity gradient	–4.743	–10.107 to 0.620	**12.5**	**–5.751**	**–11.274 to –0.228**		**–6.649**	**–13.183 to –0.116**
HbA1c	Average acceleration (*mg*)	**–0.066**	**–0.108 to –0.024**	**16.2**	**–0.056**	**–0.096 to –0.017**	+0.3	**–0.056**	**–0.103 to –0.005**
	Intensity gradient	**–2.442**	**–4.050 to –0.833**	**15.7**	**–1.723**	**–3.301 to –0.146**		–1.001	–2.954 to 0.952
Triglycerides	Average acceleration (*mg*)	**–0.008**	**–0.015 to –0.001**	**6.1**	–0.007	–0.014 to 0.001	+0.1	–0.006	–0.017 to 0.005
	Intensity gradient	**–0.278**	**–0.546 to –0.009**	**5.9**	–0.211	–0.501 to 0.080		–0.126	–0.534 to 0.282
HDL cholesterol	Average acceleration (*mg*)	**0.009**	**0.003 to 0.015**	**20.9**	**0.011**	**0.005 to 0.017**	**+1.2**	0.006	–0.001 to 0.012
	Intensity gradient	**0.261**	**0.063 to 0.458**	**21.1**	**0.426**	**0.241 to 0.610**		**0.255**	**0.035 to 0.475**
CD group									
Cardiometabolic risk	Average acceleration (*mg*)	**–0.018**	**–0.023 to –0.014**	**13.2**	**–0.026**	**–0.031 to –0.022**	+0.1	**–0.025**	**–0.031 to –0.019**
	Intensity gradient	**–0.288**	**–0.445 to –0.131**	**7.9**	**–0.564**	**–0.735 to –0.393**		–0.078	–0.276 to 0.119
Cardiometabolic risk (with WC)	Average acceleration (*mg*)	**–0.022**	**–0.026 to –0.018**	**17.1**	**–0.030**	**–0.034 to –0.026**	+0.1	**–0.029**	**–0.035 to –0.024**
	Intensity gradient	**–0.350**	**–0.503 to –0.198**	**9.8**	**–0.639**	**–0.803 to –0.747**		–0.081	–0.268 to 0.107
Waist circumference	Average acceleration (*mg*)	**–0.515**	**–0.620 to –0.409**	**13.0**	**–0.650**	**–0.763 to –0.537**	+0.2	**–0.665**	**–0.808 to –0.522**
	Intensity gradient	**–8.658**	**–12.318 to –4.997**	**7.4**	**–13.489**	**–17.375 to –9.602**		–1.365	–5.919 to 3.189
Mean arterial pressure	Average acceleration (*mg*)	–0.031	–0.127 to 0.066	**4.7**	–0.085	–0.186 to 0.017	+0.2	–0.018	–0.149 to 0.114
	Intensity gradient	–2.034	–5.338 to 1.270	**4.9**	**–3.688**	**–7.279 to –0.096**		–2.874	–7.321 to 1.574
HbA1c	Average acceleration (*mg*)	**–0.022**	**–0.032 to –0.012**	**7.4**	**–0.034**	**–0.045 to –0.023**	+0.3	**–0.032**	**–0.045 to –0.019**
	Intensity gradient	**–0.403**	**–0.728 to –0.077**	**6.0**	**–0.855**	**–1.226 to –0.484**		–0.305	–0.719 to 0.109
Triglycerides	Average acceleration (*mg*)	**–0.018**	**–0.027 to –0.009**	**5.9**	**–0.026**	**–0.036 to –0.016**	+0.2	**–0.024**	**–0.035 to –0.012**
	Intensity gradient	**–0.382**	**–0.661 to 0.103**	**4.5**	**–0.664**	**–0.983 to –0.345**		–0.237	–0.576 to 0.103
HDL cholesterol	Average acceleration (*mg*)	**0.011**	**0.007 to 0.014**	**15.3**	**0.014**	**0.011 to 0.018**	**+0.3**	**0.016**	**0.012 to 0.021**
	Intensity gradient	0.594	–0.060 to 0.179	**10.8**	**0.194**	**0.073 to 0.315**		**–0.134**	**–0.257 to –0.011**

Model 1: unadjusted. Model 2: adjusted for sex, age, height, body mass, ethnicity, SES, lipid lower and blood pressure altering medication status. Model 3: further adjusted for alternate physical activity metric and the product term (average acceleration × intensity gradient) entered to investigate interactive effects.
Significant associations are denoted in bold.
Continuous variables were centered before entry into the analysis. Physical activity interaction terms were calculated from the centered scores.
WC, waist circumference; 95% CI, 95% confidence interval.

Healthy group. Both higher overall activity and higher activity intensity were associated with lower cardiometabolic risk (model 1), with the associations maintained after accounting for covariates (model 2). Both average acceleration and the intensity gradient were associated independently of each other, with intensity adding a further 1% ($P < 0.05$) to the variance explained (model 3). The associations between physical activity and cardiometabolic risk score did not differ whether cardiometabolic risk score was calculated with or without a measure of adiposity (waist circumference).

When looking at risk factors individually, both higher overall activity and higher intensity were beneficially associated with waist circumference, HbA1C, and HDL cholesterol independent of covariates, but only the intensity with mean arterial pressure (model 2). When both activity metrics were entered (model 3), the association with intensity remained significant for waist circumference, mean arterial pressure and HDL cholesterol, whereas for HbA1c, the association with overall activity remained significant. Triglycerides were not associated with either physical activity metric in any model. There were no significant interactions between overall activity and intensity for cardiometabolic risk or individual risk factors. The VIF was less than 1.8 in all cases.

Chronic disease group. Both higher overall activity and higher activity intensity were associated with lower cardiometabolic risk (model 1). These associations were maintained after adjusting for co-variates (model 2); however, only overall activity was independently associated with cardiometabolic risk, with intensity not adding significantly to the model (R^2 change = 0.1%, $P > 0.05$) (model 3). This suggests that there is not an association between cardiometabolic risk and physical activity intensity over and above that accounted for by overall physical activity. The associations between physical activity and cardiometabolic risk score did not differ whether cardiometabolic risk score was calculated with or without a measure of adiposity (waist circumference). Associations between physical activity and cardiometabolic risk for the CD subgroups are shown in Supplemental Table S4 (see Supplemental Digital Content, Associations between physical activity and cardiometabolic risk in the CD subgroups, http://links.lww.com/MSS/C573).

When looking at risk factors individually, both higher overall activity and higher intensity were beneficially associated with waist circumference, HbA1c, triglycerides, and HDL cholesterol independent of co-variates, but only intensity for mean arterial pressure (model 2). When both activity metrics

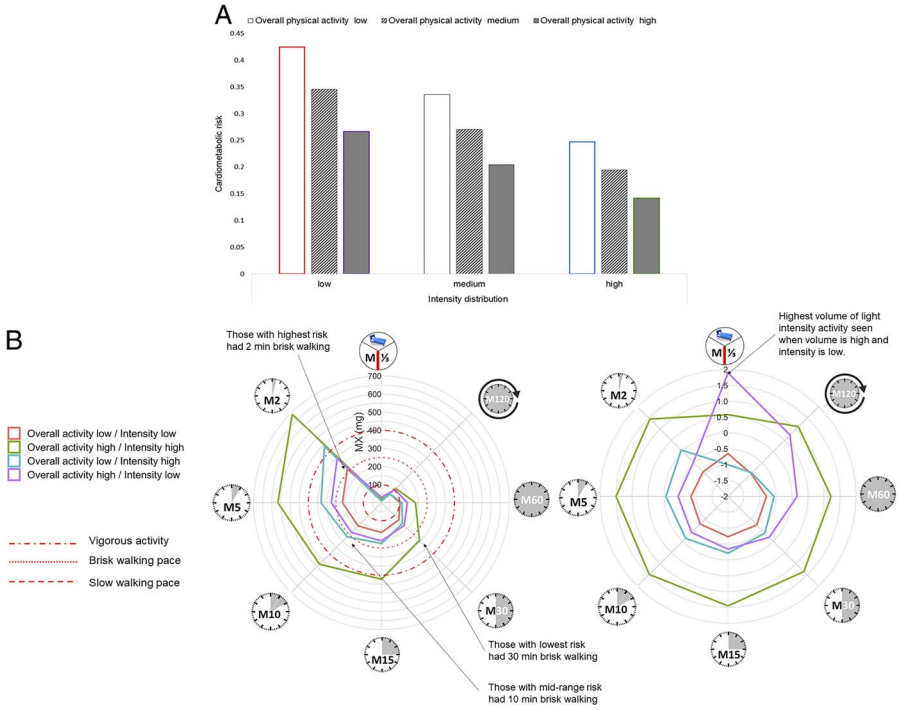

FIGURE 2—Translation of the additive effect of average acceleration and intensity gradient on cardiometabolic risk in in ostensibly healthy office workers. The color of the lines in panel B correspond with the color of the column borders in panel A. A, The relationship between intensity gradient and cardiometabolic risk when overall activity was low (1 SD below the mean), medium (at its mean) and high (1 SD above the mean). Root mean square error = 0.49. B, Illustration of the physical activity profile (MX metrics) associated with low intensity and low overall activity, low intensity and high overall activity, high intensity and low overall activity and high overall activity and high intensity for raw MX metrics (left) and standardized MX metrics (right). Each plot shows (clockwise) the most active 8 h·d^{-1} (M⅓DAY), 120 min (M120), 60 min (M60), 30 min (M30), 15 min (M15), 10 min (M10), 5 min (M5), and 2 min (M2).

were entered (model 3), only the association with overall activity remained beneficially associated for waist circumference, HbA1c, triglycerides and HDL cholesterol. There were no significant interactions between overall activity and intensity for cardiometabolic risk or individual risk factors. The VIF was less than 1.9 in all cases.

Illustration of the associations between physical activity and cardiometabolic risk. The significant associations between physical activity (overall and intensity) and cardiometabolic risk are presented in Figure 2A (healthy, additive association of overall activity and intensity) and 3A (CD, independent association with overall activity). The physical activity patterns indicative of the intensity gradient/average acceleration combinations associated with poorer and better cardiometabolic risk are illustrated in Figure 2B (healthy), and Figure 3B (CD). The color of the lines for the activity profiles in Figures 2B and 3B correspond with the color of the bar borders in Figures 2A and 3A to link the average acceleration/intensity gradient combination with the associated cardiometabolic risk.

In the healthy group, those with the lowest cardiometabolic risk within this group had high amounts of overall activity and intensity of activity (Fig. 2A, *green bar border*), whereas those with the highest cardiometabolic risk had low overall activity and intensity (Fig. 2A, *red bar border*). However, the cardiovascular risk was similar for those with high overall activity at low intensity (Fig. 2A, *purple bar border*) and those with low overall activity at high intensity (Fig. 2A, *blue bar border*).

Those with the lowest cardiovascular risk (Fig. 2B, *green line*) had 30 min of brisk walking compared with only 2 min of brisk walking in those with the highest risk (Fig. 2B, *red line*). The two groups with similar risk (Fig. 2B, *blue and purple lines*) both had 10 min of brisk walking, but very different patterns of low- and high-intensity physical activities.

For the CD group, cardiometabolic risk within this group was lowest in those with high overall activity (Fig. 3A, *green bar border*) and cardiometabolic risk highest in those with low overall activity (Fig. 3A, *red bar border*), irrespective of the intensity. Figure 3B shows those with the lowest risk (Fig. 3B, *green line*) had 5 min of brisk walking, compared with 2 min of brisk walking for those with the highest risk (Fig. 3B, *red line*). Only the group with the highest risk did not achieve 60 min of slow walking (Fig. 3B, *red line*).

DISCUSSION

Physical activity was associated with lower cardiometabolic risk in healthy people and those with chronic diseases; however, the relative importance of the amount and intensity of physical activity was not consistent across different groups. For those who have a chronic disease, higher levels of overall physical activity, regardless of the intensity of that activity, were associated with lower cardiometabolic risk. Whereas for

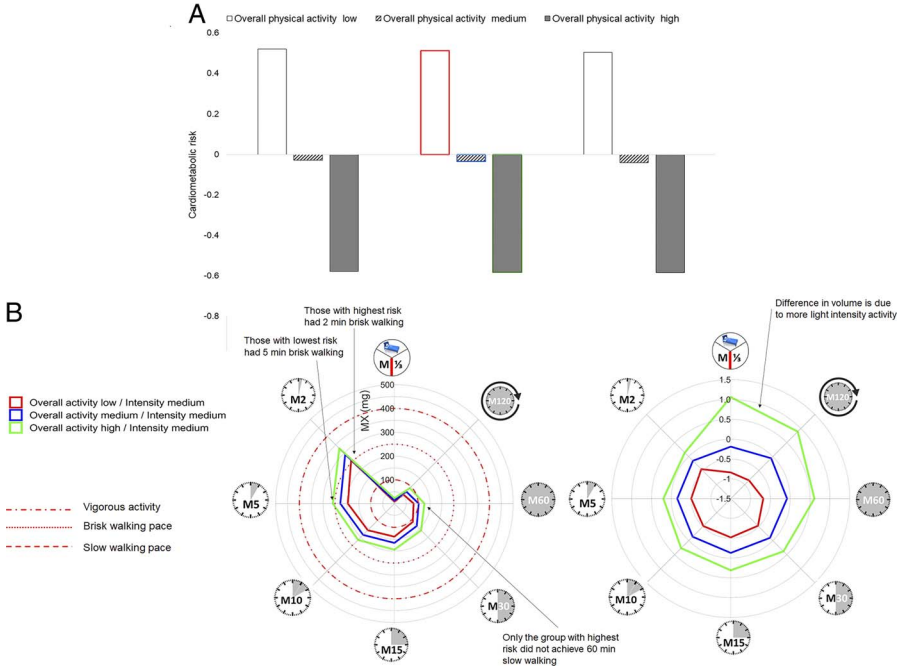

FIGURE 3—Translation of the main effect of average acceleration on cardiometabolic risk in those with one or more chronic disease. The color of the lines in panel B correspond with the color of the column borders in panel A. A, The relationship between intensity gradient and cardiometabolic risk when average acceleration was low (1 SD below the mean), medium (at its mean) and high (1 SD above the mean). Root mean square error = 0.54. B, Illustration of the physical activity profile (MX metrics) associated with low, medium and high amount of activity but similar intensity for raw MX metrics (left) and standardized MX metrics (right). Each plot shows (clockwise) the most active 8 h·d^{-1} (M⅛DAY), 120 min (M120), 60 min (M60), 30 min (M30), 15 min (M15), 10 min (M10), 5 min (M5), and 2 min (M2).

apparently healthy office workers, cardiovascular risk was lowest in those with high overall activity and high activity intensity. Notably, high levels of overall activity at low intensity, or low levels of overall activity but at high intensity, were also favorably associated with cardiovascular risk.

The finding that higher physical activity is associated with better cardiometabolic health is consistent with previous literature (4,5,7,9), as are similar results regardless whether or not adiposity is included in the risk score (21). However, assessing physical activity using these metrics provides novel insight into the relative contributions of overall activity and its intensity with health (28). Although this method has been implemented previously this is the first time, it has been used to assess cardiometabolic risk in adults and to assess how these associations differ in those with and without a chronic disease. As shown, the associations differ based on the health status of the participant, thus it is likely to be important to apply the findings to people relative to this. This also aligns with the most recent World Health Organization guidelines (2020) which for the first time included guidance specific to those with a chronic disease, and allows the needs of this specific population to be considered (15).

Importantly, these methods could facilitate the development of evidence-based tailored recommendations. Translating these findings into more meaningful health messages is important for improving the potential impact of the message. For example, for those with chronic disease, increasing overall activity can be explained as simply moving more and more often; this may be achieved through replacing inactivity with light activity such as slow walking. For those without chronic disease, an increase in the overall activity and its intensity is warranted; here more of an emphasis should be placed on increasing work rate, for example when walking, walk briskly. These recommendations align with research demonstrating brisk walking is associated with reduced mortality and longer life expectancy (33,34), and that replacing sedentary or inactive time with standing or walking benefits cardiometabolic health in inactive populations (35–37). In the current study, in people free from chronic disease, brisk walking was key with a more favorable cardiometabolic risk profile seen in those who achieved 10 min of brisk walking, alongside either 1 to 2 h of slow walking or brief periods (~2 min) of vigorous intensity activity. However, for those with a chronic disease, those who undertook at least 60 min of walking, albeit at a slow pace, had better cardiometabolic risk than those who did not.

Assessing the components of the cardiometabolic risk score provides further insight into the associations of physical activity and health markers. For example, waist circumference was significantly associated with activity intensity in the healthy group but overall activity in the CD group. In practice this translated to a person in the CD group having a 4.7-cm smaller waist circumference when overall activity was 1 SD higher and a person in the healthy group having 3.8 cm smaller waist circumference when activity intensity was 1 SD higher. Similar differences in waist circumference were seen in both groups, in relation to a 1-SD difference, but importantly, this was for overall activity in the CD group, whereas it was for intensity of activity in the healthy group. This indicates that higher amounts of activity regardless of intensity may improve

these factors for individuals with a chronic disease; however, for those free from a chronic disease, ensuring some higher-intensity activity is undertaken may be needed to gain the same benefit.

It is possible that the lack of importance of intensity of activity for the CD group reflects a lower physiological capacity, resulting in little activity of a higher absolute intensity in their profile and thus a narrower intensity distribution. The translation of accelerometer data to slow and brisk walking used the same absolute cutpoints for both groups. Although it is likely that walking at a given pace represents a higher relative physiological intensity for the people in the CD group, this does not impact on the overall message for the CD group—to move more, i.e., focus on volume rather than intensity.

This study has some limitations. First, the analysis is cross-sectional and as such there is potential for reverse causality and residual confounding due to unmeasured factors and/or error in measured variables. As such, the findings should be conferred by future prospective interventional studies. It should also be noted that our translation of results into slow and brisk walking used the same accelerometer values to represent slow and brisk walking for the healthy and CD groups. Further, the group sizes were unbalanced with the CD group larger than the healthy group, and sex and age balances differed between groups. These factors may have impacted on our findings. Despite the sample being slightly unbalanced, the study benefits from a large sample size, using accelerometers assessed physical activity across a 24-h·d^{-1}.

Finally, although the volume and intensity of physical activity are inherently related, the shared variance between the average acceleration and intensity gradient metrics was low at under 40%, indicating the two metrics provided complementary information. This facilitated investigation of the relative importance of intensity and volume of physical activity, adding insight into how physical activity is associated with cardiometabolic health in those who are both healthy and those who have a chronic disease. Thus, this approach to analyzing accelerometer-assessed physical activity data has potential to inform individualized tailored interventions as part of precision medicine. Furthermore, the accelerometer data were processed in the open-source software GGIR, ensuring transparent and replicable methods. Biomarkers were used to assess cardiometabolic risk; future research should use direct health outcomes to build on the findings of this study.

CONCLUSIONS

In conclusion, this study demonstrates how the intensity gradient and average acceleration can be used together to facilitate a simple investigation into the relative importance of intensity and volume of activity for cardiometabolic health. Results from this cross-sectional study suggest that lower cardiometabolic risk was associated with higher amounts of overall physical activity in both people who are healthy and those with chronic disease. However, although the healthy group had more favorable cardiometabolic risk if this activity was higher intensity, the intensity did not matter for the CD group. In those who are free from chronic disease lower cardiometabolic risk was seen in those with high levels of overall activity and/or intensity of activity while also undertaking at least 10 min of brisk walking. In those with chronic disease, lower risk was seen in those who undertook at least 60 min of slow walking. These findings are cross-sectional but support physical activity recommendations emphasizing that if low-active "every minute counts" and "some is better than none," with an increasing focus on moderate and vigorous intensity for those who are more active/free from chronic conditions (15). Longitudinal studies are needed to confirm the findings of this study.

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The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the presented study do not constitute endorsement by the American College of Sports Medicine.

Conflict of interest: The authors report no conflict of interest.

N. P. D., A. V. R., and T. Y. planned the study. N. P. D. completed the main analysis of the study, with contributions from A. V. R., T. Y. N. P. D. prepared the first draft of the article. All authors read, provided feedback, and approved the final article.

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