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From Single Movement Behaviors to Complete 24-h Behaviors Profiles and Multiple Health Outcomes—A Cross-Sectional Study Using Accelerometry

Nidhi Gupta[1] | David M. Hallman[2] | Mette Korshøj[3] | Charlotte Lund Rasmussen[4] | Andreas Holtermann[1,5]

[1]Department of Musculoskeletal Disorders and Physical Work Load, National Research Centre for the Working Environment, Copenhagen, Denmark | [2]Department of Occupational Health, Psychology and Sport Sciences, University of Gävle, Gävle, Sweden | [3]Department of Occupational and Social Medicine, Holbæk Hospital, Copenhagen University Hospital, Holbæk, Denmark | [4]School of Allied Health, Curtin University, Perth, Australia | [5]Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark

Correspondence: Nidhi Gupta (ngu@nfa.dk)

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ABSTRACT

Movement behaviors research has evolved from focusing on single behaviors to multiple behaviors within a 24-h perspective. However, it is unknown if 24-h movement behavior profiles are consistently associated across multiple health outcomes. Thus, we aimed to investigate this. We used data from 807 adults who wore thigh accelerometers and recorded daily sleep/work times over 1–4 days and were categorized into four 24-h movement behavior profiles: "Chimpanzees" (balanced distribution of movement behaviors in work and leisure; $n = 226$, reference), "Lions" (more active work and sleep, and less active leisure; $n = 179$), "Ants" (more active overall, less sedentary work and similar sleep, $n = 244$), and "Koalas" (more sedentary and sleep, and less active overall $n = 158$). Cardiorespiratory fitness and systolic blood pressure were measured, while low back pain and self-rated health were self-reported. Linear or ordinal logistic regression assessed the cross-sectional associations between these profiles and outcomes, adjusting for age, sex, BMI, smoking, alcohol, occupational lifting/carrying, and work type. We found that referencing Chimpanzees, Lions were detrimentally associated with cardiorespiratory fitness ($B = -2.70$ mLO$_2$/min/kg, $p < 0.01$), but beneficially associated with systolic blood pressure ($B = -3.49$ mmHg, $p < 0.05$) and low back pain (odds ratio, OR = 0.67, $p = 0.03$). Koalas were detrimentally associated with systolic blood pressure ($B = 3.66$ mmHg, $p < 0.05$) and cardiorespiratory fitness ($B = -2.83$ mLO$_2$/min/kg, $p < 0.01$). Ants were detrimentally associated with self-reported health (OR = 1.78, $p < 0.01$). We conclude that no 24-h movement behavior profile was consistently (i.e., solely beneficial or detrimental) associated with the health outcomes. These findings indicate that research and practice about 24-h movement behaviors need to consider multiple outcomes.

1 | Background

The benefits of more moderate-to-vigorous physical activity (MVPA), less prolonged sitting, and sufficient sleep duration are shown to be consistent across multiple health outcomes [1–3]. More MVPA is shown to be associated with reduced risk for diabetes, cardiovascular diseases, and premature mortality [1, 4]. Similar associations are observed for less sitting [5] and optimum sleep duration [3, 6].

In recent times, there has been a notable shift in the approach to research and recommendations on health-promoting physical activity in various populations. Previously, the emphasis was primarily on understanding the health benefits of individual movement behaviors such as MVPA, sitting, or sleeping. However, there is now a growing recognition of the importance of understanding the health effects of the combinations of movement behaviors throughout a day.

In light of this shift, researchers have adopted novel person-centered approaches, like cluster analysis or latent class or profile analysis that create meaningful groups of individuals based on certain characteristics [7]. In the movement behavior research field, researchers have been adopting such approaches to identify groups of individuals with various combinations of movement behaviors throughout the day and studying their associations with health [8–13]. However, these studies have either investigated the combination of two or three behaviors and not all [12] or were conducted primarily on children or adolescents [9, 14–17].

Another limitation of previous research is the lack of consideration of the domain of movement behaviors, that is, work and leisure. Although current physical activity guidelines do not differentiate between the domains of physical activity [18], this is important to consider as job requirements are likely to predict behaviors. For example, a person in a cleaning job must stand and walk frequently while sitting less, due to the nature of the job tasks. Previous research has also shown that the association of movement behaviors with health might be dependent on the domain [19, 20]. For example, it has been reported that more physical activity during leisure time is beneficially associated with cardiovascular diseases, musculoskeletal pain, sickness absence, and all-cause mortality [20–23]. However, such benefits were not observed for physical activity performed at work, especially for those who were engaged in physically demanding jobs [20, 21, 24]. Thus, WHO recommends performing more high-quality research on the domain-specific physical activity and its association with health [25].

Following WHO recommendation, we previously identified four distinct combinations of 24-h movement behavior across work and leisure domain in an adult population. We called them "profiles of 24-hour movement behavior". For instance, in one profile, individuals evenly distributed their work time among the movement behaviors but were predominantly active during leisure. In another profile, individuals were more active at work, sedentary during leisure, and spent more time in bed.

These profiles were found to be associated with obesity [10]. However, their association with other important health outcomes, such as cardiorespiratory fitness, musculoskeletal pain, blood pressure, and self-rated health is unknown. These outcomes are important because of their high prevalence and relevance for public health. For example, musculoskeletal disorders are one of the leading contributors to societal burden due to years lived with disability [26]. Self-rated health, on the other hand, captures a holistic view of the physical, mental, and social health of individuals and is one of the strongest general health markers for mortality [27]. These outcomes are relevant particularly for individuals with physically demanding jobs since they have a high prevalence of these outcomes.

All movement behaviors may be of importance for improving these outcomes. However, we hypothesize that a balance between physical activity behaviors and recovery (sleep and sitting) has a different influence on various health outcomes [1, 5]. Our hypothesis is based on the established Supercompensation theory [28] that implies that health is influenced by how the body is stimulated by physical activity behaviors and adapts to the stimuli in the following recovery period (e.g., sleep and sitting). According to this theory, the health effects are determined by "the balance" between the stimuli (in this case physical activity behaviors) and recovery (in this case sleep and sitting). For cardiorespiratory fitness improvement, higher intensities of physical activity are the key stimulus [29], and it can be improved in a normal adult population under less optimal recovery conditions [30].

High intensity physical activity is well documented to reduce blood pressure [31]. However, without sufficient recovery (subsequent sitting and sleep), it can lead to dysregulation of the autonomic cardiac activation and increased inflammation [32], which is shown to be associated with increased blood pressure [33]. This is in line with the theory of overtraining. Overtraining may occur when the volume of physical activity exceeds the ability to recover [34], leading to increased systemic inflammation [35] and lack of enhanced physical capacity. Likewise, since musculoskeletal pain is also considered to be influenced by the similar mechanisms as blood pressure, much physical activity without sufficient recovery may have a detrimental effect on musculoskeletal pain as well [24].

Previous studies investigating the health effects of such profiles have primarily focused on one of these outcomes, such as cardiometabolic health [36] without focusing on other types of health outcomes, like musculoskeletal pain, within the same study sample. Exploring the association between the 24-h movement behavior profiles and multiple health outcomes on a similar sample is important for minimizing confounding from sample variability, which has significant implications for research, guidelines, communication, and practice.

Thus, we conducted an exploratory study using a cross-sectional design, aiming to investigate if 24-h movement behavior profiles are consistently associated with cardiorespiratory fitness, systolic blood pressure, low back pain, and self-rated health.

2 | Methods

This study used the cross-sectional data from the Danish PHysical ACTivity cohort with Objective measurements (DPhacto) cohort [37]. Workers from 15 companies engaged in cleaning, transport, or manufacturing were recruited in collaboration with a large labor union between December 2011 and March 2013. In total, 2107 workers were invited to participate, of which 1119 consented. The inclusion criteria were > 20 working hours/week and be able to participate during working hours. Exclusion criteria were being employed in a management position, intern, pregnant, having fever on the day of testing, or bandage allergy.

All workers provided their informed consent prior to participation. The present study was conducted according to the Helsinki declaration and approved by the Danish data protection agency and the local Ethics Committee (The Capital Region of Denmark, H-24029326).

The data collection was conducted from spring 2012 to spring 2013. The volunteered and eligible workers were invited to fill out a questionnaire, perform physical examination tests, and participate in diurnal accelerometry measurements.

2.1 | Accelerometry to Determine 24-h Movement Behaviors

Workers were mounted with a triaxial Actigraph accelerometer (Actigraph GT3X+, Actigraph LLC, Florida, USA) on the right thigh, approximately midway between the anterior superior iliac spine and the patellar tendon, for four consecutive days (24-h per day) including at least two working days [38]. Workers were also asked to fill in a short paper-based diary noting the start and end of their workday, time in bed (going to bed and getting out of bed), non-wear time, and time of reference measurement (i.e., standing in an upright position for 15 s) during the measurement period. Workers were instructed to remove the device if it caused any kind of discomfort.

The raw data from the accelerometers were downloaded using the ActiLife software (v.5, ActiGraph LLC, Pensacola, FL, USA) and later processed using an open-source MATLAB program, Acti4 (The National Research Centre for the Working Environment, Copenhagen, Denmark and Federal Institute for Occupational Safety and Health, Berlin, Germany) [39]. The Acti4 has been shown to determine time spent in various postures (sedentary, and standing) and activities (walking, running, stair climbing, and cycling) with high sensitivity and specificity [40]. In this study, light physical activity (LPA) was defined as time spent moving (small movements which are not considered as walking) and slow walking, and moderate to vigorous physical activity (MVPA) was defined as time spent fast walking (> 100 count per minute), running, stair climbing, and cycling based on the recommended MET cutoff from WHO [18]. In a previous laboratory study, we found that using thigh accelerometry to estimate energy expenditure is more accurate when the posture and activity type are first identified, and energy expenditure is then estimated separately for each posture/activity type, compared to indirect calorimetry [41]. This approach of using posture and activity type information to calculate LPA and MVPA has been used before [42, 43].

Non-wear periods were recognized according to the procedures explained elsewhere [44]. All non-wear periods and non-working days were excluded from the analyses. A day consisted of 24-h starting from midnight. Based on the diary-based information, these measurements were divided into work and leisure. A work period was defined as the self-reported working hours spent on primary occupation, while the remaining hours, except time in bed periods, within a day, were considered as a leisure period. Periods of work and leisure were considered valid if they comprised at least 4 h or 75% of the worker's average working/leisure time. Time in bed was used as a proxy for sleep time and was measured using information from the self-reported diary and was confirmed by visual inspection of accelerometry data during the time in bed period. It was considered valid if it was at least 4 h in duration [10]. Those workers who had measurements on at least 1 day with valid work, leisure, and time in bed periods were included in the analyses.

2.2 | Determining Profiles of Daily Movement Behaviors

The profiles of 24-h movement behaviors were identified using latent profile analysis and described in detail in our previous study [10]. In brief, we calculated averages of the time spent on all movement behaviors (sedentary, standing, LPA, and MVPA at work and leisure and time in bed) measured across all valid days for each worker.

Time spent on movement behaviors constitutes mutually exclusive components of the complete day (i.e., 24 h). As such, it is impossible to increase time in one behavior without decreasing time in at least one other behavior within that day. To analyze such data, Compositional Data Analysis (CoDA) is recommended [45, 46]. Thus, we used CoDA to determine the profiles of movement behaviors.

The data on time spent on all movement behaviors at work (sedentary, standing, LPA, and MVPA) and leisure (sedentary, standing, LPA, MVPA, and time in bed) were isometrically log-transformed (ilr) resulting in eight ilr log-ratios. The descriptive statistics of the movement behavior data in raw and log-transformed format are provided in the Supporting Information Appendix S1. Using a compositional latent profile analysis [10] on eight ilr log-ratio values, we chose the best fitted model out of the one to five profile solutions. We chose a four-profile solution because it performed best on the following statistics and criteria: (1) the Lo–Mendell–Rubin Test indicated that the five-profile solution was not statistically significant anymore ($p > 0.05$), (2) Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values were low compared to the five-profile solution, (3) the entropy value was high (above 0.70 on a scale of 0–1) indicating the certainty of the classification of the chosen solution, (4) the minimum number of participants in one of the profiles was more than 50, and (5) the chosen four-profile solution was clinically relevant. More details on how we chose these profiles are given in our previously published open access article [10]. After choosing the best-fit model, each participant was allocated to one of the four profiles using the posterior probability approach.

Descriptive of the four profiles are given in the same article [10] and in Table 1 below. In short, the four distinctively different movement behavior profiles were a 'Chimpanzee' profile ($n = 226$, 28%), a 'Lion' profile ($n = 179$, 22%), an 'Ant' profile ($n = 244$, 30%), and a 'Koala' profile ($n = 158$, 20%). We named the profiles after these animals since their movement patterns match with movement behaviors traits of our profiles. Chimpanzees consisted of workers with an even distribution of time spent in various movement behaviors at work, combined with an active leisure time (matching with Chimpanzees who search for food, climb and travel, and in their leisure time, play and socialize).

Compared to Chimpanzees (Table 1);

- Lions were more active at work while more sedentary and less active at leisure (matching with Lions that are highly

TABLE 1 | Demographical, lifestyle, obesity, and work-related descriptive statistics for the total population and the four profiles of movement behaviors as published previously [10].

Variables	Total ($n = 807$)				Chimpanzees ($n = 226$)				Lions ($n = 179$)				Koalas ($n = 158$)				Ants ($n = 244$)			
Demographic variables	***n***	**M**	**SD**	**%**	***n***	**M**	**SD**	**%**	***n***	**M**	**SD**	**%**	***n***	**M**	**SD**	**%**	***n***	**M**	**SD**	**%**
Age (years)	807	45.1	9.7		226	44.0	9.0		179	43.4	11.3		158	45.7	8.7		244	47.0	9.5	
Male	439			54.4	144			63.7	130			72.6	87			55.1	78			32.0
Alcohol intake (units/week)	761	4.5	6.0		216	4.3	5.1		171	5.1	6.7		152	4.8	6.0		222	3.9	6.3	
Poor diet (0–3)[a]	792	1.8	1.0		222	1.9	1.1		177	1.7	1.0		157	2.1	1.0		236	1.8	1.1	
Smokers	216			27.4	50			22.7	62			35.2	33			21.2	71			30.2
BMI (kg/m^2)	790	27.2	4.8		221	26.9	4.6		172	27.8	5.1		157	27.0	4.4		240	27.3	4.8	
Blue-collar workers	671			83.1	196			86.7	173			96.6	61			38.6	241			98.8
Job groups																				
Cleaning	142				24			10.6	27			15.1	5			3.2	86			35.2
Manufacturing	601				175			77.4	143			79.9	131			82.9	152			62.3
Transport	64				27			11.9	9			5.0	22			13.9	6			2.5
Compositional means of sedentary behaviors, standing still, LPA, and MVPA at work and leisure and time in bed (as % of 24 h)																				
Sedentary behavior at work		10.3				13.7				9.5				23.2				4.4		
Standing still at work		9.5				10.1				11.6				4.7				10.8		
LPA at work		4.9				4.1				5.5				1.8				8.6		
MVPA at work		4.2				4.0				5.3				1.9				5.5		
Sedentary behavior at leisure		24.5				21.3				26.4				24.0				23.7		
Standing still at leisure		7.2				8.4				4.3				6.6				8.5		
LPA at leisure		4.0				4.3				3.0				3.0				4.8		
MVPA at leisure		3.1				3.6				1.9				2.7				3.6		
Time in bed		32.4				30.6				32.5				32.1				30.0		

Note: $\bar{x}$ = mean.
Abbreviations: BMI, body mass index; LPA, light intensity physical activity; MVPA, moderate-to-vigorous physical activity.
[a]0 = never, 3 = everyday.

active during hunting (work) and tend to relax during their downtime).

- Ants had more standing and physical activity at work, and had almost similar activity but higher sedentary time at leisure and similar time in bed (matching with Ants that are always on move busy performing various tasks like searching for food).
- Koalas had more sedentary time and less activity both at work and leisure and had slightly higher time in bed (matching with Koalas that are predominantly inactive, are sedentary and sleep most of the time).

2.3 | Cardiorespiratory Fitness

Cardiorespiratory fitness in mLO_2/min/kg was estimated using the one point Åstrand sub-maximal test on a bicycle ergometer (model 874E, Monark, Stockholm, Sweden) according to the procedure explained in another study [47]. The test started with an initial ergometer power based on the participant's age and self-reported cardiorespiratory fitness level, typically between 60 and 90 W with a speed of 60 rounds per minute. The heart rate from the fingertip of the participant was measured using the Oximeter (Nellcor OxiMax N-65, US) throughout the test. If the heart rate of the participant was below 110 beats/min after the first minute of the test, the power was increased with the aim of obtaining a heart rate of 60% of the estimated maximum heart rate [48], and a minimum of 120 beats/min. The test continued until the worker reached a steady state heart rate, defined as less than 5 beats/min difference between the 5th and 6th minute of the test. If the steady state heart rate was not achieved, the test was continued until the steady state was achieved or until 10 min testing in total. The power of the bicycle and the steady state heart rate were used to estimate cardiorespiratory fitness (mLO_2/min/kg) with the Åstrand-Rhyming nomogram [47] correcting for age and sex.

2.4 | Low Back Pain Intensity

Self-reported information on the intensity of low back pain was obtained using a single item from the Standardized Nordic questionnaire for the analysis of musculoskeletal symptoms [49]. Workers were asked to report their pain intensity in the lower back during the last 3 months on a scale from 0 to 10, where 0 meant no pain and 10 meant worst imaginable pain.

2.5 | Systolic Blood Pressure

Blood pressure measurements were conducted on the first day of data collection. Participants were asked to rest in a seated position for 5 min. While resting, the back was supported, legs were uncrossed, and the arm was supported. Blood pressure was measured on the left arm using the Omron M6 Comfort three times at an interval of 1–2 min. The average of the last two recordings was used.

2.6 | Self-Rated Health

Self-rated health was determined using a single item "how will you rate your health" in five response categories: very good, good, fair, poor, and very poor [50].

2.7 | Confounders

We chose age, sex, smoking, alcohol, BMI, and type of work as the potential confounders in our study. We selected these confounders a priori based on similar previous studies investigating the associations between movement behaviors and cardiorespiratory fitness, blood pressure, low back pain and self-rated health where these confounders were adjusted for [20, 23, 24, 51]. These confounders have shown to influence various movement behaviors and the chosen health outcomes of our study [52–59]. Age was determined using a unique Danish civil registration number. Sex was determined by a single item "are you male or female?". Smoking status was determined using a single item "do you smoke?" with four responses summarized into smokers (smoking regularly, smoking occasionally) and non-smokers (used to smoke not anymore, never smoked). Alcohol intake was determined using a single item "how much alcohol did you drink during the last week?" with responses in units per week. Occupational lifting and carrying duration was determined using a single item "how much of your working time do you carry or lift?" with 6 responses ranging from almost all the time to never [51]. The information on type of work was collected using single item "are you a worker engaged in administrative work tasks (white-collar) or in production (blue-collar)?". Height, without shoes, was measured using a stadiometer (Seca, model 213) to the nearest 0.1 cm. Body weight (i.e., body mass) was measured using the Tanita (model BC418 MA) bio-impedance segmental body composition analyzer, to the nearest 0.1 kg. Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared.

2.8 | Statistical Analyses

All analyses were conducted in R software (4.1.0; 2021-05-18) using the packages *Compositions* [60], MASS [61], and *MplusAutomation* [62].

Of the four outcomes of this study, two were ordinal (self-rated health and low back pain intensity) and the remaining two were continuous (cardiorespiratory fitness and systolic blood pressure) in nature. Thus, we performed ordinary logistic regressions and multiple linear regressions, respectively, to investigate the association between movement behavior profiles as the independent variable and the outcomes as the dependent variable. The models were subsequently adjusted for age, sex, BMI, smoking, alcohol, occupational lifting and carrying duration, and type of work [10]. For self-rated health, since the last two categories ("poor" and "very poor") had very few responses, we merged them with the "fair" category, resulting in a three-point scale.

Since linear regression and logistic regression produce different kinds of estimates, it is difficult to compare their magnitude (estimates in Table 3). Thus, for the sake of comparison of the estimates across health outcomes, we converted the coefficients obtained from linear regressions to odds ratios based on Cohen's approach using the procedure explained elsewhere [63]. We chose to convert the linear estimates to odds ratios as they are well known in epidemiology and thus likely easier to interpret.

We also performed sensitivity analyses if there was an association between the interaction of sex and profiles and various outcomes of interest. If significant ($p<0.05$), the results were stratified by sex.

3 | Results

Of the 1119 workers who consented to participate, 807 workers wore the accelerometers and provided valid accelerometry data for at least one working day, including valid work and leisure and time in bed periods. On average, workers wore the accelerometer for 7.6 ± 1.2 h at work and for 15.8 ± 1.5 h at leisure, including the time in bed period (7.0 ± 1.0 h), summing to 23.4 ± 1.2 h per day. On average, workers were measured for 3 working days (SD = 0.94 days).

The description of each profile was presented in our previously published article [10] and is reported here as well in Table 1.

Table 2 shows the descriptive statistics of all health outcomes for each 24-h movement behavior profile. Lions and Ants had the lowest cardiorespiratory fitness, while Koalas had the highest systolic blood pressure. Chimpanzees and Ants had the highest LBP, and Ants had the poorest self-rated health.

Table 3 displays the results obtained from both linear regressions and ordinary logistic regressions used to investigate the association between the four 24-h movement behavior profiles and health outcomes. As detailed in the Methods section, to facilitate the comparison of the direction and magnitude of associations obtained from different types of regressions for all outcomes, estimates obtained from linear models were converted to odds ratios. The results based on the odds ratios for all outcomes are illustrated in Figure 1. For absolute effect size interpretation, see Table 3.

Compared to Chimpanzees (Figure 1), Lions were detrimentally associated with cardiorespiratory fitness (Beta, $B=-2.70$, $p<0.001$) but beneficially associated with blood pressure ($B=-3.49$, $p<0.01$) and low back pain (OR = 0.67, $p=0.03$). Koalas were detrimentally associated with systolic blood pressure ($B=3.66$, $p=0.03$) and cardiorespiratory fitness ($B=-4.90$, $p=0.01$) but had a similar (neither detrimental nor beneficial) association with self-rated health and pain compared to Chimpanzees. Ants were detrimentally associated with self-rated health (OR = 1.78, $p=0.01$) but similarly associated with cardiorespiratory fitness, systolic blood pressure, and low back pain.

No significant association was observed for the interaction of sex and profiles with various outcomes (results not shown).

4 | Discussion

In this study, we investigated if different 24-h movement behavior profiles are associated across various health outcomes. We found that none of the observed 24-h movement behavior profiles showed consistent (i.e., solely beneficial or detrimental) associations with cardiorespiratory fitness, low back pain, systolic blood pressure, and self-rated health.

4.1 | Lions: Cardiorespiratory Fitness, Blood Pressure, and Low Back Pain Trade-Offs

Compared to Chimpanzees, Lions exhibited a unique profile by being more active and standing at work, but sedentary during leisure, accompanied by more time in bed. We found that Lions were detrimentally associated with cardiorespiratory fitness, but beneficially associated with systolic blood pressure and low back pain, compared to Chimpanzees. These findings support our hypothesis that different combinations of physical activity behaviors and recovery have different influences on various health outcomes.

Despite their similar overall physical activity levels (MVPA: 109 vs. 104 min/day for Chimpanzees and Lions, respectively),

TABLE 2 | Description of the systolic blood pressure, cardiorespiratory fitness, low back pain, and self-rated health among workers in the four distinct 24-h movement behavior profiles: Chimpanzees, Lions, Koalas, and Ants.

Health outcomes		Chimpanzees ($n=226$)	Lions ($n=179$)	Koalas ($n=158$)	Ants ($n=244$)
Systolic blood pressure (mmHg)	Mean (SD)	134.4 (13.3)	131.8 (14.2)	137.4 (14.1)	132.7 (16.0)
Cardiorespiratory fitness (mLO_2/min/kg)	Mean (SD)	34.4 (9.2)	31.0 (9.3)	32.3 (8.5)	30.9 (8.5)
Low back pain (0–10)	Mean (SD)	3.4 (3.0)	2.9 (3.0)	2.9 (2.8)	3.7 (3.2)
Self-rated health					
Very good	N (%)	26 (11.7)	15 (8.5)	9 (5.7)	14 (6.0)
Good	N (%)	137 (61.7)	110 (62.5)	109 (69.4)	129 (54.9)
Fair-poor	N (%)	59 (26.6)	51 (29.0)	39 (24.8)	92 (39.1)

TABLE 3 | Results of multiple linear regression analyses and ordinary logistic regression analyses on the association between the four 24-h movement behavior profiles (i.e., sitting, standing, light physical activity, moderate-vigorous physical activity and sleep during work and leisure) and continuous (i.e., cardiorespiratory fitness, systolic blood pressure) and ordinal (i.e., self-rated health and low back pain) health outcomes based on data from 807 workers.

Outcomes	Type of coefficients	Coefficients	95% CI		p	Profile
			Low CI	High CI		
			Reference			Chimpanzees
Cardiorespiratory fitness (mLO_2/min/kg)	Linear coefficients	-2.70	−4.47	−0.92	< 0.001	Lions
Systolic blood pressure (mmHg)	Linear coefficients	−3.49	−6.25	−0.73	0.01	Lions
Self-rated health (reference = poor)	Odds ratio	0.95	0.62	1.47	0.82	Lions
Low back pain (reference = high)	Odds ratio	0.67	0.46	0.96	0.03	Lions
			Reference			Chimpanzees
Cardiorespiratory fitness (mLO_2/min/kg)	Linear coefficients	−2.83	−4.90	−0.75	0.01	Koalas
Systolic blood pressure (mmHg)	Linear coefficients	3.66	0.46	6.85	0.03	Koalas
Self-rated health (reference = poor)	Odds ratio	1.35	0.81	2.22	0.25	Koalas
Low back pain (reference = high)	Odds ratio	0.90	0.60	1.36	0.61	Koalas
			Reference			Chimpanzees
Cardiorespiratory fitness (mLO_2/min/kg)	Linear coefficients	−0.96	−2.71	0.78	0.28	Ants
Systolic blood pressure (mmHg)	Linear coefficients	−1.75	−4.41	0.92	0.20	Ants
Self-rated health (reference = poor)	Odds ratio	1.78	1.18	2.70	0.01	Ants
Low back pain (reference = high)	Odds ratio	1.11	0.78	1.59	0.55	Ants

Note: Models adjusted for age, sex, BMI, smoking, alcohol, occupational lifting and carrying duration, and type of work; The odds ratios were interpreted as the likelihood of being in a higher category of self-rated health and pain, where higher scores indicated poorer health and higher pain.

Chimpanzees spent more time on higher intensities of physical activity (cycling, running and stair climbing = 14 min; the stimuli) than Lions (8 min) throughout the day. More time spent on higher intensity physical activity has been shown to improve cardiorespiratory fitness [29]. Additionally, while Chimpanzees had slightly less sleep than Lions (7.3 h, approximately 30 min less), their sleep time was still within an adequate range (7–9 h [6]) which might have provided sufficient recovery supporting physiological adaptation. Such balance between higher intensity stimuli combined with recovery that is not too far from optimum might explain their higher cardiorespiratory fitness. These findings are in line with results obtained in a randomized controlled trial on cleaners [64]. Cleaners are known to have poor recovery from much walking/standing at work and insufficient sleep [65]. However, when they participated in a workplace exercise session involving high intensity physical activity, their cardiorespiratory fitness improved. Similar results were also observed in a randomized controlled trial among health personnel (who generally have long work shifts with much walking and standing) when participating in a workplace intervention with high intensity physical activity [30].

Lions, who accumulated most of their physical activity during work followed by recovery in leisure (more sitting and sleeping), showed a better systolic blood pressure profile and less low back pain compared to Chimpanzees. Lions engaged in a similar amount of MVPA as Chimpanzees but had more recovery after physical activity in the form of sitting during leisure and sleep. This finding is aligned with research suggesting that a balance between moderate physical activity and recovery (sitting and sleeping) could better regulate the automatic cardiac activation and reduce inflammation [32], which is shown to be associated with reduced blood pressure [33]. Additionally, since musculoskeletal pain is influenced by a similar mechanism as for blood pressure (e.g., autonomic regulation and inflammation [24]), such moderate physical activity but sufficient recovery after activity might have reduced the pain among Lions compared to Chimpanzees. These results are in line with the abovementioned randomized controlled trial among cleaners who participated in high-intensity exercise sessions. In this trial, despite improving their cardiorespiratory fitness, cleaners increased both resting blood pressure [64] and ambulatory blood pressure at four-month follow-up [66]. Additionally, the cleaners also reported having increased pain in the lower extremities [67]. These results confirm that the balance between physical activity and recovery behaviors might influence health outcomes differently. However, we would like to highlight that our study is cross-sectional, and therefore can be influenced by reverse causality and other biases. Thus, our results should be interpreted as explorative and need to be confirmed in prospective studies.

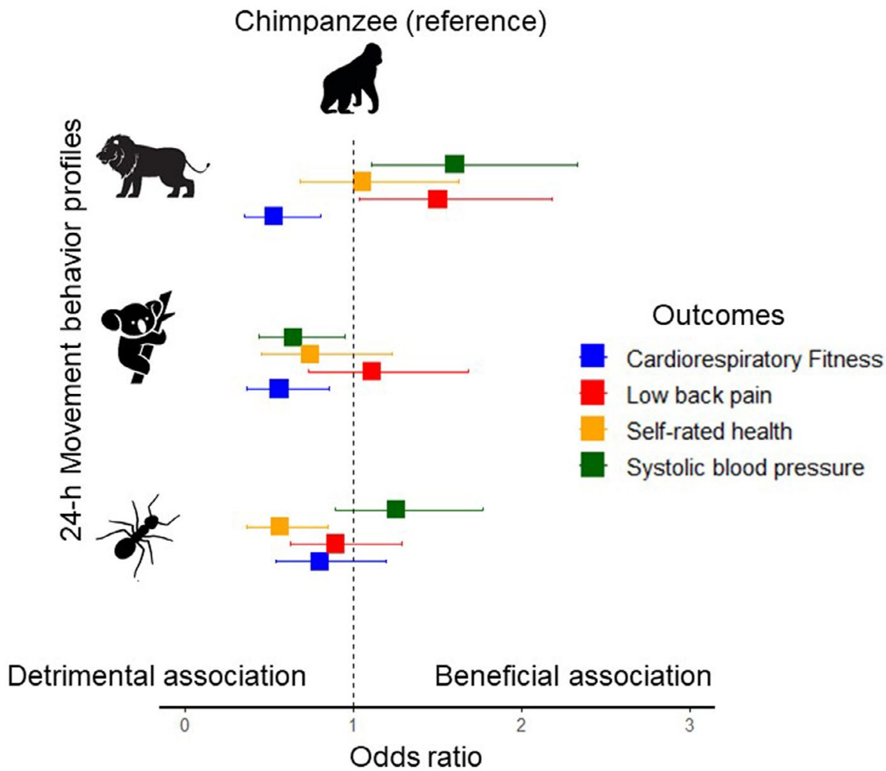

FIGURE 1 | Comparison of the direction and magnitude of the association between four 24-h movement behavior profiles and various health outcomes (cardiorespiratory fitness, systolic blood pressure, self-rated health and low back pain) based on data from 807 workers. □ represents the mean estimate while ⊢⊣ represents its 95% confidence intervals. For the purpose of comparison, the model estimates from the linear regressions (for systolic blood pressure, and cardiorespiratory fitness) were converted to odds ratios. Odds ratios higher than 1 termed "beneficial association", meaning higher probability for high cardiorespiratory fitness, lower low back pain, good self-reported health and low systolic blood pressure, compared to Chimpanzees. Odds ratios at 1 meant "similar" probability (neither detrimental nor beneficial) for various health outcomes.

4.2 | Ants: The Paradox of More Physical Activity but Poorer Health

Despite exhibiting more daily overall physical activity compared to Chimpanzees, Ants surprisingly displayed similar association with cardiorespiratory fitness, systolic blood pressure, and low back pain, and detrimental association with self-reported health. This finding suggests that the Ants' highly active profile may come at a cost of being compromised with less time in recovery behaviors (like sedentary time and sleep), which can be necessary for obtaining better health [68, 69]. These results are in line with previous studies that found that beneficial effect of MVPA on mortality was observed to be attenuated at higher levels of MVPA [70]. However, most of these previous studies have not explored the associations of a combination of various movement behaviors and their importance for health. Our study highlights the importance of such combinations, but the findings need to be interpreted in light of the cross-sectional design. Nevertheless, they challenge the current paradigm that we can give univocal advice about the health benefits of single movement behaviors (like MVPA and sitting) as well as for a specific 24-h movement behavior profile.

4.3 | Koalas: A Classic Case of Poor Health From Much Sitting and Little Physical Activity

Compared to Chimpanzees, Koalas generally sat more and performed less standing, LPA, and MVPA irrespective of the domain, and spent more time in bed. As expected, Koalas were detrimentally associated with cardiorespiratory fitness and systolic blood pressure, aligning with documentation on the detrimental effects of high sitting and insufficient physical activity [1, 71]. These findings underscore the classic association between high sitting and insufficient physical activity and poorer health outcomes. However, Koalas had a similar association with self-reported health and low back pain intensity compared to Chimpanzees, indicating the need for further investigations into psychosocial and behavioral factors influencing these outcomes [72, 73].

4.4 | Perspective of the Findings

In this study, we posed a novel hypothesis that the balance between stimuli (physical activity behaviors) and recovery (sleep and sitting) has a different influence on various health outcomes including cardiorespiratory fitness, systolic blood pressure, low back pain, and self-rated health. Our findings supported this hypothesis and indicated that none of the 24-h movement behavior profiles were consistently (i.e., solely detrimental or beneficial) associated with multiple health outcomes. This highlights the need to consider multiple behaviors as well as multi-dimensional aspects of health, instead of solely focusing on one movement behavior and one health outcome. Nevertheless, it should be acknowledged that this is the first exploratory study based on cross-sectional data. Thus, more research is required to understand the relationship between 24-h movement behaviors and a wide variety of health outcomes, based on large cohorts using a prospective design. If such future studies confirm the findings of our study, stakeholders from research, policy, and practice ought to collaborate on translating and communicating these findings into easy to understand and practical recommendations.

4.5 | Strengths and Limitations

One strength of the study was the high accelerometry wear time (mean and standard deviation 23.4 ± 1.2 h per day) compared to previous studies where participants usually take off the accelerometry in water activities and during the night. Another strength was the usage of the valid open-source Acti4 program to process the accelerometry data [39]. Instead of relying on the arbitrary thresholds on the count per minute (CPM), this program relies on identifying exact postures and activities based on the thigh-based accelerometry. The Acti4 program has shown to have high sensitivity and specificity of $>80\%$ and $>90\%$, respectively, during semi-standardized and free-living conditions [40, 74, 75]. Usage of recommended Compositional Data Analysis enabled us to consider the full 24-h movement behavior profiles [45, 46]. The inclusion of a sample of participants engaged in manual jobs was another strength of this study. It is crucial to include participants across various occupations to have the variety of 24-h movement behavior profiles and explore how these profiles are associated with multiple health outcomes. Cohorts dominated by participants with high socioeconomic office jobs with minimal representation from various manual jobs will primarily provide knowledge on health effects of movement behavior profiles for high socioeconomic groups. This can further increase the existing socioeconomic health disparity [76]. Thus, future studies should consider including participants from a wide range of occupations, including low socioeconomic manual jobs. Another key strength was the ability to distinguish between work and leisure time movement behaviors, allowing for an analysis of domain-specific movement behaviors, which have been shown to have different health impacts [22, 77].

A major limitation of the study was the cross-sectional study design that does not conclude on the causality. Thus, future studies should confirm the results of this study using a prospective design. Another limitation was the inclusion of only 37% of the total invited participants. However, previous studies on the cohort used in this study, DPhacto, have shown no relevant differences between participants and non-participants [78]. Additionally, using a convenience sample and having a predominance of manual workers may limit the generalizability of the study results to the broader working population. We used information on the posture/activity type to calculate LPA and MVPA time. Although this method aligns well with the definitions of LPA and MVPA as provided by WHO, there is no direct validation performed comparing energy expenditure based on such definition and a gold standard. Another limitation was that workers were, on average, monitored for approximately 3 days. While this duration appears sufficient to provide representative estimates of movement behaviors [79], it does not account for potential seasonal variations. Future studies could address this by incorporating measurements across different seasons to capture changes in movement behaviors over time.

5 | Conclusion

We found that none of the observed 24-h movement behavior profiles showed consistent associations with cardiorespiratory fitness, low back pain, systolic blood pressure, and self-rated health. Hence, research and practice need to recognize that 24-h movement behavior profiles can have different effects across various health outcomes. If these findings are confirmed in large prospective studies, stakeholders from research, policy, and practice ought to collaborate on how to translate and communicate them into easy to understand and practical recommendations.

Author Contributions

N.G. acquired funding for this study. N.G. and A.H. conceptualized the study. N.G. and D.M.H. designed the analytical strategy and N.G. performed the analysis. N.G. wrote the first draft of the manuscript. All authors provided scientific expertise and feedback throughout the study. All authors have edited, reviewed, and approved drafts of this manuscript, including the final version. All authors take full responsibility for and have read and approved this final version of this manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in rigsarkivet.dk at https://digidata.rigsarkivet.dk/aflevering/38016, reference number 10.5279/dk-sa-dda-28618.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.