Research progress of 24-hour movement behaviors in chronic non-communicable disease

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Abstract
Chronic non-communicable diseases (NCDs) represent a significant impediment to improve life expectancy and remain a focal point in global public health and disease prevention efforts. 24-hour movement behaviors, which include sleep, sedentary behavior (SED), and physical activity, underscore the inherent connections between different daily activities and the comprehensive impact of overall movement patterns on health. Evidence suggested that modifying patterns of 24-hour movement behaviors can aid in preventing and attenuating the progression of NCDs. This study systematically delineated the concept, evolution, analytical methods, and intrinsic associations of 24-hour movement behaviors, emphasizing their pivotal role in the prevention and management of NCDs such as obesity, mental disorders, cardiovascular diseases, diabetes, and renal diseases. Future research endeavors should focus on refining methodologies, broadening study populations, developing research tools, and exploring precise intervention strategies and interdisciplinary approaches to comprehensively enhance the effectiveness of NCDs prevention and management from a temporal perspective. Such efforts are poised to provide substantive guidance and support for public health practices.

Keywords: chronic non-communicable diseases; 24-hour movement behaviors; time-use epidemiology; isotemporal substitution model; compositional data analysis
Introduction

With the rapid advancement of science and technology and the improvement of living standards, chronic non-communicable diseases (NCDs) such as cardiovascular diseases, cancer, diabetes, and chronic respiratory diseases have emerged as significant global public health challenges [1, 2]. Characterized by their prevalence, long duration, and difficulty in complete cure, NCDs constitute the leading causes of death and disability worldwide, accounting for approximately 71% of global deaths annually [3, 4]. Human activities within a 24-hour period encompass various intensities of physical activity, sedentary behavior (SED), and sleep [5]. Early researchers predominantly regarded these behaviors as independent health risk factors, confirming the beneficial role of physical activity in the prevention and management of NCDs, while sedentary lifestyles dominated by SED were found to increase the incidence of NCDs [6, 7]. However, these studies overlooked the “co-variance” constraints among 24-hour behaviors, whereby various behaviors inevitably influence each other in their temporal allocation. Consequently, in 2008, Prochaska proposed the “Co-Variation” theory, emphasizing the comprehensive effects of multiple behavior changes throughout the day on health outcomes [8]. Subsequently, with the introduction of the Activity Balance Model, Pedisić conceptualized sleep, SED, standing, moderate to vigorous physical activity (MVPA), and light physical activity (LPA) as independent variables, exploring the temporal balance between behaviors, thus forming the field of time-use epidemiology [9, 10]. Since then, awareness has grown regarding the interdependence of various activity behaviors daily and the closed nature of 24-hour activity data, gradually forming the concept of 24-hour movement behaviors. Currently, a substantial body of research has delved into the associations between 24-hour movement behaviors and NCDs such as cardiovascular diseases, diabetes, and renal diseases. Adjusting 24-hour activity behavior patterns has become a crucial means of preventing and slowing the progression of NCDs [11, 12]. This paper comprehensively review the concept, development, analytical methods, inherent correlations between behaviors, alongside the impact of 24-hour movement behaviors on NCDs such as overweight and obesity, mental disorders, cardiovascular diseases, diabetes, renal diseases, and mortality risk. By reviewing existing research findings and looking ahead to innovations in research methods, diversification of research subjects, optimization of research tools, and more precise intervention strategies, as well as advancing interdisciplinary research, we aim to provide a forward-looking perspective and innovative ideas for research and intervention in the health domain. By thoroughly examining the complexity and correlations of 24-hour movement behaviors, we seek to gain deeper insights of their potential roles in NCDs, thus offering a more forward-thinking perspective and innovative approaches for research and intervention in the field of health.

24-hour movement behaviors and analytical methods

The development of 24-hour movement behaviors

The term ‘24-hour movement behaviors’ originated from the 24-Hour Movement Guidelines for Children and Youth proposed in Canada in 2016, describing various activities such as MVPA, LPA, sleep, and SED within a day, as well as the interplay between these behaviors [13]. Historically, scholars regarded these activities as isolated health risk factors, until Tremblay et al. (2007) emphasized the importance of considering these activities comprehensively [14]. Subsequently, Prochaska examined the effects of temporal variations in multiple behaviors on health from a “co-variation” perspective [8]. In 2009, Mekary et al. introduced the instantaneous substitution model (ISM) into the field of physical activity research [15]. Australian scholar Pedisić proposed the Activity Balance Theory framework in 2014, advocating for the use of compositional data analysis (CoDA) methods. Building upon this foundation, Chastin et al. [16] and Dumuid et al. [17] conducted research and established the position of CoDA in this field. By 2017, Pedisić coined the term time-use epidemiology and proposed the Framework for Viable Integrative Research in Time-Use Epidemiology (VIRTUE framework) [10]. Future research should focus on methodological aspects of time-use, relevant health outcomes, optimal time-use patterns, determinants of health-related time-use, and time-use interventions, providing scientific evidence for health education and promotion.

Analytical methods for 24-hour movement behaviors

As research on the relationship between activity behaviors and health progresses, related tools and methods have also rapidly evolved. The focus has shifted from examining the impact of physical activity on health in isolation to exploring the interdependence of daily behaviors and their relationship with health through time allocation analysis. Analytical methods have transitioned from single-factor models to partition models and then to three linear regression models of the ISM. The single activity model considers only the relationship between the time spent on each activity behavior and health outcome, without accounting for the remaining activity time or total activity time. While this model is simple and easy to operate, it dissects the various physical activity behaviors. Taking MVPA as an example, the model is represented as follows: Health outcome variable = βo + β3 × MVPA time (where βo is the covariate, and β3 represents the effect size of MVPA duration on the health outcome for each unit change). The partition model considers the combined effects of time spent on different behaviors on health outcomes. It constructs a multiple regression model with each activity behavior as an independent variable, partially reflecting the relationship between 24-hour movement behaviors and corresponding health variables. However, due to the mutual influence of time spent on different activity behaviors, it cannot determine the specific impact of a certain behavior on health. The model is expressed as: Health outcome variable = βo + β1 × MVPA time + β2 × LPA time + β3 × SED time + β4 × sleep time (where βo is the covariate, and β1, β2, β3, and β4 represent the impact of increasing time spent on each activity behavior on the health outcome variable).

In 2009, researchers started using ISM to analyze the relationship between reallocating time spent on various activities and health outcomes, quantifying its health benefits. Due to the unique nature of time data, ISM transitioned from traditional to compositional methodologies. The traditional ISM model employed multiple linear regression to simulate the effect of substituting one behavior for another in equal time increments on health outcomes while keeping total activity time constant. Taking MVPA, LPA, and sleep as replacements for SED, the model is represented as follows: Health outcome variable = βo + β1 × MVPA time + β2 × LPA time + β3 × sleep time + β4 × total activity time (where βo is the covariate, and β1, β2, β3, and β4 represent the effect sizes of substituting MVPA/LPA/sleep for SED on health outcomes with total activity time held constant, and β4 represents the coefficient for SED). Compositional ISM treats time data as CoDA and integrates it with ISM. CoDA is a type of data with compositional constraints, containing multiple components, all greater than zero, so a change in one component inevitably leads to compensatory changes in other components. Pedisić [9] (2014) proposed viewing time data as compositional data, and subsequently, Dumuid et al. [17] (2019) compared traditional regression analysis with CoDA analysis, validating the reliability of CoDA as an analytical method for time use and recommending its integration with other statistical methods such as isotemporal substitution, cluster analysis, and principal component analysis.

The influence of different activity behaviors on chronic NCDs

Physical activity encompasses bodily movements generated by skeletal muscles resulting in energy expenditure, including occupational, sports, conditioning, household, or other activities [18]. Moderate physical activity has been demonstrated to reduce the risk of NCDs such as cardiovascular diseases, diabetes, and cancer, thereby promoting holistic physical and mental health [19-22]. MVPA is widely recognized as the most effective intensity level for human
health. The World Health Organization (WHO) recommends that children and adolescents engage in at least 60 minutes of MVPA daily, while adults should aim for at least 300 minutes of MPA or 150 minutes of VPA weekly [23]. However, due to individual and environmental factors, most populations fail to meet these recommendations. Consequently, LPA has garnered attention as the most prevalent behavior following SED. Several studies have found that LPA can reduce metabolic risk, lower the risk of cardiovascular disease and mortality, with particular importance in older adults [24–26]. For adolescents, light physical activity (LPA) may have similar or even stronger effects on fat reduction compared to moderate-to-vigorous physical activity (MVPA) [27]. The proliferation of wearable devices has brought attention to the impact of daily vigorous intermittent lifestyle physical activity (VILPA) on health. VILPA refers to brief and intense bursts of physical activity lasting no more than 1-2 minutes (such as brisk walking or short sprints). Engagement in VILPA has been shown to significantly reduce the risk of all-cause mortality, cancer-related mortality, and cardiovascular disease-related mortality [28, 29].

In addition to physical activity, research into the physiology and health implications of SED has emerged as a burgeoning field in recent years. Approximately 55% to 60% of adults’ waking hours are spent in SED [30]. SED refers to any awake behavior performed in a seated, reclining, or lying posture with energy expenditure ≤ 1.5 METs and can be categorized into screen-based SED and non-screen-based SED [31, 32]. SED exerts qualitative and independent detrimental effects on health, irrespective of adequate physical activity [33–35]. Prolonged SED in adults is associated with increased risks of cardiovascular diseases, diabetes, cancer, elevated all-cause mortality, and neurological impairments [36–39]. Additionally, excessive screen time may lead to childhood and adolescent obesity, metabolic syndrome, and psychological issues [25, 40]. Sleep is fundamental to human physiological functioning and crucial for overall health. Multiple studies have indicated a close relationship between insufficient sleep, sleep disorders, or excessive sleep duration and cognitive decline, compromised immune function, emotional issues, and increased risk of chronic diseases [41–43]. Moreover, shortened sleep duration may correspondingly increase SED time, exacerbating its detrimental effects on the body [44]. Research on 24-hour movement behaviors should consider individuals’ bedtime, wake-up time, and sleep quality, focus on the transition from SED to physical activity, and fully acknowledge the importance of sleep in 24-hour movement behaviors.

The comprehensive impact of 24-hour movement behaviors on NCDs

24-hour activity behavior, as a novel epidemiological paradigm, is widely employed to investigate the comprehensive benefits of time allocation across various activity behaviors concerning different NCDs health outcomes (Table 1). Commonly studied NCDs include overweight and obesity, psychological disorders, cardiovascular diseases, diabetes, renal diseases, and mortality rates (Figure 1).

Obesity
Research on improving the 24-hour activity behavior pattern to reduce the risk of overweight and obesity suggests that individuals of different age groups can benefit from adjustments in time allocation, with interventions targeting different areas. In children and adolescents, substituting 30 minutes of MVPA for LPA, sleep, or SED results in reduced waist circumference (WC) and waist-to-hip ratio, alongside an increase in fat-free mass index [45]. Similarly, in another 15-minute ISM, replacing MVPA for LPA, sleep, or SED leads to a decrease in zBMI, with asymmetric substitution effects [46]. Achieving the recommended level of MVPA has also been effective in controlling overall and central obesity development in children and adolescents [47]. Hence, increasing daily MVPA time is crucial for improving obesity in children and adolescents, while reducing SED or interrupting prolonged periods of SED is also necessary. Studies have found that moderate amounts of sedentary time are significantly associated with fat mass percentage (FM%) and visceral adipose tissue (VAT), while replacing short sedentary time with moderate sedentary time correlates with decreased FM% [48, 49]. The impact of sedentary behavior on health varies depending on different environments; for instance, substituting SED with LPA outside of school significantly reduces FM% and fat mass index (FMI) [50]. For older adults experiencing declines in physical function, replacing SED with LPA yields positive effects. Pelclova noted that both MVPA and LPA substitution for SED are associated with decreases in BMI and body fat percentage, with MVPA substitution showing the best effects [51]. Additionally, the importance of sleep in older age cannot be overlooked. Suorsa et al. [52], while supporting the benefits of MVPA in preventing obesity, found that increases in sleep and standing time were associated with higher obesity levels. They recommended replacing standing time with LPA as a weight loss strategy for older adults while maintaining current levels of sleep [53]. In studies on non-alcoholic fatty liver disease (NAFLD) caused by obesity, Tsunoda found that redistributing 60 minutes of sedentary behavior to MVPA reduced disease incidence by 22%, while reverse substitution increased it by 69%, confirming MVPA as a target for preventing NAFLD [54].

Figure 1 24-hour movement behaviors and Prevention and Management of Different NCDs

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Table 1 Isotemporal substitution studies of 24-hour movement behaviors and NCDs

<table>
<thead>
<tr>
<th>NCDs</th>
<th>Study Sample</th>
<th>ISM</th>
<th>Result</th>
<th>Suggestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaba A, et al, 2020</td>
<td>Children</td>
<td>Replacing moderate-duration SED 1 h/week of MVPA</td>
<td>FM% ↑, FMI ↑, VAT ↓</td>
<td>Replace SED with MVPA, frequent standing or activity breaks</td>
</tr>
<tr>
<td>Obesity</td>
<td></td>
<td>Replacing moderate-duration SED 2 h/week of short-duration SED</td>
<td>FM% ↓</td>
<td></td>
</tr>
<tr>
<td>Gaba A, et al, 2021</td>
<td>Older Adults</td>
<td>Replacing out-of-school SED with 30 min/d of out-of-school LPA</td>
<td>Female students: BMI ↑, body fat ↑, fat mass ↓</td>
<td>Replace standing time with LPA</td>
</tr>
<tr>
<td>Powell C, et al, 2020</td>
<td>Preschool Children</td>
<td>Replacing 15 min/d of MVPA with LPA, sleep or SED</td>
<td>body shape ↑, physical fitness ↑</td>
<td>Increase MVPA and decrease LPA</td>
</tr>
<tr>
<td>Chang Z, et al, 2020</td>
<td>Undergraduates</td>
<td>Replace 30 min/d of MVPA and sleep with SED or LPA</td>
<td>total physical fitness assessment scores ↓</td>
<td>Increase MVPA and sleep</td>
</tr>
<tr>
<td>Tsunoda K, et al, 2021</td>
<td>Adults</td>
<td>Replace 60 min/d of MVPA with NAFLD ↑, depression symptoms ↓</td>
<td>Increase MVPA and decrease SED</td>
<td></td>
</tr>
<tr>
<td>Murray R M, et al, 2023</td>
<td>Teenagers</td>
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<td>depression symptoms ↓</td>
<td>Increase MVPA</td>
</tr>
<tr>
<td>Sampasa-Kanyinga H, et al, 2021</td>
<td>Mental disease</td>
<td>Replace 15 min/d of MVPA with LPA, sleep or SED</td>
<td>body shape ↑, physical fitness ↑</td>
<td>Increase MVPA</td>
</tr>
<tr>
<td>Cabañas-Sánchez V, et al, 2023</td>
<td>Older Adults</td>
<td>Replace 30 min/d of MVPA</td>
<td>cardiovascular health ↑</td>
<td>Increase MVPA or LPA</td>
</tr>
<tr>
<td>Full K M, et al, 2023</td>
<td>Adults</td>
<td>Replace 10 min/d of VPA, MPA or SED</td>
<td>cardiovascular health ↑</td>
<td>Promote VPA, MPA, and LPA to replace SED</td>
</tr>
<tr>
<td>CVD</td>
<td>Teenagers</td>
<td>Replace 91 min/d of sleep</td>
<td>WC ↓, BMI ↓</td>
<td>Reallocate sleep time</td>
</tr>
<tr>
<td>Badon S E, et al, 2023</td>
<td>Pregnant Women</td>
<td>Replace LPA, sleep or SED with 30 min/d of MVPA</td>
<td>LDL ↓, Total cholesterol ↓</td>
<td>Achieve the recommended level of MVPA</td>
</tr>
<tr>
<td>Aadahi M, et al, 2021</td>
<td>Adults</td>
<td>Replace 30 min/d of MVPA or LPA</td>
<td>diabetes risk ↑</td>
<td>Replace SED with MVPA/LPA</td>
</tr>
<tr>
<td>Kouiti M, et al, 2023</td>
<td>Pregnant Women</td>
<td>Replace 60 min/d of MVPA</td>
<td>gestational diabetes risk ↑</td>
<td>Increase VPA by 1 hour per week</td>
</tr>
<tr>
<td>Bellettiere J, et al, 2020</td>
<td>Older women</td>
<td>Replace LPA or SED with 30 min/d of MVPA</td>
<td>diabetes risk ↑</td>
<td>Increase MVPA</td>
</tr>
<tr>
<td>Kosaki K, et al, 2020</td>
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<td>Replace 30 min/d of MVPA</td>
<td>eGFR ↓</td>
<td></td>
</tr>
<tr>
<td>Yoshioka M, et al, 2021</td>
<td>Older Adults</td>
<td>Replace 10 min/d of MVPA</td>
<td>bone density ↑</td>
<td>Replace SED with MVPA</td>
</tr>
<tr>
<td>Ohata T, et al, 2023</td>
<td>Adult</td>
<td>Replace 30 min/d of MVPA or LPA</td>
<td>eGFR ↑</td>
<td></td>
</tr>
<tr>
<td>Niemela M, et al, 2023</td>
<td>All-cause mortality</td>
<td>Replace sleep with 15, 30, 45 or 60 min/d of MVPA</td>
<td>mortality risk ↓</td>
<td>Regular participation in MVPA</td>
</tr>
<tr>
<td>Miguélez J H, et al, 2021</td>
<td>Older women</td>
<td>Replace 10 min/d of MVPA or HLP</td>
<td>mortality risk ↓</td>
<td>Replace SED with LPA</td>
</tr>
<tr>
<td>Gilchrist S C, et al, 2020</td>
<td>Cancer mortality</td>
<td>Replace 30 min/d of MVPA or LPA</td>
<td>cancer mortality risk ↓</td>
<td>Replace SED with MVPA/LPA</td>
</tr>
<tr>
<td>Sanchez-Sanchez J Z, et al, 2019</td>
<td>Sarcopenia</td>
<td>Replace SED or LPA with 60 min/d of MVPA</td>
<td>Handgrip strength ↓, gait speed ↓</td>
<td>Replace SED or LPA with MVPA</td>
</tr>
</tbody>
</table>
On the other hand, promoting a balanced 24-hour allocation contributes to improving the physical fitness of children and adolescents, thereby reducing the risk of overweight and obesity. For preschoolers, increasing levels of MVPA and LPA is crucial for promoting physical fitness. Studies have found that promoting the transition from SED to sleep or LPA and from LPA to MVPA can enhance physical fitness, agility, and lower limb muscle strength in preschoolers [55, 56]. Moreover, replacing LPA with MVPA, replacing the promotion of fundamental movement skills in preschoolers but also reduces the risk of overweight and obesity [57, 58]. The influence of 24-hour movement behaviors on physical fitness in children and adolescents is similar to that of obesity. Research indicates that substituting 10 minutes of LPA or SED for MVPA has significantly more detrimental effects on physical fitness than reverse substitution, emphasizing the importance of maintaining MVPA levels rather than simply reducing sedentary time [59]. University students are the main group for monitoring physical fitness, and for the first time, Song studied Chinese university students, finding that promoting the transition from MVPA to SED also has a positive effect on physical fitness [60]. Additionally, some studies suggest that the improvement in physical fitness weakens with longer durations of MVPA substitution, while increasing LPA is also beneficial for the physical fitness of university students [61].

Mental disease
In children, adolescents, and the elderly, adjusting the 24-hour activity pattern can promote their mental health, with a recommendation to ensure an adequate amount of sleep while promoting the transition from SED to MVPA. Currently, promoting adherence to the 24-hour activity guidelines for adolescents has become a critical goal in intervening in mental health issues [62]. A systematic review indicated that adherence to the 24-hour activity guidelines in children and adolescents was associated with a better tendency towards mental health and a lower risk of mental illness [40]. Garcia-Hermoso et al. [63] underscored, through cohort studies, the importance of adhering to activity guidelines from adolescence to adulthood in preventing and improving mental health problems. Substituting MVPA or LPA for SED also enhances the mental health of children and adolescents. A study replacing 10 minutes of LPA with SED showed improvements in depression and anxiety scores, while substituting 15 minutes of SED or LPA for MVPA was associated with increased depressive symptoms in adolescents [64, 65]. Additionally, sleep has a similar positive impact on the mental well-being of adolescents. Patte et al. [66] considered adherence to the sleep component of the activity guidelines as the best predictor of adolescent depressive symptoms. Liang suggested limiting screen time and ensuring adequate sleep while promoting adherence to the guidelines [67]. Similarly, isotemporal substitution analysis found significant benefits for mental health when replacing 60 minutes of MVPA or sleep for screen time, with the greatest improvement observed when replacing 60 minutes of sleep for screen time [68, 69]. In certain special cases among adolescents, altering the 24-hour activity behavior is also an effective means of promoting mental health. Adhering to the 24-hour exercise guidelines can improve the physical and mental health of children with mental, behavioral, and developmental disorders, and promote and maintain the quality of life for children with autism spectrum disorders [31, 70]. For some college students with chronic diseases and diet disorders, compliance with exercise guidelines is also beneficially associated with mental health indicators [71]. However, these college students have limited physical activity abilities, and guidelines should consider additional requirements for behavioral interventions based on different health conditions. For the elderly population, cross-sectional studies have found that MVPA is associated with a reduction in depressive symptoms, loneliness, and an increase in happiness, with prospective associations with global mental health improvement. Isotemporal substitution analysis suggests that substituting MVPA for LPA, sleep, and SED or LPA for SED can lead to moderate improvements in mental health indicators, while substituting MVPA for LPA did not yield positive benefits [72-74]. Additionally, for patients with dementia-related diseases, whether or not they engage in physical activity, reducing cognitive passive SED (such as TV time) and increasing cognitive active SED (such as computer time) may be effective behaviors in reducing the risk of dementia [75].

Cardiovascular disease
Insufficient physical activity is recognized as a major risk factor for cardiovascular disease (CVD) incidence and mortality. However, recent research suggests that attention to overall activity behavior also contributes to CVD prevention. A recent isotemporal substitution study found a 9% reduction in adult CVD risk associated with replacing 20 minutes of MVPA with other activity behaviors, while substituting 60 minutes of SED was associated with a 5% increased risk [12]. Similarly, replacing sedentary behavior with activities of different intensities reduces CVD incidence, with MVPA replacement showing the most significant effect, and high levels of MVPA mitigating the increased CVD risk associated with excessive SED [76]. Thus, increasing MVPA and reducing SED may be the optimal strategy for CVD prevention, although determining the optimal substitution time is crucial. For older adults, elevating or maintaining MVPA levels is equally important. Yerramalla et al. [77] found that replacing MVPA with LPA/SED was associated with a decrease in CVD incidence, while CVD risk was unrelated to LPA/SED levels when MVPA remained unchanged. However, due to declining physical fitness in older adults, some may struggle to meet daily MVPA requirements. In such cases, substituting sedentary behavior with walking (i.e., LPA) is also an effective option for reducing CVD risk among older adults [78]. Therefore, as a simpler and more feasible activity behavior, LPA may have greater potential in promoting cardiovascular health. Twenty-four-hour activity behavior in children, adolescents, and adults is closely associated with markers of cardiac metabolism risk. Substituting VPA or MPA for SED has positive effects on improving cardiac metabolic health in children. Studies focusing on children of different weight statuses have shown that in weight-healthy children, replacing 10 minutes of VPA with SED is associated with better levels of high-density lipoprotein cholesterol (HDL-C) and triglycerides; in overweight samples, substituting VPA for SED is associated with improvement in overall cardiac metabolic scores [79]. Further analysis indicates that substituting 10 minutes of VPA, MPA, and LPA for SED contributes to improving cardiovascular risk health in obese children and adolescents, with VPA or MPA showing more significant effects [80]. For adults, substituting MVPA or LPA for 15, 30, 45 and 60 minutes of SED is associated with improvements ranging from 0.2% to 13.7% in cardiac metabolic health markers [81]. Gender and regional differences may exist in the relationship between cardiac health and 24-hour activity behavior. Cheng et al. [82] suggest that expected changes in cardiac metabolic markers due to the reallocation of time from SED to MVPA or LPA vary by gender and age. A study on elderly women found that substituting 91 minutes of sleep for SED was associated with decreases in WC and BMI, but this indicator may increase in women with prolonged sleep durations [83]. Promoting the transition from SED to MVPA/LPA in early pregnancy can improve cardiac metabolic health indicators in late pregnancy [84]. Additionally, reallocating sedentary time to MVPA or LPA may also positively impact cardiac metabolic health in sedentary Asian populations [85]. Therefore, future research should further explore cardiovascular outcome differences based on gender, region, and age to develop more precise health guidelines.

Diabetes and kidney disease
In diabetes-related research, both MVPA and SED are regarded as primary influencing factors, with gender and disease subtypes also playing significant roles. During adolescence, encouraging teenagers to adhere to 24-hour activity guidelines, particularly regarding physical activity and screen time, has shown to improve the risk of type 2 diabetes mellitus (T2DM) in adulthood [86]. Multiple isotemporal substitution studies have confirmed the importance of
MVPAs and LPAs in the prevention and management of diabetes in adults. Adadah et al. [87] found that replacing 30 minutes of MVPA/LPA with SED reduced the risk of diabetes in adults; Rosen [88] suggested the roles of these activity behaviors in reducing cardiometabolic risk in prediabetic patients; and Swindell et al. [89] found that replacing SED with LPA also improves insulin sensitivity. A prospective study observed that substituting 30 minutes of MVPA or LPA for SED was associated with reduced all-cause mortality in prediabetic and diabetic patients [90]. Among middle-aged and elderly populations, replacing sedentary time with walking improves blood glucose, and engaging in less sitting and more standing benefits older adults at higher risk of T2DM [91]. Gender differences also exist in diabetes research, with studies on women showing that substituting 60 minutes of VPA for screen time significantly reduces the odds of gestational diabetes [92]; and substituting MVPA for LPA or SED is associated with reduced diabetes risk in elderly women [93]. Additionally, different activity patterns exist among subtypes of T2DM, with the lowest levels of physical activity and poorest sleep seen in obesity-related diabetes subtype patients, suggesting the consideration of different diabetes subtypes in future studies [94]. Elevating MVPA levels is a reliable approach in improving chronic kidney disease (CKD). A study focusing on elderly individuals demonstrated that replacing 30 minutes of MVPA for SED was associated with improvements in estimated glomerular filtration rate (eGFR) [95]. For elderly CKD patients, research indicates that even mild increases in MVPA (10 minutes/day) help slow down the decline in bone density, thus maintaining skeletal muscle strength [96, 97]. Gender is also a significant factor in CKD, with studies showing a significant interaction between gender and MVPA, indicating a stronger negative correlation between MVPA levels and CKD in males, suggesting that males should adopt physical activity to replace sedentary behavior to prevent CKD incidence [98]. Kidney transplantation is one of the effective clinical treatments for CKD. Ohata found that substituting 30 minutes of MVPA for SED improved and maintained eGFR levels post-kidney transplantation [99]. Additionally, sleep has potential implications for kidney health, with a study finding that increasing sleep duration or improving sleep quality can reduce the incidence of CKD [100]. Future isotemporal substitution studies can further explore the benefits of sleep for CKD.

Mortality risk and other diseases
The levels of SED and MVPA significantly impact the risk of mortality, with the role of LPA also being noteworthy. Research indicates that SED independently influences the risk of mortality. Lin et al. [34] found that individuals exceeding 10 hours of daily SED experienced an advancement in age at the occurrence of cancer or death by 4.09 years and 2.79 years, respectively, at the age of 50, and failing to meet recommended MVPA levels may exacerbate this adverse association. Other studies suggest that interrupting prolonged SED could be an effective means to reduce all-cause mortality rates, as increasing SED interruptions independently reduce all-cause mortality rates, recommending brief physical activity breaks every 30-60 minutes to interrupt SED and reduce mortality rates [101, 102]. In addition to interrupting SED, several studies propose substituting MVPA or LPA for SED to lower the risk of mortality. Isotemporal substitution analyses show that substituting MVPA for SED yields the greatest reduction in risk, highlighting the importance of encouraging adults to increase MVPA levels and decrease SED [103]. A cohort study found that substituting 30 minutes of LPA for SED significantly reduced the risk of cancer mortality by 8%, while substituting MVPA for SED reduced the risk of cancer mortality by 31% [104]. For individuals with different MVPA levels, intervention focuses vary. For those with ≤ 17 minutes of daily MVPA, substituting MVPA/LPA for SED is associated with a 45% and 14% reduction in mortality risk, respectively; whereas for those with > 30 minutes of daily MVPA, substituting MVPA, LPA or SED is unrelated to mortality risk, suggesting the adoption of LPA to replace appropriate amounts of SED to reduce premature mortality risk in inactive adults [105]. Different intensities of LPA also yield varied health benefits for older adults. Migueles et al. [106] found that substituting 10 minutes of vigorous LPA for SED was associated with a 6% reduction in mortality risk in elderly women, while substituting 90 minutes of vigorous LPA or 120 minutes of light LPA for SED was associated with a 43% reduction in mortality risk.

Substituting MVPAs/LPAs for SED of varying durations also reduces the risk of mortality caused by NCDs. A longitudinal study demonstrated that isotemporal substitution of 30 minutes of MVPA or LPA for SED was associated with a 6% reduction in dementia incidence and a 9% reduction in mortality rates [107]. Kim et al. [108] found that substituting 10 minutes of LPA for SED significantly reduced all-cause mortality and NCD-specific mortality risk, with the risk decreasing gradually with increasing substitution time, suggesting the potential health benefits of moderate LPA substitution for SED in reducing heart failure mortality rates. Similarly, Lansitie et al. [109] found that increasing LPA and avoiding prolonged sitting time at any intensity level were associated with reduced cardiovascular disease risk in older adults. A prospective study showed that increasing MPA maximally reduced the risk of stroke and myocardial infarction in elderly individuals and counteracted the negative effects of SED [110]. In studies on bone health (BM), optimal interventions show gender differences. A longitudinal study suggested that increasing MVPA improves bone health in elderly men, while elderly women should increase LPA to maintain MVPA levels [111]. Another study recommended that elderly men reduce SED and elderly women increase LPA to promote BM [112]. For elderly individuals with sarcopenia, substituting MVPA for LPA or SED can reduce the risk of developing the condition and improve muscle mass, gait speed, and grip strength [113]. Increasing physical activity has been shown to improve chronic obstructive pulmonary disease (COPD), with guidelines suggesting specific activity durations [114, 115]. However, the effects of sedentary behavior and sleep on COPD are less studied, and little is known about the impact of overall 24-hour activity patterns. Considering the positive effects of physical activity, integrating the entire spectrum of 24-hour behaviors is vital for advancing COPD treatment.

Outlook and prospects
The impact of 24-hour movement behaviors on NCDs has become a major focus of large-scale public health interventions. Comprehensive analyses of combined activity behaviors prove superior to singular actions, making a holistic consideration of daily activities a continuing focal point for future research. Despite the progress in studying 24-hour movement behaviors and NCDs, numerous issues persist regarding research tools, subjects, methodologies, intervention strategies, and interdisciplinary studies. Regarding research tools, both subjective and objective measurements have their advantages and drawbacks. Subjective measurements, typically in the form of questionnaires and diaries, are suitable for large-scale epidemiological studies, providing detailed activity behavior types, but are susceptible to data biases. Objective measurements utilize devices such as accelerometers, pedometers, and motion sensors, offering precise measurements with minimal subjective influence. However, current accelerometers often overlook posture characteristics and the variances in the measurement “thresholds” among different populations, besides being cost-intensive and not commonly employed in large-scale surveys [116]. Thus, improving existing accelerometer algorithms or developing new measurement tools is crucial for advancing time-use research [117]. Concerning research subjects, existing studies gradually encompass various age groups and different NCD patients, inferring personalized optimal usage patterns based on time use. However, there is scarce research from perspectives such as gender, disciplines, regions, and ethnicities, lacking studies on the differential relationship between 24-hour time allocation patterns under different environmental conditions and health outcomes. In research methodologies, the commonly adopted ISM categorizes physical activity into MVPA or LPA and substitutes for other activity behaviors, often overlooking the types and qualities of SED and sleep.
and their relationships with health benefits. Additionally, DSM studies mostly rely on cross-sectional data, primarily deriving dose-response relationships through hypothetical analyses, necessitating further high-quality longitudinal research to validate the reliability and scientific integrity of the results. Concerning intervention strategies, future efforts should focus on developing personalized interventions tailored to different populations, such as various NCD patients and their gender, age, and physical condition differences. Through interventions in time use, lifestyle changes, and medication therapies, promoting the formation of healthy activity behavior patterns can effectively prevent and control NCDs. In interdisciplinary research, the fusion of biology and medicine is an emerging intersection. By combining knowledge from biomedical and clinical disciplines, further exploration of the biological mechanisms between 24-hour movement behaviors and NCDs will provide solid evidence support for promoting public health research fields.

**Conclusion**

24-hour movement behaviors have emerged as a forefront focus in the field of public health promotion research. With the refinement of analytical methods and the diversification of research subjects, numerous studies have indicated that adopting healthy 24-hour activity behavior patterns is a crucial measure in preventing and managing NCDs. This paper provides a detailed overview of the concept, development, and analytical methods of 24-hour movement behaviors. It elucidates the current international academic landscape regarding the study of three activity behaviors: physical activity, sleep, and SED, respectively. Furthermore, it explores the research progress and advantages of 24-hour movement behaviors in NCDs such as overweight and obesity, mental disorders, cardiovascular diseases, diabetes, kidney diseases, and mortality risk. By offering guidance for developing personalized time-use intervention strategies for different NCD patients, it highlights the need for researchers to enhance their efforts in four areas: developing research tools, expanding research subjects, refining research methods, and advancing interdisciplinary research. This aims to provide scientific evidence and theoretical guidance for the development of personalized physical activity guidelines for NCD patients.

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