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Original article

2024 Wheelchair Compendium of Physical Activities: An update of activity codes and energy expenditure values

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Abstract

Purpose: This paper presents an update of the 2011 Wheelchair Compendium of Physical Activities designed for wheelchair users and is referred to as the 2024 Wheelchair Compendium. The Wheelchair Compendium aims to curate existing knowledge of the energy expenditure for wheelchair physical activities (PAs).

Methods: A systematic review of the published energy expenditure of PA for wheelchair users was completed between 2011 and May 2023. We added these data to the 2011 Wheelchair Compendium data that was compiled previously in a systematic review through 2011.

Results: A total of 47 studies were included, and 124 different wheelchair PA reported energy expenditure values ranging from 0.8 metabolic equivalents for wheelchair users (filing papers, light effort) to 11.8 metabolic equivalents for wheelchair users (Nordic sit skiing).

Conclusion: In introducing the updated 2024 Wheelchair Compendium, we hope to bridge the resource gap and challenge the prevailing narratives that inadvertently exclude wheelchair users from physical fitness and health PAs.

Keywords: Disability; Exercise; MET; Mobility

1. Introduction

Physical activity (PA) is essential to health promotion and disease prevention, contributing to physiological well-being and enhancing quality of life across the population spectrum.^{1–3} However, as recently as 2021, a review noted that populations of people who use wheelchairs due to a physical disability are “broad and poorly captured in the literature on PA”.⁴ One in four U.S. adults report living with a disability, with mobility disability being the most common disability in adults 45 years and older.^{5,6} The World Health Organization estimated that 1.3 billion people worldwide live with a

disability,⁷ with at least 80 million people worldwide who require the use of a wheelchair for mobility.⁸

Wheelchair users commonly report low levels of habitual PA^{9,10} and a heightened prevalence of cardiovascular disease risk factors.^{11,12} Contemporary research has underscored the multifaceted benefits of PA for wheelchair users, ranging from improved cardiometabolic health and increased muscle strength and fitness^{13–15} to positive impacts on mood and overall quality of life.¹⁶ Consequently, regular PA is vital for wheelchair users. However, there is a lack of consensus for defining and measuring PA in populations of wheelchair users.¹⁷ This context underscores the urgency and significance of providing resources and strategies to promote PA among this population.

In 2011, Ginis et al.¹⁸ developed PA guidelines for adults with spinal cord injury (SCI), which have since been updated to reflect exercise guidelines¹³ and are widely adopted.¹⁹

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These guidelines recommend a minimum of 20 min of moderate (3.0–5.9 metabolic equivalent of tasks (METs))-to-vigorous (≥ 6 METs) intensity aerobic exercise 2 times per week and 3 sets of strength exercises for each major functioning muscle group at a moderate-to-vigorous intensity 2 times per week. Additionally, to improve cardiometabolic health, these authors propose performing 30 min of moderate-to-vigorous intensity aerobic exercise 3 times per week, which differs from other recommendations more akin to the general population guidelines (e.g., at least 150 min per week).^{20,21} Besides discrepancies in the recommended volume of PA between non-disabled and SCI adults, the metabolic demands associated with upper-body movements involving smaller skeletal muscles will undoubtedly be less than relative intensity matched lower-body or whole-body activity.²² Consequently, performing upper-body movements for the same period as lower-body exercises will constrain total energy expenditure. This observation is further compounded by the fact that there are multiple reasons for wheelchair use, and the amount of muscle mass available for recruitment (and thus energy expenditure) is highly variable between and within medical conditions requiring a wheelchair. Therefore, this complicates the ability of healthcare professionals and exercise practitioners to determine whether wheelchair users are achieving sufficient metabolic perturbations to achieve health benefits. Further, the guidelines mentioned above do not provide a detailed list of the activities that achieve guideline criteria and whether the guidelines should apply to all or some of the wide variety of wheelchair users, including amputees, stroke, spina bifida, multiple sclerosis, and SCIs with different neurological lesion levels (causing paraplegia or tetraplegia).

The Compendium of PA for non-disabled adults was first published in 1993²³ and influenced PA research and public health guidelines.^{24–29} The Compendium was updated in 2000, 2011, and 2024 (herein: Adult Compendium) to provide updated lists of the energy expenditure of many PAs.^{30,31} The Compendium of PA for Wheelchair Users was compiled in 2011 (2011 Wheelchair Compendium).³² Since then there has been an increase in studies reporting energy expenditure during PA performed by wheelchair users. Thus, an update to the 2011 Wheelchair Compendium is warranted. The purpose of this paper was (a) to complete a systematic review and focused literature searches to identify studies reporting the energy expenditure of PA in wheelchair users, and (b) to provide an updated 2024 Compendium explicitly for those individuals leading a wheelchair-based lifestyle.

2. Methods

2.1. Search strategy

PAs and their respective energy expenditure values were obtained using a systematic review of studies published in the scientific literature, abstracts published in conference proceedings, and additional targeted literature searches. A comprehensive search of published articles was completed for dates following the release of the 2011 Wheelchair Compendium³² (January 1, 2011, to May 19, 2023). Searches were conducted using PubMed,

Embase, SPORTDiscus (EBSCOhost), and Scopus. The search terms used to identify articles appear in [Appendix 1](#).

2.2. Eligibility criteria and study selection

Articles were included if (a) the study participants were adults, (b) the energy expenditure of wheelchair PA was measured using indirect or direct calorimetry, and (c) full-text articles were published in English. Articles were excluded if (a) the study population included non-disabled individuals, (b) values were not available to calculate energy expenditure (e.g., participant weight or wheelchair speed), or (c) PAs were completed without the use of a wheelchair (e.g., standing, walking, stair climbing).

After the initial search, all articles were exported to Endnote X9 (Clarivate, Philadelphia, PA, USA) for removal of duplicates and then imported into Covidence systematic review software (Veritas Health Innovation, Melbourne, VIC, Australia; available at www.covidence.org) for abstract screening and full-text review management. Five reviewers (SAC, EAW, TEN, JRS, and SDH) independently screened all abstracts, resolved conflicts, and screened full-text articles for eligibility criteria. A detailed description of the Covidence abstract screening processes is available from Herrmann et al.³³

2.3. Data extraction and calculation of energy expenditure

Sample characteristics (reason for wheelchair use, sample size, and body weight), activity descriptions, and associated energy expenditure values were extracted from the articles. As previously described, energy expenditure values were converted to kilocalories per kilogram body weight per hour (kcal/kg/h) (hereafter MET_{WC}),³² representing the MET for wheelchair users. MET_{WC} is computed by dividing the activity energy expenditure in kcal/kg/h by a baseline energy expenditure (0.992 kcal/kg/h). For example, an activity with an energy expenditure of 4.0 kcal/kg/h divided by 0.992 kcal/kg/h has an MET_{WC} of 4.03. We present the equation^{32,34} used to compute the denominator for the MET_{WC} in [Appendix 2](#). When multiple studies measured energy expenditure for the same PA, we weighted the average MET_{WC} value using sample sizes from each study from the combined 2011 and 2024 Wheelchair Compendia. Weighting increases the precision of the MET_{WC} by giving studies with larger sample sizes and narrower confidence intervals more weight. See Willis et al.³⁵ for the equation weighting the MET_{WC} values.

3. Results

Thirty-six articles published since the 2011 Wheelchair Compendium³² met the inclusion criteria and were included in the 2024 Wheelchair Compendium. The review and selection process to identify included articles are summarized in [Fig. 1](#). The articles included energy expenditure values for 190 PAs, some of which were measured in multiple studies. When combined with the 2011 Wheelchair Compendium,³² 371 PAs from 47 studies were extracted for inclusion in the 2024 Wheelchair Compendium. The 47 studies included 972

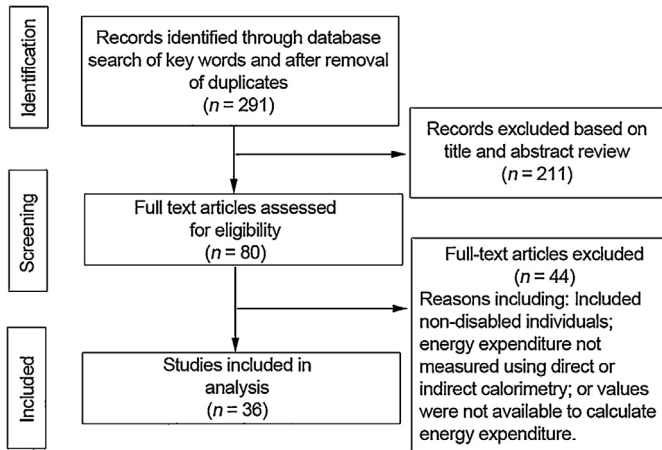


Fig. 1. Selection of articles from the systematic review of studies on wheelchair physical activities.

participants, 85% male. The median number of participants in a study was 15.5, with sample sizes ranging from 1³⁶ to 170³⁷ participants across all studies. Most studies included participants with SCI at different levels (64%), while 34% included participants with multiple reasons for wheelchair use (including SCI). One study limited its participants to individuals with severe athetospastic cerebral palsy.³⁸

A total of 124 different wheelchair activities are included in the 2024 Wheelchair Compendium. Each activity is grouped into 1 of 5 Major Headings (Table 1). Each Major Heading includes a Specific Activity, its MET_{WC}, and the associated references. The 2024 Wheelchair Compendium tables are located at <https://pacompendium.com>. An example of a Specific Activity from each Major Heading and its associated MET_{WC} value is presented in Table 2.

The Wheelchair Compendium uses a 5-digit code to identify Major Headings and Specific Activities for wheelchair users. The first digit “9” indicates the Specific Activities are for wheelchair users. Digits 2 and 3 identify the Major Headings (e.g., Exercise (01), Household Activities (02), Inactivity (03)), and Digits 4 and 5 identify the Specific Wheelchair Activities (e.g., 01, 02, 03). For example, code 90102 identifies a wheelchair PA (09), performed for exercise (01), using an arm ergometer at an intensity of 16 watts (02), with an associated energy expenditure of 2.2 MET_{WC}.

Table 1
Major Headings and the number of Specific Activities in the 2011 and 2024 Wheelchair Compendia of Physical Activities.

Major Heading	No. of Specific Activities in the 2011 Wheelchair Compendium	No. of Specific Activities in the 2024 Wheelchair Compendium
01 Exercise	22	66
02 Home Activities	10	18
03 Inactivity	3	9
04 Miscellaneous	3	0
05 Sports/Recreation	12	19
06 Transportation	12	12

Table 2

Organization of the 2024 Wheelchair Compendium of Physical Activity energy expenditure for selected activity codes.

Activity Code	Major Heading	Specific Activity	MET _{WC}
90102	Exercise	Arm Ergometry (16W)	2.2
90210	Household Activities	Washing Dishes	1.9
90302	Inactivity	Reading	1.2
90510	Sports/Recreation	Table Tennis	2.7
90611	Transportation	Wheeling on Tile Floor	2.2

Notes: The first digit “9” denotes a wheelchair PA; the second and third digits (1–6) identify the Major Heading; the fourth and fifth digits identify the Specific Activity. MET_{WC} represents the PA energy expenditure.

Abbreviations: MET_{WC} = metabolic equivalent of task for wheelchair users; W = watt.

4. Discussion

In this study, we identified 36 new articles that included 62 new PAs completed by wheelchair users. In the 2011 Wheelchair Compendium,³² 62 different activities were identified from 11 studies. When combined with the 2011 data, the 2024 Wheelchair Compendium includes a total of 47 studies reporting 124 wheelchair PAs. The number of unique participants in these studies increased from 365 to 972 in the 2011 and 2024 Wheelchair Compendia, respectively. Consistent with the 2011 Wheelchair Compendium, the participants were primarily male (85%) and relatively young (mean age = 37.1 ± 6.9 years; mean ± SD). There is an increase in the number of Specific Activities in most Major Headings in the 2024 Wheelchair Compendium, with most new Specific Activities in the Exercise Major Heading. Three Specific Activities previously classified in the Miscellaneous Major Heading (driving, fishing/casting, and grocery shopping) were reassigned to Transportation, Sports/Recreation, and Household Activities, respectively. While research on the energy expenditure of PA in adult disabled populations has increased substantially since the development of the 2011 Wheelchair Compendium, it still pales compared to that of the non-disabled adult literature.³³

Measuring the energy expenditure of PA in wheelchair users is a relatively new field. In 1985, Burke et al.³⁹ reported the energy expenditure of 4 wheelchair athletes during a 30-min basketball practice. Their research was the first study to report the steady state energy expenditure of a wheelchair PA. It was another 17 years before Mukherjee et al.⁴⁰ published the energy expenditure of a wheelchair PA. This time gap indicates the dearth of research on the energy expenditure of PA among wheelchair users. By the time of the publication of the 2011 Wheelchair Compendium, there were only 11 published articles presenting energy expenditure data for wheelchair users. However, over the last 12 years, there has been a steady increase in publications on PA energy expenditure in wheelchair users. The increase is encouraging, but much work needs to be done.

The resting metabolic rate (RMR) in some populations of wheelchair users is generally lower than the 1 MET (3.5 mL/kg/min) often presented for non-disabled adults.³⁷ However, RMR varies considerably among wheelchair users, ranging from

2.5 mL/kg/min in a group with a high-level SCI³⁷ to 5.7 mL/kg/min in a sample with severe athetospastic cerebral palsy.³⁸ An alternative option to using 1 MET as the RMR is to present the energy expenditure based on the average RMR of the SCI population of 2.7 mL/kg/min (SCI METs), as was done by Collins et al.³⁷ However, this option is problematic even within populations with SCI. For example, those with higher-level injuries tend to have a lower RMR than those with lower-level injuries.^{37,41,42} The approach taken in the 2024 Wheelchair Compendium was to present the energy expenditure as MET_{WC} with a baseline value of 0.992 kcal/kg/h (Appendix 2). While this method of reporting PA energy expenditure differs from reporting the energy expenditure of PAs as mL/kg/min in the Adult Compendium,³³ it acknowledges that the RMR of some wheelchair users may differ from able-bodied populations.

A significant challenge associated with the 2024 Wheelchair Compendium is generalizing energy expenditure for wheelchair users. One reason is the wide range in the type, mass, and quality of the wheelchairs used by participants in this study. More importantly, people use a wheelchair for a wide range of various etiologies, acute musculoskeletal issues in the lower limbs, or chronic disabling conditions, including SCIs, cerebral palsy, multiple sclerosis, muscular dystrophy, arthritis, scoliosis, fibromyalgia, Parkinson's disease, poliomyelitis, amputations, and many more reasons. This heterogeneity is reflected in the 2024 Wheelchair Compendium's participants with various disabilities. Energy expenditure during leisure time PA or activities of daily living can vary from individual to individual based on several factors, including age, weight, biological sex, and level of cardiorespiratory fitness. This variability in energy expenditure is further exaggerated across different chronic disabling conditions due to differing amounts of neurologically intact and metabolically active muscle mass, which alters specific movement patterns and is also closely associated with RMR.^{43,44} Even within specific disabling conditions, factors such as the duration of diagnosis, the condition's progression or severity, and the amount of skeletal muscle individuals can utilize during voluntary contractions will all impact the energy expenditure achieved during a Specific Activity. For example, Collins et al.³⁷ observed disparate SCI METs for weight training depending on the neurological level of injury; participants with motor-complete C5–C8 ($n=4$) and T9–L4 ($n=2$) had SCI METs of 2.2 and 3.4, respectively. However, those authors did not test whether these differences were statistically significant due to the low statistical power caused by small sample sizes.

Conversely, the 2011 Wheelchair Compendium revealed that the energy expenditure of different PAs was similar between individuals with tetraplegia (C8 or above) and paraplegia (T1 or below).³² Besides the differing motor-sensory impairments between persons with tetraplegia and paraplegia, other factors contribute to differing exercise capacities of these individuals with lesions at or above the sixth thoracic (T6) level, who have diminished supra-spinal sympathetic control to the heart and blood vessels. This results in cardiovascular blunting (peak heart rate of <130 beats/min), reduced circulating catecholamines and cardiac contractility, low blood pressure, impaired blood flow redistribution, reduced capacity of the venous muscle pump, and restricted stroke volume.^{45,46}

Collectively, these factors result in a reduced aerobic capacity in persons with tetraplegia and may also explain the differing energy expenditures that Collins et al.³⁷ observed across PAs for individuals with SCI.

Despite the limitations of averaging data for a given PA across all individuals, irrespective of the type of disability or the neurological level or severity of SCI, reporting the average energy expenditure for a specific PA is necessary to ensure generalizability to the broader population of individuals who use wheelchairs. Thus, in the 2024 Wheelchair Compendium, we justified using MET_{WC} as the intensity metric as none of the studies reviewed in the literature presented data separately for different chronic disabling conditions. For example, only 7% of the studies presented data by neurological levels of SCI to facilitate the generation of more precise energy expenditure data in the 2024 Wheelchair Compendium. The most appropriate dichotomization of participants with SCI (e.g., paraplegia, tetraplegia, above or below T6) remains to be established. To overcome this limitation, we encourage authors to make anonymized, individualized participant data available on public repositories to permit more precise energy expenditure estimates based on the specific characteristics of the individual's disability. However, at this time, providing more specific information about disability details is impossible. Like the Adult Compendium,³³ the 2024 Wheelchair is not subdivided by age, gender, body composition, cardiorespiratory fitness, or movement quality, which are all factors known to explain energy expenditure variability.

There are strengths to this study. When combined with the literature search from the 2011 Wheelchair Compendium,³² we reviewed over 550 abstracts and identified 47 studies with nearly 1000 participants. The 2024 Wheelchair Compendium has more than double the Specific Activities included in the 2011 Wheelchair Compendium. However, there are some limitations. While the 2024 Wheelchair Compendium provides a resource for estimating the energy expenditure of PAs in wheelchair users, several factors may impact the values' validity. Individuals with SCI may be disproportionately represented in many of the Specific Activities included in the 2024 Wheelchair Compendium. Over 95% of the studies in this review included some participants with an SCI. However, SCI is not in the top 10 most common reasons for wheelchair use.⁴⁷ Furthermore, many PAs (i.e., wheelchair basketball, tennis) are inherently intermittent. A person who completes these intermittent PAs for 60 min will likely have periods of inactivity interspersed within the 60 min of reported PA. This pattern of participation could lead to potential overestimation of energy expenditure. The age of participants can also be an essential factor to consider. Many participants in the reviewed studies were in the 20- to 40-year age range (mean age = 37.1 ± 6.9 years). Applying these estimates to older adults may not be appropriate, given that RMR declines with age.^{35,48} As is consistent with many research studies in this field,⁴⁹ women are underrepresented. This underrepresentation introduces challenges with generalizing the information to women, especially within some populations of wheelchair users.⁹ It is important to remember that the 2024 Wheelchair Compendium

provides the energy expenditure of various types of PA at the population level, even though these values may result in under- or over-estimations at the individual level. Despite these limitations, the 2024 Wheelchair Compendium improves on the energy expenditure values for wheelchair users as compared to the 2011 Wheelchair Compendium.³²

5. Conclusion

The 2024 Wheelchair Compendium of PA expands upon the 2011 Wheelchair Compendium by summarizing the energy expenditure of 124 different Specific Activities in wheelchair users into a single resource. This resource can aid in reducing barriers to PA for wheelchair users, including a lack of knowledge about suitable exercises and exercise energy expenditure. By providing a diverse array of wheelchair PAs, we aim to foster inclusivity in PA and fitness opportunities and empower wheelchair users to exercise regularly to elicit physiological adaptations for health promotion and disease prevention. We hope that this work will contribute to improving public health and social inclusivity by stimulating further dialogue, research, and advances in studies focused on assessing PA energy expenditure. The 2024 Wheelchair Compendium can be accessed at <https://pacompendium.com>.

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Authors' contributions

SAC performed article screening and extracted data, drafted the manuscript, interpreted the findings, and revised the manuscript for intellectual content; SDH conceived the Compendium update, designed the literature review protocol, monitored the review process, performed article screening, extracted data, drafted the manuscript, interpreted the findings, and revised the manuscript for intellectual content; EAW designed the literature review protocol, monitored the review process, interpreted the findings, and revised the manuscript for intellectual content; TEN performed article screening, extracted data, drafted the manuscript, interpreted the findings, and revised the manuscript for intellectual content; JRS performed article screening, extracted data, and revised the manuscript for critical content; BEA assisted with drafting the manuscript, interpreted the findings, revised the manuscript for intellectual content, and provided critical feedback. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Appendix 1.

Search terms used in the literature search

("Para-Athletes"[Mesh] OR "Wheelchairs"[Mesh] OR wheelchair[tiab] OR "wheel chair"[tiab] OR wheelchairs[tiab] OR "wheel chairs"[tiab] OR para-athlete[tiab] OR para-athletes[tiab] OR "paralympic athlete"[tiab] OR "paralympic athletes"[tiab] OR paralympian[tiab] OR paralympians[tiab]) AND ("Oxygen Consumption"[Mesh] OR "Metabolic Equivalent"[Mesh] OR "Energy Metabolism"[Mesh: NoExp] OR "oxygen consumption"[tiab] OR "oxygen costs"[tiab] OR "oxygen cost"[tiab] OR "oxygen uptake"[tiab] OR "metabolic equivalent"[tiab] OR "metabolic equivalents"[tiab] OR "energy metabolism"[tiab] OR "energy cost"[tiab] OR "energy costs"[tiab] OR "energy expenditure"[tiab] OR "energy expenditures"[tiab] OR bioenergetic[tiab] OR bioenergetics[tiab]) NOT (("Adolescent"[Mesh] OR "Child"[Mesh] OR "Infant"[Mesh]) NOT "Adult"[Mesh]) NOT (animals[mh] NOT humans[mh]) NOT (Editorial[ptyp] OR Letter[ptyp] OR Case Reports[ptyp] OR Comment[ptyp]) AND ("2011"[Date - Publication]: "3000"[Date - Publication]) AND English[lang].

Appendix 2.

Calculation of MET_{WC}

The denominator for the MET_{WC} (0.992 METs) is computed as a 2-step process.

First, calculate the energy expenditure for an activity as kcal/kg/h. Second, divide the standard MET (defined as 1.0 kcal/kg/h) by the calculated value.

- Step 1. $1.008 \frac{\text{kcal}}{\text{kg} \times \text{h}} = \frac{3.5 \text{ mL}}{\text{kg} \times \text{h}} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{4.8 \text{ kcal}}{1 \text{ L}} \times \frac{60 \text{ min}}{1 \text{ h}}$
- Step 2. $0.992 = 1.0 \text{ kcal/kg/h} / 1.008 \text{ kcal/kg/h}$

Abbreviation: MET = metabolic equivalent.

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