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Consensus

Short bouts of accumulated exercise: Review and consensus statement on definition, efficacy, feasibility, practical applications, and future directions

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Abstract

Background: Insufficient physical activity and prolonged sedentary behavior have emerged as major global public health challenges. Short bouts (≤10 min) of accumulated exercise (SBAE) throughout the day may be a promising strategy to mitigate the adverse effects of prolonged sitting and promote physical activity, ultimately promoting overall health. However, previous ambiguity in defining this concept has resulted in a fragmented and inconsistent evidence base, impeding practical applications, the development of guidelines, and policymaking. The purpose of this study is to establish an operational definition of SBAE by synthesizing systematic reviews and research trials alongside an expert consensus. Additionally, it seeks to evaluate acute and long-term efficacy and feasibility, providing evidence-based recommendations for practice and future research directions.
Methods: A literature search was performed across PubMed and Web of Science, followed by systematic screening and summarization of eligible studies based on predefined inclusion criteria. Inclusion criteria encompassed various modes/types of SBAE (bouts lasting ≤10 min, performed multiple times daily with ≥30 min intervals); both aerobic and resistance exercise were considered. Relevant systematic reviews and research trials were included. Methodological quality, risk of bias, and evidence certainty were assessed. Expert consensus was obtained through a survey to evaluate recommendations and agreement levels on findings.
Results: After analyzing 27 systematic reviews, 135 research studies, and an expert consensus involving 48 researchers from 11 countries, SBAE is defined as any exercise mode of activity, regardless of intensity, that is accumulated in either continuous or intermittent bouts lasting ≤10 min per session (including multiple intermittent sets) that are performed multiple times (≥2 sessions/day) per day, with intervals of ≥30 min between bouts or otherwise sufficient time for recovery. When used to interrupt prolonged periods of sedentary time, SBAE mitigates the acute adverse effects of sedentary behavior on more than 10 clinical biomarkers of endocrine, cardiovascular, and brain health/function among adults of diverse ages and conditions. Moreover, SBAE was superior for improving acute glycemic control compared to a single continuous exercise session. As a long-term intervention (average of 11 weeks), SBAE can improve over 20 health outcomes, including peak oxygen uptake, resting blood pressure, and metabolic health. Additionally, SBAE might be more effective than continuous exercise for improving longer-term glycemic control and body composition. Long-term completion rates for SBAE interventions are generally high (95%), with low dropout rates (12%) and high adherence rates even without supervision (85%), and its safety has been preliminarily validated.
Conclusion: An operational definition of SBAE is provided along with its classification and acute and long-term efficacy. Practical exercise prescription recommendations and evidence-based strategies for various populations and contexts are provided. Future research should focus on generating high-quality evidence for SBAE in 5 key areas: quantification and monitoring, population-specific responses, optimization of exercise prescriptions, intervention efficacy, and practical implementation. Additionally, addressing policy, environmental, and promotional barriers is crucial for transitioning from expert consensus to public consensus, and for facilitating the application of this strategy in real-world environments.

Keywords: Short bouts of accumulated exercise; Exercise snacks; Consensus statement; Sedentary breaks

1. Introduction

Insufficient physical activity (PA)—defined as failing to accumulate at least 75 min/week of vigorous-intensity, 150 min/week of moderate-intensity PA, or a combination of both[1]—poses a significant global public health challenge.[1–3] It is associated with increased incidence and mortality rates from non-communicable diseases, contributing to at least 5 million premature deaths annually,[4] of which an estimated 3.9 million could be prevented through adequate PA.[5] Survey data from 1.9 million participants across 168 countries indicate that 27.5% of the global population engages in insufficient PA,[6] with rates among adolescents reaching 81.0%.[7]

Sedentary behavior, another pressing public health issue,[8] is defined as any waking behavior characterized by a low rate of energy expenditure (≤1.5 metabolic equivalents of task (MET)) while sitting or lying down.[9] Self-reported sedentary time among adolescents rose from 7.0 h to 8.2 h daily between 2001 and 2016 year,[10] while adults reported 8.8 h daily.[11] Prolonged sedentary behavior negatively impacts glucose metabolism, lipid metabolism, and vascular function.[12,13] For instance, a single prolonged sitting session can increase postprandial blood glucose levels by 18.0%,[14] reduce insulin sensitivity by 28.0%,[15] and decrease flow-mediated dilation by 2.1%.[16] Chronic prolonged sedentary behavior also adversely affects body composition and the cardiovascular and musculoskeletal systems.[13] These acute and chronic pathophysiological effects increase the risk of developing non-communicable diseases (including neurological, cardiovascular, and chronic metabolic conditions) and, ultimately, increase the risk of all-cause mortality.[12,17]

Increasing PA and incorporating movement with large muscle groups to break up prolonged sitting are crucial strategies to address associated health challenges. Traditional efforts to promote continuous aerobic exercise have been largely unsuccessful, as current PA levels remain low and have not improved in recent years.[18] Numerous studies, including interviews and surveys, suggest an important barrier to PA participation is the perceived lack of time.[19,20] Therefore, shortening the duration of each exercise bout may be a more promising strategy for promoting participation in exercise. While traditional exercises, such as regular moderate-intensity continuous sessions, offer significant health benefits and can increase total PA levels,[1] they can be limited in their ability to counteract the adverse effects of extended sitting periods, including elevations in postprandial glucose.[21] In contrast, incorporating short bouts of accumulated exercise between periods of sitting (i.e., regularly interrupting sedentary behavior) may more effectively prevent the immediate adverse effects of prolonged sitting on glucose, lipid metabolism, and vascular function.[12,13,22–24] These findings highlight the importance of increasing PA and regularly interrupting sedentary behavior as complementary lifestyle strategies. Therefore, accumulating short bouts of exercise is a promising approach to mitigate the adverse effects of prolonged sitting and promote PA, ultimately promoting health.

Epidemiological evidence supports associations of interrupting sedentary time with metabolic health, disease prevention, and the reduction of all-cause mortality. Healy et al.[25] first confirmed that moderate- to vigorous-intensity activity, mean intensity during breaks, and more frequent interruptions in sedentary time were beneficially associated with metabolic risk variables, particularly adiposity measures, the concentration of triglycerides, and plasma glucose levels. Cohort studies also indicate that sitting for 60 min or more is associated with an increased risk of all-cause mortality, while sitting in shorter bouts of 1–29 min is linked to a reduced risk.[26] Additionally, vigorous intermittent lifestyle PA (VILPA)/moderate to vigorous intermittent lifestyle PA[27] involving brief (∼1 min) multiple bouts of incidental PA (e.g., stair climbing) performed during daily living activities[28,29] can lower mortality and disease incidence rates.[30-32] This further highlights the potential benefits of accumulating short bouts of exercise for improving metabolic markers, preventing disease, and reducing long-term mortality risk.

In the scientific literature, various terms describe strategies for interrupting sedentary behavior through regular short bouts of accumulated exercise throughout the day, including "accumulated exercise",[33–35] "exercise snacks",[36–41] "breaks or interrupting prolonged sitting".[12,13,16,21,38,39,42–54] Although these terms have different operational definitions, they all share the same principle: accumulating multiple short bouts of exercise to reduce or break up prolonged sedentary periods and/or increase overall PA to promote health. For clarity, we will consistently use the term "short bouts (≤10 min) of accumulated exercise (SBAE)" in this paper to refer to these strategies.

A growing body of research evidence has prompted the World Health Organization[1] to emphasize the importance of "reducing sedentary behavior" in its latest PA guidelines (2020 edition). The guidelines address "sedentary behavior" and strongly recommend that "replacing sedentary time with physical activity of any intensity (including light intensity) provides health benefits." This evidence builds on the recommendation of accumulating 75–150 min of vigorous-intensity or 150–300 min of moderate- to vigorous-intensity PA per week.[1] Additionally, it recommends regular muscle-strengthening activity for all age groups. For older adults, the guidelines emphasize varied multicomponent PA that includes functional balance and strength training at moderate or greater intensity on 3 or more days a week to enhance functional capacity and prevent falls. As part of these guidelines, SBAE should involve recommendations regarding frequency, intensity, duration, and exercise parameters tailored to different populations and contexts.[1] However, inconsistent terminology has led to fragmented evidence regarding the health benefits of SBAE, resulting in a limited understanding of this lifestyle approach.[54] Despite its potential health benefits and feasibility, there is a lack of consistency in the concepts and definitions of SBAE and a scarcity of relevant evidence compared to that for single sessions of moderate- to vigorous-intensity continuous exercise, which limit its practical application. Additionally, a comprehensive review and synthesis of the available evidence is needed to understand SBAE fully. Reaching a consensus would offer evidence-based practical recommendations and contribute essential insights for updating PA or exercise prescription guidelines.[1,56,57]

Our study draws on 27 systematic reviews[16,21,33–35,42–54,58–66] and 135 original studies, including 87 acute randomized crossover trials,[67–153] 37 longitudinal controlled intervention trials,[154–190] and 11 feasibility/qualitative studies.[153,160,162,191–198] Based on expert consensus, this paper proposes an operational definition of SBAE and summarizes its effects across 2 key dimensions: breaking up sedentary behavior (acute efficacy) and promoting health (including long-term chronic efficacy/effectiveness and feasibility). It also aims to categorize evidence-based practice recommendations by application contexts, anticipated outcomes, and target populations, guiding non-pharmacological lifestyle prevention, interventions for various non-communicable diseases, and the development of an exercise prescription database.[199–201] Finally, based on expert consensus, the paper aims to identify research challenges and future directions for the field of SBAE when it comes to increasing PA, reducing sedentary behavior, improving health, and preventing disease.

2. Methods

The first step in this consensus process involved systematically organizing and summarizing all available evidence on SBAE. A search was conducted across various literature databases. Following this, experts in the field were invited to form a consensus group where they evaluated the strength of recommendations and the level of agreement for each item to finalize the consensus.

2.1. Information sources and search strategy

The PubMed (NCBI) and Web of Science (Core Collection) databases were searched from their inception to July 2024, with updates in October 2024. Included studies were full-text articles written in English or Chinese. No date or sample restrictions were applied during the search for this review. We conducted a comprehensive search for terms related to SBAE, including "multiple short bouts of exercise", "accumulated exercise", "exercise snacks", "sedentary breaks", "interrupting prolonged sitting", Snacktivity™, and VILPA. The search strategy and results are presented in Supplementary File 1. No restrictions were applied to populations, outcomes, study designs, or comparator groups, as we aimed to provide a complete review of SBAE literature.

2.2. Selection process

De-duplication of records was performed manually by an independent reviewer (HKZ) using EndNote X9 (Clarivate Analytics, Philadelphia, PA, USA). Two researchers (MY and HKZ) exported and screened the deduplicated records in Zotero 7.0 (Corporation for Digital Scholarship, Vienna, VA, USA), applying predefined inclusion and exclusion criteria to titles and abstracts. Discrepancies were resolved through discussion, with a 3rd researcher (YL) assisting if needed. The 2 researchers (MY and HKZ) then reviewed the full texts to finalize inclusion, following the same resolution protocol for discrepancies.

2.3. Eligibility criteria

A priori inclusion and exclusion criteria were applied to evaluate study eligibility under the Population, Intervention, Comparator, Outcome, and Study design (PICOS) framework. (a) Participants were humans of all ages and health statuses. (b) Interventions focused on SBAE, where each bout lasts $\leq$10 min (regardless of intensity and including various modes such as aerobic and resistance exercise) and is performed multiple times a day ($\geq$2 sessions/day), with recovery or rest intervals of $\geq$30 min between sessions. The choice of "each bout lasts $\leq$10 min" is based on our current focus on short bouts. Previous PA guidelines have often used "10 min" as a cutoff/minimum threshold for what is defined as a bout of continuous exercise.[202] The inclusion criterion of "multiple daily sessions ($\geq$2 sessions/day) with $\geq$30-min inter-session intervals" aligns with 2 key considerations. First, it operationalizes the accumulated exercise paradigm central to SBAE. Second, the 30-min threshold reflects epidemiological evidence on sedentary behavior segmentation and corresponds with most SBAE research conventions, where $\geq$30-min intervals are used.[26] However, studies on exercise performed in a single session, such as high-intensity interval training (HIIT), which is characterized by repeated short bursts of vigorous-intensity exercise followed by periods of low-intensity exercise or passive recovery lasting seconds to minutes,[203] were excluded. (c) Comparisons include a no-PA/exercise control group, where participants maintain their usual daily PA habits, and an exercise control group, where activities/exercises were performed in a single session. (d) Outcomes were based on existing literature with no exclusions to ensure a comprehensive presentation of results. (e) Study designs eligible for inclusion encompassed cross-sectional acute studies, longitudinal controlled trials (randomized or non-randomized), and systematic reviews (including meta-analyses). Editorials, abstracts, and narrative reviews were excluded.

2.4. Data extraction

Data extraction was performed by the 2 reviewers (MY and HKZ) using a customized Excel worksheet finalized before the full-text screening. They independently extracted author and study details, participant information, intervention protocols, and outcomes. Discrepancies were resolved by a 3rd researcher (YL). Authors were contacted for missing or graphical data; if unsuccessful, data were extracted using WebPlotDigitizer 4.1 (Ankit Rohatgi, Austin, TX, USA), which has high reliability and validity.[204]

2.5. Risk of bias and methodological quality

Two reviewers (HKZ and HHY) independently assessed the quality of the included systematic reviews using the AMSTAR 2 tool (Ottawa Hospital Research Institute, University of Ottawa, Ottawa, Canada) based on 16 items related to review planning and delivery. Reviews were rated as "high", "moderate", "low", or "critically low" based on identified weaknesses[203] (Supplementary File 2). The risk of bias in acute cross-sectional and longitudinal controlled trials was assessed using the Cochrane RoB 2 tool (The Cochrane Collaboration, London, UK),[205,206] covering random sequence generation, allocation concealment, blinding, incomplete outcome data, and selective reporting. Additionally, recognizing that risk of bias and methodological quality are distinct concepts,[207,208] the methodological quality of the acute cross-sectional and longitudinal controlled trials was evaluated using the PEDro scale developed by the Physiotherapy Evidence Database.[209] For longitudinal controlled trials, we also applied the TESTEX scale (tool for the assessment of study quality and reporting in exercise)[210] to evaluate the quality of control measures and reports related to their long-term exercise training process (Supplementary File 3).

2.6. Calculation of effect size

When outcome indicators lacked systematic review or meta-analytic evidence and included multiple original trials, the mean difference and standard deviation from the experimental and control groups were extracted to determine an accurate effect estimate. A random-effects model, based on the inverse variance method and the DerSimonian-Laird,[211] was used to combine the main effects and calculate the effect size (ES) and 95% confidence interval (95%CI).[211] Given the small sample sizes of most included studies, Hedge's *g*, an unbiased and corrected ES indicator, was employed. ES was classified as 0.2, 0.5, and 0.8 representing small, medium, and large effects, respectively.[212] These calculations were conducted using the meta package in statistical software R (V.4.2.0; R Core Team, Vienna, Austria). Additionally, the statistical power of the primary pooled effect was calculated, and precision was assessed using the GRADE approach. Statistical power calculations were conducted using the *metameta* package.[213]

2.7. Certainty of the evidence

The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) methodology was used to rate the certainty of the evidence as "high", "moderate", "low", or "very low".[214] GRADE was completed by the lead author (MY), and evidence was rated based on the following criteria: (a) The risk of bias, downgraded by one level if "some concerns" and 2 levels if "high risk" of bias; (b) Inconsistency, downgraded by one level when statistical heterogeneity (I^2) is moderate (>25%) and by 2 levels when high (>75%). If the body of evidence primarily comprised meta-analyses, inconsistency was considered a serious concern when the aggregated results demonstrated variation (for instance, different authors may report inconsistent results when pooling data). Conversely, if inconsistency was not observed in the pooled outcomes, it was not considered serious; (c) Imprecision: downgraded by one level when statistical power was <80% and if there was no clear direction of the effects;[215] (d) Risk of publication bias: downgraded by one level if Egger's test result was <0.05. All results are detailed in Supplementary File 4.

The hierarchy of evidence types for addressing a specific question was as follows: meta-analysis > systematic review > single original trial. If an outcome indicator included meta-analysis and single original trial data, the meta-analysis was prioritized to avoid duplication because it typically involved a larger sample size and provided a more precise effect estimate. In such cases, single original trials were not reported. When multiple meta-analyses were available for a particular outcome, all relevant meta-analyses were included, as differences in populations, interventions, and outcomes might have existed between them. These results were considered collectively to determine the final evidence level and the degree of recommendation.

2.8. Formulation of recommendations

Recommendations were formulated using the GRADE Evidence to Decisions (EtD) framework, which provides a systematic, transparent approach to guideline recommendations. This framework integrates research evidence, its certainty, expert opinion, and relevant expertise. It evaluates the balance between benefits and harms, confidence in the evidence, participants' values, resource use, potential effects on health inequalities, and the acceptability and feasibility of recommendations. Each recommendation was based on a comprehensive evaluation of evidence across key outcomes, leading to a consensus recommendation score.

2.9. Consensus group and consultation

Two authors (MY and YL) developed the inclusion criteria for potential Expert Consensus Group members. To participate in this consensus, experts must hold a doctoral degree in (a) PA, (b) exercise, or (c) sports science, and meet at least one of the following criteria:

- Have published academic papers related to SBAE in peer-reviewed national (in Chinese) and/or international journals (in English);
- Have a significant influence on the promotion of a healthy lifestyle through exercise or PA, ultimately providing broad and diverse perspectives on SBAE.

Potential Expert Consensus Group members were contacted via email or WeChat to gauge their interest in participating in this consensus statement. Two authors (MY and YL) outlined the major topics for agreement in this article, including the definition and characteristics of SBAE, specific program derivations, acute efficacy during long-term sitting, longer-term (chronic) health effects, feasibility evaluation, recommendations for practical application, and future research directions. Two authors (MY and YL) contacted the proposed Expert Consensus Group members to invite them to participate in manuscript revision and discussion. The Expert Consensus Group members evaluated the recommendation levels and degree of agreement on all conclusions and opinions presented in this statement.

In the 1st survey round, we used the WenJuanXing online platforms (www.wjx.cn) and Google Forms to create links and collect expert opinions. There were 113 questions included, focusing on recommendation-level assessment related to SBAE. These questions addressed acute exercise effects of SBAE when it is applied to break up sedentary behavior, its chronic effects on various health biomarkers, the feasibility of applying it in different populations, and recommendations for exercise variables and protocols to optimize its benefits. The grading of recommendations was based on whether the desirable effects of an intervention outweighed the undesirable effects. The GRADE system categorized recommendations into 4 levels: "strong recommendation", "weak recommendation", "weak non-recommendation", and "strong non-recommendation":

- Strong recommendation is given when there is clear evidence that the benefits of the intervention outweigh the risks, with a firm recommendation for all groups to adopt the intervention.
- Weak recommendation is made when the benefits likely outweigh the risks, but the intervention is recommended only for specific groups based on individual circumstances.
- Weak non-recommendation is issued when the risks likely outweigh the benefits, advising against the intervention for certain groups under specific circumstances.
- Strong non-recommendation is given when there is clear evidence that the risks outweigh the benefits, with a strong recommendation for all groups to avoid the intervention.

The items assessing the degree of recognition included SBAE: (a) terminology; (b) classification; (c) exercise variables and protocol recommendations; and (d) future research directions. A five-point Likert scale was used to assess the degree of recognition from *strongly disagree* to *strongly agree*. Additionally, 2 open-ended questions were included to obtain experts' supplementary insights and suggestions for practical applications and future directions. The final recommendation level and degree of approval are based on the mean of the expert ratings.

The list of experts in the field includes key contributors who responded to our invitation as well as practitioners in SBAE and/or those focused on promoting a healthy lifestyle through exercise or PA. The group was carefully selected to ensure diversity, including individuals with strong scientific backgrounds and those with practical experience in implementing physical activity programs. Thirty-eight experts completed the final consensus survey, while the remaining experts provided valuable feedback and suggestions for refining the consensus process.

3. Characteristics of the consensus group

The final expert group comprises 48 members, with 25% female representation. All members have publishing experience or international influence in exercise and sport science, with expertise spanning areas such as exercise physiology, PA, sports medicine, sports psychology, training science, and physical education. Each member holds a doctoral degree, and the group includes 31 professors/China researchers equivalent to professors (65%), 7 associate professors/China associate researchers equivalent to associate professors (15%), 5 lecturers (10%), 3 postdoctoral researchers (6%), 1 senior researcher (2%), and 1 PhD researcher (2%). Many members are recognized leaders in key areas such as "exercise snacks", "sedentary behavior interventions/breaks", and "low-volume high-intensity interval training", and have contributed to influential global projects and research. Geographically, the experts are first-affiliated with institutions in 11 countries across 5 continents, representing diverse cultural and academic backgrounds. These countries include China (28, 59%), Australia (5, 11%), Canada (3, 6%), the USA (3, 6%), the UK (3, 6%), the United Arab Emirates (1, 2%), Brazil (1, 2%), Singapore (1, 2%), Thailand (1, 2%), Ireland (1, 2%), and Chile (1, 2%). The sample size is large enough to support consensus-building, and the geographical and disciplinary diversity strengthens the robustness of the consensus process. This collaborative effort ensures that the final consensus reflects the collective expertise and perspectives of leading professionals in the field.

4. Definition of terms

4.1. Exercise, and sedentary behavior

PA is any bodily movement produced by skeletal muscles that results in energy expenditure.[216] PA is categorized into light-intensity (1.6−2.9 METs),[1,217] moderate-intensity (3.0−5.9 METs),[1,217] and vigorous-intensity PA (≥6.0 METs).[1,217] The intensity classification of exercises also follows this standard.[1]

Insufficient PA refers to levels of PA that do not meet the current recommendations of 150−300 min of moderate-intensity, 75−150 min of vigorous-intensity PA per week, or some combination of both.[1]

VILPA escribes brief and sporadic bouts of vigorous-intensity PA, typically lasting around 1 min, that occur in daily life.[29−31] An example is climbing stairs as part of routine activities.[218]

Low- to moderate-intensity intermittent lifestyle PA (Snacktivity^{TM}) involves moderate-duration, isolated bouts of low- to moderate-intensity PA, typically lasting 2−5 min, such as brisk walking integrated into daily routines.[191,196,198]

Exercise is a subset of PA that is planned, structured, and repetitive with the improvement or maintenance of physical fitness as the final or intermediate objective.[1,216]

Exercise snacks are isolated bouts of vigorous exercise lasting ≤1 min and performed periodically throughout the day.[36−40]

Physical fitness is a set of attributes that are either health- or skill-related. The degree to which people have these attributes can be measured with specific tests.[216]

Sedentary behavior refers to activities such as sitting, reclining, or leaning in a waking state with an energy expenditure of 1.0−1.5 METs.[1,9] Sedentary behavior includes tasks like office desk work, driving, or watching television.

Sedentary breaks or interrupting prolonged sitting refers to any non-sedentary period that breaks up extended bouts of sitting.[1,9]

4.2. SBAE

SBAE is defined as any PA performed in any mode and at any intensity, with a continuous or intermittently accumulated duration of ≤10 min per bout, conducted in multiple bouts (≥2 sessions/day) throughout the day. Recovery intervals between sessions, which differ from interval training, can allow for complete recovery or last ≥30 min. The consensus group ultimately reached an average approval rating of "agree" for this operational definition.

Establishing cutoff points or thresholds for continuous variables can be challenging; however, ≤10 min is a generally accepted threshold for SBAE for several reasons: (a) previous PA guidelines have often used "10 min" as a cutoff/minimum threshold for what is defined as a bout of continuous exercise;[202] (b) the American College of Sports Medicine defines moderate-intensity continuous exercise as reaching 64%−76% of maximum heart rate (HR_{max}) within sessions lasting longer than 10 min;[219] thus, using ≤10 min distinguishes SBAE from moderate-intensity continuous exercise and reduces confusion; and (c) most existing any-intensity accumulated exercise sessions last ≤10 min.[33,35]

For structured exercise studies, the choice of ≥30 min as the rest interval was based on several factors: (a) all known longitudinal intervention trials involving SBAE have used intervals greater than 1 h; (b) the majority of studies on SBAE and acute interruptions in sedentary behavior report intervals of ≥30 min;[16,21,42−54,58−60,62,65,66] (c) prospective cohort studies suggest that accumulated sedentary periods of 1−29 min has a minimal association with increased risk of all-cause mortality, while sedentary periods lasting ≥30 min are significantly associated with increased mortality risk;[26] (d) from a practical perspective, intervals shorter than 60 min may not be perceived as "time-saving" and are less likely to be adopted in real-world settings, such as workplaces.[220] It is important to note that ≥30 min is a reference point; as long as each exercise interval allows for complete recovery, it can be classified as SBAE. It is difficult to give a specific operational definition of "complete recovery", as a bout of exercise may have physiological or molecular effects on the bodily systems that last for several hours or days.[221] Here, we refer to "complete recovery" as when, during the recovery interval, the individual can comfortably engage in daily tasks or activities unrelated to SBAE, and this period is no longer considered part of the SBAE session. This distinguishes it from interval training, where intervals allow for only incomplete recovery.[222]

4.3. *Classification of SBAE*

Current SBAE research primarily categorizes these bouts into 3 protocols. They are:

(a) Low frequency, short duration, and vigorous intensity, such as a single exercise session comprising a single 20−30 s bout of cycling at full sprint, performed thrice daily with 1- to 6-h recovery intervals in between. In our categorization, the classification of "short duration" within a single session aligns with the current operational definitions of "exercise snacks", which refers to "isolated bouts of vigorous exercise lasting ≤1 min and performed periodically throughout the day".[36−40] The "short duration and vigorous-intensity" classification is supported by prospective epidemiological VILPA evidence from objective accelerometer data on 25,241 adult participants in the UK Biobank study that 95% of all vigorous bouts last up to 1 min.[30]

(b) Low frequency, long duration, and low to moderate intensity, such as walking for 5−10 min at 65% HR_{max}, performed thrice daily with recovery intervals in between. The "long duration" classification aligns with early longitudinal intervention designs focused on low-frequency, moderate- to low-intensity exercise.[33−35]

(c) High frequency, moderate duration, and low to moderate-intensity. This protocol may include walking for 2−5 min at 50% HR_{max} every 30 min during prolonged sitting (e.g., over 6 h). These less intense, high-frequency sessions of SBAE are commonly prescribed in acute randomized crossover trials aimed at interrupting prolonged sitting. The "moderate duration" classification aligns with the existing majority of acute cross-sectional and longitudinal controlled intervention protocols.

The intensity classification above adheres to established definitions found in current PA[1] and exercise prescription guidelines.[223] The rationale for the above SBAE protocol derivations is based on several key justifications: (a) different exercise protocols correspond to various application contexts and are associated with distinct expected health benefits (see Section 7.2 for details); (b) prospective cohort studies (VILPA) support the cutoff classifications for "single exercise bout duration":[30] (c) existing intervention protocols are primarily designed around the three categories mentioned above. Given the robust evidence supporting these protocols, subsequent summaries of application outcomes and evidence-based recommendations will primarily focus on these models.

However, variables such as frequency, single exercise bout duration, and exercise intensity can be combined in different ways to create more specific prescription schemes, many of which have yet to be thoroughly explored or validated in research. Thus, this consensus provides a comprehensive classification of SBAE from a prospective perspective, considering daily frequency, single exercise duration, and intensity (Table 1). This classification aims to guide further research, expand the conceptual boundaries of SBAE, and enrich the body of evidence in this field.

While outside the scope of this study, the SBAE protocol can be further expanded into various subtypes, such as aerobic SBAE, resistance/muscle strengthening SBAE,[40] balance SBAE, and combined/multimodal SBAE, depending on the targeted health outcomes. The definitions of these subtypes will align with current guidelines to address different health targets.[1] Future research should further develop this framework and integrate diverse exercise methods and types into the SBAE protocol to enhance its applicability and impact.

5. Acute effects of sbae to break sedentary behavior

Research on SBAE aimed at mitigating the adverse effects of prolonged sedentary behavior explores 3 comparative approaches regarding acute impacts on glucose-lipid metabolism, cardiovascular function, and brain health (Table 2): (a) comparing intermittent sedentary behavior interspersed with SBAE to continuous sedentary behavior without interruption; (b) examining variations in frequency, intensity, modes, duration, or combinations of short-bout protocols; and (c)

Table 1
Summary of the intervention protocols.

	Frequency of bouts (h)	Duration (min)	Intensity (RPE 0–10)
Low frequency, short duration, low intensity[a]	Every 1–6	≤1	2–3
Low frequency, short duration, moderate intensity[a]	Every 1–6	≤1	4–6
Low frequency, short duration, vigorous intensity[b]	Every 1–6	≤1	≥6
Low frequency, moderate duration, low intensity[b]	Every 1–6	2–5	2–3
Low frequency, moderate duration, moderate intensity[a]	Every 1–6	2–5	4–6
Low frequency, moderate duration, vigorous intensity[a]	Every 1–6	2–5	≥6
Low frequency, long duration, low intensity[b]	Every 1–6	5–10	2–3
Low frequency, long duration, moderate intensity[b]	Every 1–6	5–10	4–6
High frequency, short duration, low intensity[a]	Every 0.5–1.0	≤1	2–3
High frequency, short duration, moderate intensity[a]	Every 0.5–1.0	≤1	4–6
High frequency, short duration, vigorous intensity[b]	Every 0.5–1.0	≤1	≥6
High frequency, moderate duration, low intensity[b]	Every 0.5–1.0	2–5	2–3
High frequency, moderate duration, moderate intensity[b]	Every 0.5–1.0	2–5	4–6
High frequency, moderate duration, vigorous intensity[a]	Every 0.5–1.0	2–5	≥6
High frequency, long duration, moderate intensity[a]	Every 0.5–1.0	5–10	4–6

Notes: Frequency of bouts represents the interval between each exercise; for example, 1–6 h means SBAE every 1–6 h. R is a scale ranging from 0 to 10, where 0 indicates rest, 1 represents very light activity, 2–3 corresponds to light activity that can be maintained for hours, 4–5 refers to moderate activity with heavier breathing but still manageable conversation, 6–7 indicates vigorous-intensity physical activity with difficulty holding a conversation, 8–9 reflects very hard activity near maximum effort, and 10 signifies maximal exertion where continuing feels impossible.[276]

[a] Refers to protocols of SBAE with no current research evidence.

[b] Refers to protocols of SBAE with current research support.

Abbreviations: RPE = rating of perceived exertion; SBAE = short bouts of accumulated exercise.

Table 2
Summary of the evidence on SBAE to break sedentary behavior.

Outcome	Type of evidence	Number of studies (references)	Quality of the evidence	SMD	MD	GRADE	Recommended level
Interrupted with SBAE *vs.* uninterrupted prolonged sitting							
Metabolic health							
Glucose iAUC	SR and meta-analysis	9[21,42,45,46,48,51,52,59,66]	Very low to moderate	0.54	n/a	⊕⊕⊕◯	Strong recommendation
Postprandial C-Peptide	RCTs	4[108,110,142,149]	Moderate	0.50	n/a	⊕⊕◯◯	Weak recommendation
Insulin iAUC	SR and meta-analysis	6[42,45,46,48,51,66]	Very low to moderate	0.56	n/a	⊕⊕⊕◯	Strong recommendation
Triglyceride iAUC	SR and meta-analysis	4[41,44,47,65]	Very low to moderate	0.26	n/a	⊕◯◯◯	Weak recommendation
Cardiovascular health							
SBP	SR and meta-analysis	5[42–44,46,47]	Low to moderate	0.26	4.4 mmHg	⊕⊕◯◯	Weak recommendation
DBP	SR and meta-analysis	5[42–44,46,47]	Low to moderate	0.19	2.4 mmHg	⊕⊕◯◯	Weak non-recommendation
MAP	SR and meta-analysis	3[43,44,47]	Low to moderate	n/a	n/a	⊕◯◯◯	Strong recommendation
HR/HR variability	Meta-analysis	1[54]	Moderate	n/a	4 beats/min	⊕◯◯◯	Strong recommendation
Pulse wave velocity	RCTs	5[71,94,113,119,131]	Moderate	n/a	n/a	⊕◯◯◯	Strong recommendation
Vascular blood flow	Meta-analysis	2[50,62]	Moderate	0.48	12.08 mL/min	⊕⊕⊕◯	Weak recommendation
Vascular shear stress	Meta-analysis	3[50,62,65]	Moderate	0.65	7.58–12.7 s^{-1}	⊕⊕⊕◯	Weak non-recommendation
FMD	Meta-analysis	5[42,49,50,62,65]	Moderate	0.51	1.5%–1.91%	⊕⊕⊕◯	Weak non-recommendation
Brain health							
Cognitive performance	SR and meta-analysis	2[53,60]	Moderate	0.20	n/a	⊕⊕◯◯	Weak non-recommendation
MCABFv	Meta-analysis	1[60]	Moderate	0.15	n/a	⊕◯◯◯	Weak recommendation
Cerebral autoregulation	Meta-analysis	1[60]	Moderate	0.13	n/a	⊕◯◯◯	Weak recommendation
Cerebrovascular reactivity	Meta-analysis	1[60]	Moderate	0.08	n/a	⊕◯◯◯	Weak recommendation
BDNF	RCTs	1[148]	Moderate	n/a	514 ng/mL/h	⊕⊕◯◯	Weak recommendation
Interrupted with SBAE *vs.* single bout continuous exercise							
Metabolic health							
Glucose iAUC	Meta-analysis	3[21,45,63]	Moderate	0.26–0.39	n/a	⊕⊕⊕◯	Weak recommendation
Insulin iAUC	Meta-analysis	2[45,63]	Moderate	n/a	n/a	⊕⊕◯◯	Weak recommendation
Triglyceride iAUC	Meta-analysis	2[45,63]	Moderate	n/a	n/a	⊕⊕◯◯	Weak recommendation

Notes: ⊕◯◯◯: very low level of evidence; ⊕⊕◯◯: low level of evidence; ⊕⊕⊕◯: moderate level of evidence; ⊕⊕⊕⊕: high level of evidence.

Abbreviations: BDNF = brain-derived neurotrophic factor; DBP = diastolic blood pressure; FMD = flow-mediated dilation; GRADE = Grading of Recommendations Assessment, Development, and Evaluation; HR = heart rate; iAUC = incremental area under the curve; MAP = mean arterial pressure; MCABFv = middle cerebral artery blood flow velocity; MD = mean difference (represents the raw difference between means, where applicable); n/a = not applicable; RCTs = randomized cross-over trials; SBAE = short bouts of accumulated exercise; SBP = systolic blood pressure; SMD = standardized mean difference (represents the effect size in meta-analyses); SR = systematic review.

comparing SBAE during sedentary periods to a single continuous exercise session (typically performed before initiation of sedentary behavior). Most studies are conducted during nondiscretionary time (i.e., controlled laboratory settings), employing acute (<7 days), randomized crossover designs with a 3- to 7-day washout period between trials. While most participants are healthy adults, some studies also include clinical populations and individuals with chronic conditions (e.g., individuals living with prediabetes or diabetes). The short-bout exercise protocols generally emphasize high-frequency sessions (every 30−60 min), moderate duration (2−5 min per bout), and low-intensity activities.

5.1. Acute effects (vs. uninterrupted prolonged sitting)

5.1.1. Glucose and lipid metabolism

Primary indicators of glucose-lipid metabolism include the concentration of blood glucose, C-peptide, insulin, and triglycerides, with regular measurements typically taken over several hours and in response to several meals throughout the day. Chastin et al.[48] conducted the first meta-analysis on the acute effects of SBAE, which included 6 studies, and reported that low- to moderate-intensity SBAE significantly reduced postprandial blood glucose, insulin, and C-peptide concentrations in both healthy adults and individuals with type two diabetes (T2D) compared to continuous sedentary behavior. Saunders et al.[42] performed a subsequent analysis of 20 studies and similarly found that SBAE significantly reduced postprandial blood glucose (ES = −0.36, 95%CI: −0.50 to −0.21) and insulin (ES = −0.37, 95%CI: −0.53 to −0.20) in healthy individuals of all ages. Loh et al.,[45] in an updated meta-analysis of 37 studies, showed that SBAE significantly reduced postprandial blood glucose (ES = −0.54, 95%CI: −0.70 to −0.37), insulin (ES = −0.56, 95%CI: −0.74 to −0.38), and triglycerides (ES = −0.26, 95%CI: −0.44 to −0.09) in adults (both healthy and in patient with chronic disease). It is important to note that the results on triglycerides were inconsistent across individual studies, likely due to variations in the time course of the triglyceride response that was captured. It is generally accepted that exercise does not immediately (i.e., on the same day) impact postprandial lipid responses and is more likely to impact responses the following day. This delayed response may account for the higher incidence of null findings in studies measuring triglycerides immediately after SBAE. Smith et al.[59] only focused on 7 studies that included adults with T2D, finding that SBAE reduced postprandial blood glucose (ES = −0.82, 95%CI: −1.26 to −0.38) compared to continuous sedentary behavior.

Taken together, these findings provide consistent evidence that SBAE improves key markers of glucose-lipid metabolism in healthy individuals and those with impaired glucose compared to continuous sedentary behavior (very low to moderate GRADE). Given that modest improvements in glycemic control are associated with a reduced risk of cardiovascular events, even in healthy adults, this benefit may have clinical significance.[224,225] Moreover, this approach offers a promising strategy for lowering blood glucose levels in individuals with impaired glucose regulation, where improved glycemic control is a key therapeutic target.[226]

5.1.2. Cardiovascular health

The main biomarkers used in research on cardiovascular function include flow-mediated dilation (FMD), peripheral vascular shear stress, blood flow, central arterial blood flow velocity, blood pressure (BP), and heart rate. Saunders et al.[42] conducted the first meta-analysis on the acute effects of SBAE on FMD during interrupted sedentary behavior (including 6 studies) and reported a significant effect on FMD (ES = 0.57) compared to uninterrupted sedentary behavior. Paterson et al.[16] included seven studies to quantify the pooled effects through meta-analysis, reporting a significant increase in FMD of 1.9% (ES = 0.57) following SBAE. However, Taylor et al.[49] found inconsistent results, reporting a non-significant effect of SBAE on FMD (ES = 0.13, 95%CI: −0.02 to 0.45). Subsequently, the Soto-Rodríguez et al.[50] and Zheng[65] meta-analyses, which included 9 and 12 studies, respectively, reported significant increases in FMD of 1.7% and 1.5% following SBAE, respectively. Both studies also found that SBAE significantly improved peripheral vascular shear stress (by 7.58/s to 12.7/s, respectively) and blood flow (by 12.08 mL/min). Yin et al.[62] updated the evidence with 22 studies, confirming moderate increases in FMD (ES = 0.43, 95%CI: 0.15−0.72), peripheral vascular shear stress (ES = 0.65, 95%CI: 0.37−0.93), and blood flow (ES = 0.48, 95%CI: 0.14−0.82) following SBAE. However, they found no significant effect on arterial pulse wave velocity. Notably, the populations in these studies primarily consisted of young and healthy adults.

Prolonged sitting negatively impacts cardiovascular health, with studies linking it to increased BP and heart rate. Increased sitting duration was associated with elevated systolic blood pressure (SBP) increased by 0.42 mmHg/h (95%CI: 0.18−0.60) mmHg/h, diastolic blood pressure (DBP) by 0.24 mmHg/h (95%CI: 0.06−0.42), and mean arterial pressure by 0.66 mmHg/h (95%CI: 0.36−0.90).[47] The initial systematic review on SBAE and BP was inconclusive.[42] Subsequently, Buffey et al.[46] included 6 studies and found SBAE had no significant effect on BP. However, Paterson et al.[44] updated review of 22 studies found SBAE significantly reduced SBP by −4.4 mmHg (ES = 0.26, 95%CI: −7.4 to −1.5) and DBP by −2.4 mmHg (ES = 0.19, 95%CI: −4.5 to −0.3) compared to prolonged sitting. Adams et al.[47] found SBAE during sedentary breaks reduced SBP and DBP by 0.24 mmHg/h and 0.27 mmHg/h, respectively, but did not affect mean arterial pressure.

Overall, SBAE can improve endothelial function, mainly through increased FMD, and enhance vascular shear stress and blood flow, particularly in young and healthy adults (moderate GRADE). However, the effects on pulse wave velocity remain inconclusive (very low GRADE). The acute FMD improvement could be clinically relevant, as a 1% increase in FMD has been linked to a 17% reduction in cardiovascular event risk.[227] While SBAE's effects on BP and resting heart rate are inconsistent (low GRADE), even small increases in SBP are linked to higher cardiovascular disease,[228] mortality,[229] and stroke mortality,[230] while small reductions (∼2 mmHg) lower the risks of coronary heart disease and stroke, potentially saving thousands of lives annually.[231] Further research is needed to confirm SBAE's impact on BP.

5.1.3. Brain health

Brain health encompasses cognitive performance at the behavioral, systemic neural (structure and function), and molecular levels, along with mental health indicators.[232] Key metrics include executive function, brain-derived neurotrophic factor (BDNF), and middle cerebral artery blood flow velocity. A systematic review by Chueh et al.,[53] which included 7 studies, suggested that SBAE during prolonged sitting positively impacted cognitive performance (including attention, inhibitory control, working memory, and cognitive flexibility). However, the results of the review were inconsistent, and no quantitative synthesis was performed. Feter et al.[60] conducted a meta-analysis that demonstrated SBAE during intermittent sitting resulted in a small but significant improvement in cognitive performance (ES = 0.20, 95%CI: 0.06−0.35), though there was no significant effect on middle cerebral artery blood flow velocity (ES = 0.15, 95%CI: −0.11 to 0.40), autoregulatory function (ES = 0.13, 95%CI: −0.14 to 0.40), or cerebrovascular reactivity (ES = −0.08, 95%CI: −0.37 to 0.21). Other single trials have explored the acute effects of BDNF and related systemic indicators. Wheeler et al.[148] found that SBAE during intermittent sitting significantly increased the area under the curve for serum BDNF levels in older adults within an 8-h measurement period compared to prolonged sitting. Additionally, some single trials suggested that SBAE can prevent decreases in middle cerebral artery blood flow velocity that are observed during prolonged sitting in elderly individuals with obesity or hypertension[103,147] as well as in children.[139] Conversely, no significant differences were observed in young adults.[75,77,81,133]

In conclusion, SBAE shows some promise in enhancing cognitive performance and preventing declines in brain blood flow (very low to low GRADE), especially in older adults and children. However, the effects are inconsistent and may vary across age groups and health conditions. Additionally, the clinical significance of acute improvements in cognitive function remains uncertain. However, the effective prevention of declines in cerebral blood flow may be closely linked to reducing the risk of conditions such as vascular dementia and stroke.[233]

5.2. Factors influencing the efficacy of SBAE during interrupted sedentary behavior on health indicators (vs. continuous sedentary behavior)

5.2.1. Differences in population characteristics

Different population characteristics can have varying impacts on the effects of SBAE during interrupted prolonged sitting. For example, Loh et al.[45] found that individuals with higher body mass index (BMI) who were overweight and/or obese experienced a greater acute reduction in blood glucose and insulin during SBAE than those with normal BMI. A larger reduction was also observed among individuals with abnormal blood glucose levels (prediabetes and diagnosed diabetes) compared to normoglycemic individuals.[45] Regarding vascular function, significant improvements in cerebral middle artery blood flow velocity were observed only in older adults and children after SBAE during interrupted sedentary behavior.[103,139,147] In contrast, this benefit was not observed in healthy young adults.[75,77,81,133] In summary, the efficacy of SBAE varies across population characteristics, with factors such as BMI, blood glucose status, and age influencing its impact on metabolic and vascular responses during prolonged sitting.

5.2.2. Differences in protocols of SBAE

Regarding SBAE protocol characteristics, Buffey et al.[46] conducted a meta-analysis of 7 studies on various interruption modes for SBAE. They found that low-intensity SBAE walking was more effective than standing interruptions for reducing blood glucose (ES = −0.30, 95%CI: −0.52 to −0.08) and insulin (ES = −0.54, 95%CI: −0.75 to −0.33). Dempsey et al.[89] conducted a randomized crossover trial comparing low-intensity walking with bodyweight resistance exercises and found that both protocols resulted in similar reductions in postprandial blood glucose responses, 22-h average blood glucose concentrations, insulin concentrations, and C-peptide concentrations. However, they observed a significant advantage of body weight resistance exercise in reducing postprandial triglycerides.

Regarding the frequency of SBAE, the current evidence is inconsistent; however, most studies support that higher-frequency SBAE is more effective in acutely lowering blood glucose compared to lower-frequency[92,112,130,142,144,150] (e.g., (30 min/session, 3 min/session) *vs.* (60 min/session, 6 min/session)). A 3-level meta-analysis by Yin et al.[58] found that interrupting sitting at a frequency of ≤30 min significantly outperformed interruptions at >30-min intervals in lowering blood glucose (ES = −0.30, 95%CI: −0.57 to −0.03). However, no significant differences were observed in insulin, lipids, BP, or vascular function between different frequencies.

Quan et al.[51] investigated the effect of exercise intensity in a network meta-analysis that included 13 studies. They found that interrupting prolonged sedentary behavior with moderate-intensity SBAE was more effective than light-intensity SBAE for reducing postprandial blood glucose(ES = −0.69, 95%CI: −1.00 to −0.37) and insulin (ES = −0.47, 95%CI: −0.77 to −0.17) concentrations. Collectively, existing evidence suggests that the characteristics of SBAE (including mode, frequency, and intensity) can influence its efficacy for reducing blood glucose, insulin, and lipid responses.

Further research is needed to refine these protocols and determine the optimal SBAE for metabolic health benefits.

5.3. Acute effects of SBAE during interrupted sedentary behavior (vs. single session or bout of continuous exercise)

Several studies have compared the acute benefits of SBAE *vs.* a continuous or intermittent exercise session on glucose and lipid metabolism. A meta-analysis of 22 studies by Loh et al.[45] found that SBAE significantly outperformed single continuous exercise of equivalent energy expenditure for acutely lowering blood glucose (ES = −0.26, 95%CI: −0.50 to −0.02). However, no significant differences were observed for triglyceride (ES = 0.08, 95%CI: −0.22 to 0.37) or insulin levels (ES = 0.35, 95%CI: −0.37−1.07). Gouldrup et al.[21] included seven studies in their meta-analysis. Similarly, they found that SBAE was significantly more effective than a single bout of continuous exercise of equivalent energy expenditure for acutely lowering blood glucose (ES = −0.39, 95%CI: −0.72 to −0.06). Interestingly, they noted that compared to continuous sedentary behavior, a single exercise session undertaken before sitting did not result in a significant reduction in postprandial blood glucose (ES = 0.02, 95%CI: −0.32 to 0.35).[21] However, regularly interrupting sedentary behavior with SBAE significantly reduced postprandial blood glucose (ES = −0.44, 95%CI: −0.64 to −0.25).[21] Zhang et al.,[63] in a meta-analysis of 12 studies, also found that SBAE significantly improved same-day blood glucose levels compared to a single exercise session (ES = −0.36, 95%CI: −0.56 to −0.17). However, no significant differences were observed in insulin or triglyceride levels. Participants in these studies were primarily young, healthy adults, though a small number of individuals with abnormal glucose levels were also included. In summary, SBAE appears more efficacious than a single continuous or intermittent exercise session in acutely lowering blood glucose (moderate GRADE), while it shows no difference in reducing insulin or triglyceride concentrations (low GRADE).

6. Chronic effects of SBAE on health promotion

The chronic effects of SBAE have primarily been examined through longitudinal controlled trials aimed at understanding: (a) the health-promoting effects of SBAE (compared to a no-exercise control group) and (b) the differences in chronic effects between SBAE and single continuous or intermittent exercise sessions. These trials included interventions conducted in laboratory and real-world settings (such as workplaces) using parallel or crossover designs with fixed intervention frequencies. Outcome measures primarily included markers of cardiovascular and metabolic health, skeletal muscle health and function, body composition, perceived benefits, total PA levels, and sedentary behavior (Tables 3 and 4). The study populations mainly consisted of healthy young adults and older adults. Research has involved 3 SBAE protocols: (a) low frequency (1−6 h/session) with short-duration (<1 min) vigorous-intensity exercise, (b) moderate-duration (2−5 min) moderate- to vigorous-intensity exercise, and (c) long-duration (5−10 min) moderate- to low-intensity exercise.

6.1. Health-promoting effects of SBAE (vs. no-exercise control)

6.1.1. Cardiovascular fitness and function

Direct measures of cardiorespiratory fitness (CRF), peak oxygen uptake ($\dot{V}O_{2peak}$) and maximal aerobic power, can be significantly improved by SBAE. Randomized controlled trials (RCTs) have shown that short-duration (<1 min) vigorous-intensity exercises, such as stair climbing or cycling 3 times a week for sessions lasting 20−30 s at high to supramaximal intensity, demonstrated a $\dot{V}O_{2peak}$ increase of 3.3 mL/kg/min (ES = 1.16, 95%CI: 0.65−1.67) after 6 weeks.[155,164,168] Similarly, RCTs have also shown that moderate-duration (2−5 min) moderate-vigorous intensity SBAE, like stair climbing 5 times a week for 2-min sessions, resulted in a $\dot{V}O_{2peak}$ increase of 2.0 mL/kg/min (ES = 0.81, 95%CI: 0.38−1.25) after 8 weeks.[163,177,183] A meta-analysis has shown long-duration (10 min), moderate- to low-intensity exercise, consisting of walking 3 times a week for 10-min sessions, exhibited a $\dot{V}O_{2peak}$ increase of 2.3 mL/kg/min (ES = 0.52, 95%CI: 0.24−0.81) after 8−12 weeks.[33] Only 2 RCTs consisting of short-duration (<1 min) vigorous-intensity SBAE measured improvements in maximal aerobic power, revealing an increase of ∼ 28 W (ES = 1.04, 95%CI: 0.47−1.62) after 6 weeks.[155,168] These studies show that different intensities of SBAE can significantly enhance $\dot{V}O_{2peak}$, especially in young, previously inactive, healthy adults (moderate GRADE). $\dot{V}O_{2peak}$ as a direct measure of CRF should be considered a clinical vital sign,[234] as low CRF is associated with an increased risk of metabolic disease,[235] cardiovascular disease, and cancer.[236] A $\dot{V}O_{2peak}$ increase of just 3 mL/kg/min is associated with a 19% reduction in cardiovascular mortality and a 15% reduction in all-cause mortality,[237] highlighting the clinical relevance of SBAE on $\dot{V}O_{2peak}$.

In addition to improved CRF, improvements in several resting cardiovascular indicators have been observed, including reductions in resting heart rate, SBP, and DBP among middle- to older-aged adults (low GRADE). A meta-analysis by Murphy et al.[33] indicated that long-duration, moderate-low intensity SBAE (primarily walking) significantly reduced resting heart rate by ∼8 beats/min, SBP by ∼3 mmHg, and DBP by ∼5 mmHg. These long-term improvements in BP might be associated with decreased risk of coronary heart disease and stroke mortality.[231]

6.1.2. Skeletal muscle health

Important indicators of skeletal muscle health include lower-limb muscle mass, strength, and functional performance (e.g., sit-to-stand tests). Long-duration, moderate- to low-intensity SBAE, primarily involving body-weight resistance exercises, have shown moderate improvements in muscle strength (ES = 0.44),[157,162,166] muscle mass (ES = 0.59),[157,166] and muscle function (ES = 0.62)[158,160−162,166] (low GRADE). These findings have primarily focused on older adults, and there is a need for studies in other populations. However, given that age-related declines in skeletal muscle strength, mass, and functional capacity strongly influence morbidity, mortality, and quality of life in late life,[238] the potential benefits of SBAE for skeletal muscle health in older adults warrant attention and further investigation.

6.1.3. Body composition

Body composition indicators include body weight and BMI, body fat mass and body fat percentage, waist circumference and hip circumference, and skinfold thickness. Research by Murphy et al.[33] and Kim et al.[34] found significant small-to-large reductions in these indicators (ES: 0.33−0.96) following

Table 3
Summary of the evidence on long-term (>7 days) health benefits of SBAE.

Outcome	Type of evidence	Number of studies (references)	Quality of the evidence	SMD	MD	GRADE	Recommended level
SBAE *vs.* no exercise control							
Cardiovascular fitness and function							
Short-duration, vigorous-intensity effect on $\dot{V}O_{2peak}$	RCTs	3[155,164,168]	Moderate	1.16	3.30 mL/kg/min	⊕⊕⊕◯	Strong recommendation
Short-duration, vigorous-intensity effect on peak aerobic power	RCTs	2[155,168]	Moderate	1.04	28.25 W	⊕⊕⊕◯	Strong recommendation
Moderate-duration, moderate-vigorous intensity effect on $\dot{V}O_{2peak}$	RCTs	3[163,177,183]	Moderate	0.84	2.00 mL/kg/min	⊕⊕⊕◯	Strong recommendation
Long-duration, moderate-low intensity effect on $\dot{V}O_{2peak}$	Meta-analysis	1[33]	Moderate	0.52	2.32 mL/kg/min	⊕⊕⊕◯	Strong recommendation
Resting heart rate	Meta-analysis	1[33]	Moderate	n/a	8.10 beats/min	⊕⊕◯◯	Weak recommendation
Resting SBP	Meta-analysis	1[33]	Moderate	n/a	2.97 mmHg	⊕⊕◯◯	Weak recommendation
Resting DBP	Meta-analysis	1[33]	Moderate	n/a	4.83 mmHg	⊕⊕◯◯	Weak recommendation
Skeletal muscle health							
Muscle mass	Controlled trial	2[157,166]	Low to moderate	0.59	0.58 kg	⊕⊕◯◯	Weak recommendation
Muscle strength	Controlled trial	3[157,162,166]	Low to moderate	0.44	n/a	⊕⊕◯◯	Weak recommendation
Function (Sit-to-stand test)	Controlled trial	5[158,160–162,166]	Low to moderate	0.62	3 repetitions	⊕⊕◯◯	Weak recommendation
Body composition							
Body weight	Meta-analysis	2[33,35]	Moderate	0.51	1.94 kg	⊕⊕◯◯	Weak recommendation
BMI	Meta-analysis	2[33,35]	Moderate	0.61	0.97 kg/m^2	⊕⊕◯◯	Weak recommendation
Fat mass	Meta-analysis	1[33]	Moderate	0.55	n/a	⊕⊕◯◯	Weak recommendation
Body fat (%)	Meta-analysis	2[33,35]	Moderate	0.33	0.92%	⊕⊕◯◯	Weak recommendation
Waist circumference	Meta-analysis	2[33,35]	Moderate	0.44	2.62 cm	⊕⊕◯◯	Weak recommendation
Hip circumference	Meta-analysis	1[33]	Moderate	n/a	2.32 cm	⊕⊕◯◯	Weak recommendation
Skinfold thickness	Meta-analysis	2[33,35]	Moderate	0.96	6.39 mm	⊕⊕◯◯	Weak recommendation
Metabolic health							
Total cholesterol	RCTs	4[159,163,171,183]	Moderate	0.02	n/a	⊕⊕◯◯	Weak recommendation
HDL-C	RCTs	6[159,163,171,178,182,183]	Moderate	0.47	0.08 mmol/L	⊕⊕⊕◯	Weak recommendation
LDL-C	RCTs	6[159,163,171,178,182,183]	Moderate	0.38	0.22 mmol/L	⊕⊕⊕◯	Weak recommendation
Triglycerides	RCTs	6[159,163,171,178,182,183]	Moderate	0.19	0.08 mmol/L	⊕⊕◯◯	Weak recommendation
Glucose iAUC	RCTs	1[178]	Moderate	n/a	7.5%	⊕⊕⊕◯	Weak recommendation
Fasting blood glucose	RCTs	4[163,171,172,178]	Moderate	4%–12%	0.20–1.05 mmol/L	⊕⊕⊕◯	Weak recommendation
HbA1c	RCTs	2[172,178]	Moderate	n/a	0.2%–0.5%	⊕⊕⊕◯	Weak recommendation
Perceived benefits							
Self-efficacy	Meta-analysis	1[33]	Moderate	n/a	14%	⊕◯◯◯	Weak recommendation
Depression/anxiety	Meta-analysis	1[33]	Moderate	0.93	n/a	⊕⊕◯◯	Weak recommendation
Mood disorders	Meta-analysis	1[33]	Moderate	n/a	n/a	⊕◯◯◯	Weak non-recommendation
Vitality	Meta-analysis	1[33]	Moderate	n/a	n/a	⊕◯◯◯	Weak non-recommendation
PA and sedentary behavior							
Daily steps (steps/day)	RCTs	1[176]	Moderate	1.25	2039 steps	⊕⊕◯◯	Weak recommendation
MVPA (min/day)	RCTs	2[160,165]	Low to moderate	0.01	0.59 min/day	⊕◯◯◯	Weak non-recommendation
Sedentary time (min/day)	RCTs	2[160,165]	Low to moderate	0.02	2.5 min/day	⊕◯◯◯	Weak non-recommendation

Note: ⊕◯◯◯: very low level of evidence; ⊕⊕◯◯: low level of evidence; ⊕⊕⊕◯: moderate level of evidence; ⊕⊕⊕⊕: high level of evidence.
Abbreviations: BMI = body mass index; DBP = diastolic blood pressure; GRADE = grading of recommendations assessment, development; HbA1c = glycated hemoglobin; HDL-C = high-density lipoprotein cholesterol; iAUC = incremental area under the curve; LDL-C = low-density lipoprotein cholesterol; MD = mean difference (represents the raw difference between means, where applicable); MVPA = moderate-to-vigorous physical activity; n/*a* = not applicable; PA = physical activity; RCTs = randomized controlled trials; SBAE = short bouts of accumulated exercise; SBP = systolic blood pressure; SMD = standardized mean difference (represents the effect size in meta-analyses); $\dot{V}O_{2peak}$ = peak oxygen uptake.

long-duration, moderate- to low-intensity SBAE primarily involving walking over a median duration of 12 weeks (low GRADE). These changes have important clinical implications. For instance, reductions in body fat are frequently associated with lower risks of all-cause mortality, T2D, and heart disease.[239] A 10% reduction in waist circumference has also been linked to a decreased mortality risk.[240]

6.1.4. Metabolic health

Important metabolic health indicators include blood lipid concentrations and blood glucose control. Moderate-duration or long-duration, moderate-intensity SBAE does not significantly affect total cholesterol[159,163,171,183] (ES = 0.02) or triglyceride levels[159,163,171,178,182,183] (ES = 0.19) among young to older adults, including those with diverse health conditions (low GRADE). However, these interventions significantly increased high-density lipoprotein (ES = 0.47, increase of 0.08 mmol/L)[159,163,171,178,182,183] and decreased low-density lipoprotein (ES = 0.38, reduction of 0.22 mmol/L).[159,163,171,178,182,183] In older adults patients with T2D, long-duration, moderate- to low-intensity SBAE after meals reduced blood glucose incremental area under the curve (iAUC) by 7.5%,[178] fasting blood glucose by 4%–12% (0.2–1.05 mmol/L),[163,171,172,178] and glycated hemoglobin by 0.2%–0.5%.[172,178] In summary, moderate-duration or long-duration, moderate-intensity SBAE improves lipid profiles by increasing high-density lipoprotein and reducing low-density lipoprotein (moderate GRADE), though the clinical significance of these changes may be limited. However,

Table 4
Summary of the differences in effects between SBAE and single bout continuous exercise.

Outcome	Type of evidence	Number of studies (references)	Quality of the evidence	SMD	MD	GRADE	Recommended level
Moderate-intensity SBAE *vs.* no exercise control							
Cardiovascular fitness and function							
$\dot{V}O_{2peak}$	Meta-analysis	1[32]	Moderate	0.00	0.50 mL/kg/min	⊕⊕◯◯	Weak recommendation
SBP	Meta-analysis	1[33]	Moderate	n/a	1.28 mmHg	⊕⊕◯◯	Weak recommendation
DBP	Meta-analysis	1[33]	Moderate	n/a	1.27 mmHg	⊕⊕◯◯	Weak recommendation
Body composition							
Body weight	Meta-analysis	1[33]	Moderate	n/a	0.92 kg	⊕⊕⊕◯	Weak recommendation
Body fat (%)	Meta-analysis	1[33]	Moderate	n/a	0.46%	⊕⊕◯◯	Weak recommendation
Waist circumference	Meta-analysis	1[33]	Moderate	n/a	1.43 cm	⊕⊕◯◯	Weak recommendation
Hip circumference	Meta-analysis	1[33]	Moderate	n/a	2.32 cm	⊕⊕◯◯	Weak recommendation
Metabolic health							
Total cholesterol	Meta-analysis	1[33]	Moderate	n/a	0.22 mmol/L	⊕⊕◯◯	Weak recommendation
LDL-C	Meta-analysis	1[33]	Moderate	n/a	0.50 mmol/L	⊕⊕◯◯	Weak recommendation
HDL-C	Meta-analysis	1[33]	Moderate	n/a	0.06 mmol/L	⊕⊕◯◯	Weak recommendation
Triglycerides	Meta-analysis	1[33]	Moderate	n/a	0.07 mmol/L	⊕⊕◯◯	Weak recommendation
Fasting blood glucose	RCTs	1[178]	Moderate	n/a	0.05 mmol/L	⊕⊕⊕◯	Weak recommendation
Glucose iAUC	RCTs	1[172]	Moderate	n/a	n/a	⊕⊕⊕◯	Weak recommendation
Fasting insulin	Meta-analysis	1[33]	Moderate	n/a	0.37 mmol/L	⊕⊕◯◯	Weak recommendation
Vigorous-intensity exercise SBAE *vs.* single bout continuous exercise							
$\dot{V}O_{2peak}$	RCTs	2[155,167]	Moderate	0.17	0.51 mL/kg/min	⊕⊕◯◯	Weak recommendation
aerobic power	RCTs	2[155,167]	Moderate	0.44	15.34 W	⊕⊕◯◯	Weak recommendation

Note: ⊕◯◯◯: very low level of evidence; ⊕⊕◯◯: low level of evidence; ⊕⊕⊕◯: moderate level of evidence; ⊕⊕⊕⊕: high level of evidence.
Abbreviations: BMI = body mass index; DBP = diastolic blood pressure; GRADE = grading of recommendations assessment, development, and evaluation (a system for evaluating the quality of evidence and strength of recommendations); HbA1c = glycated hemoglobin; HDL-C = high-density lipoprotein cholesterol; iAUC = incremental area under the curve; LDL-C = low-density lipoprotein cholesterol; MD = mean difference (represents the raw difference between means, where applicable); MVPA = moderate-to-vigorous physical activity; n/a = not applicable; RCTs = randomized controlled trials; SBAE = short bouts of accumulated exercise; SBP = systolic blood pressure; SMD = standardized mean difference (represents the effect size in meta-analyses); $\dot{V}O_{2peak}$ = peak oxygen uptake.

the improvements in glucose control observed with SBAE in older adults with T2D might be clinically relevant (moderate GRADE), as a reduction of 0.5% in glycated hemoglobin is often considered meaningful and is associated with significantly reduced risks of all-cause mortality, myocardial infarction, stroke, and heart failure in T2D.[241]

6.1.5. Perceived health and physical activity

Currently, there is limited research on the effects of SBAE for improving quality of life,[154] anxiety,[154] self-efficacy, depression/anxiety, and mood disorders, and the studies available show inconsistent findings.[33] Similarly, there is minimal evidence with mixed findings regarding long-term changes in PA and sedentary behavior.[160,165] Liang et al.[160] found that total PA, moderate-to-vigorous PA, and sedentary time increased at follow-up relative to baseline in older adults after 4 weeks of Tai chi-based SBAE. Stork et al.[153] reported that when participants chose to perform stair climbing-based SBAE (three isolated bouts of ascending 53−60 stairs performed sporadically throughout the day), the average number of sit-to-stands performed in 24 h was significantly increased (48.3 ± 8.7 to 52.8 ± 7.8, mean ± SD; ES = 0.73) and moderate-to-vigorous PA tended to increase (21.9 ± 18.2 to 38.1 ± 22.1 min; ES = 0.60) compared to days without SBAE. However, Rodriguez-Hernandez et al.[165] did not observe significant changes in total PA levels or sedentary behavior after a 10-week walking SBAE intervention in office workers. In summary, the existing evidence regarding the effects of SBAE on perceived health and PA is limited and inconsistent (very low GRADE).

6.2. Differences in health-promoting effects between SBAE and single continuous exercise sessions

Studies published to date have mainly compared the health-promoting effects of 2 SBAE protocols (both at low frequencies) with single continuous exercise sessions: (a) long-duration, moderate-intensity SBAE (e.g., 3 sessions of 10 min, with intervals of 1−6 h, at 65%HR_{max}) *vs.* a single session of moderate-intensity continuous exercise (e.g., 30 min at 65%HR_{max}); (b) short-duration, vigorous-intensity SBAE (e.g., 3 bouts of 20−30 s, with intervals of 1−6 h, all-out sprints at supra-maximal intensity) *vs.* single continuous or intermittent bouts of exercise (e.g., 40 min at 65%HR_{max}).

Murphy et al.[33] conducted a comprehensive meta-analysis on the first comparison type (long-duration, moderate-intensity SBAE). They found no significant differences in cardiovascular, body composition, or metabolic health outcomes after long-duration, moderate- to low-intensity SBAE (median length of 12 weeks), except for weight and blood glucose indicators. An RCT in patients with T2D found that walking for 10 min after meals significantly improved postprandial blood glucose iAUC and fasting blood glucose compared to a single 30-min exercise session.[172,178]

Two studies, by Little et al.[167] and Yin et al.,[155] investigated the second comparison type (short-duration, vigorous-intensity SBAE), exploring improvements in aerobic capacity after 6 weeks (3 days per week). Little et al.[167] followed a protocol of

3 all-out cycling sprints of 20 s per day (either performed as a single session or as single sprints throughout the day), while Yin et al.[155] implemented 3 all-out stair climbing sprints of 30 s per day, both compared to traditional moderate-intensity continuous exercise (40 min at 60%–70% HR_{max}). Quantitative synthesis of the results ($\dot{V}O_{2peak}$ and aerobic power) indicated no significant differences between the protocols.

In conclusion, current evidence suggests that low-frequency SBAE protocols, whether moderate-intensity or vigorous-intensity, provide comparable benefits to single continuous exercise sessions regarding cardiovascular, metabolic, and aerobic outcomes among young to older adults, including those with diverse health conditions (low GRADE). There were some specific advantages for body weight and blood glucose (especially in elderly patients with T2D) management with long duration and moderate intensity SBAE protocols (low GRADE). Given that reductions in postprandial glucose independently contribute to improved glycemic control and reduced cardiovascular risk in patients with T2D,[242,243] the advantages of SBAE might have clinical significance.

All acute and long-term health benefits are summarized in Fig. 1.

7. Application feasibility

The design of longitudinal intervention studies can objectively assess the feasibility of long-term SBAE interventions by evaluating dropout rates, adherence and completion rates (the percentage of completed sessions compared to planned sessions, differentiated by supervision), and safety. Additionally, prospective pilot studies (some of which incorporated qualitative interviews) can explore participant perspectives, including facilitators and barriers to participation. A total of 37 longitudinal intervention studies[154–190] were conducted, involving 40 intervention groups categorized into short duration (12.5%), moderate duration (25.0%), and long duration (62.5%) SBAE. The intervention period ranged from 2 to 72 weeks, with an average of 11 weeks. Supervised interventions accounted for 25.0% of the studies, while unsupervised interventions constituted 75.0%. The settings included workplaces

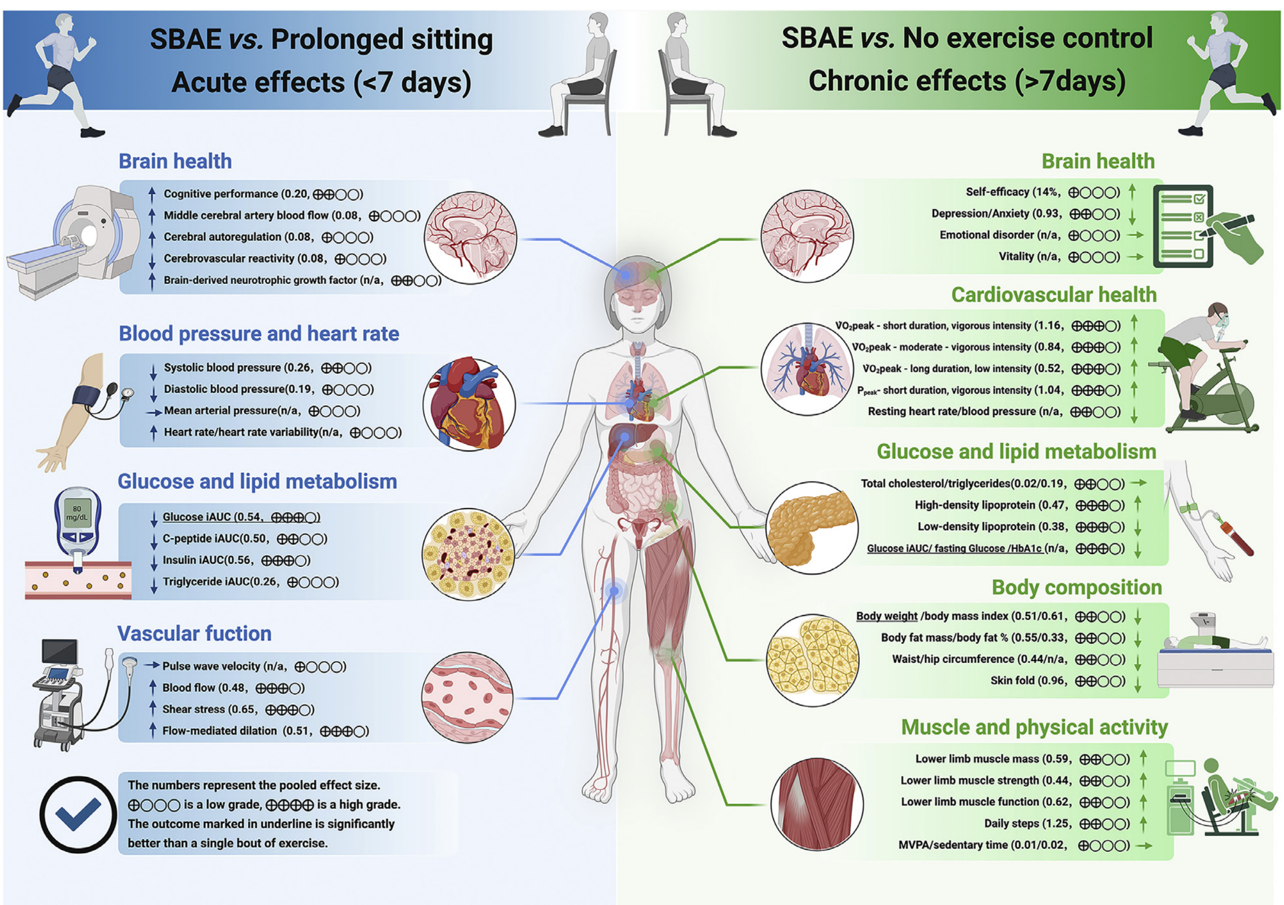

Fig. 1. Summary of the effects of SBAE to break in sedentary behavior, promote health, and prevent disease.This figure aims to show the acute (blue, left) and chronic effects (green, right) of SBAE on various systems of humans. No exercise refers to the control group in long-term intervention studies, which usually does not receive exercise intervention and maintains previous habitual behavior. Among them, the number after each outcome indicator denotes the effect size, and the GRADE of this effect follows the number; the outcome marked in red is significantly better than a single bout of exercise. ↑ / ↓ indicates a significant increase/decrease in outcome with SBAE compared to single bout continuous exercise, while → indicates no statistically significant difference. ⊕○○○: very low level of evidence; ⊕⊕○○: low level of evidence; ⊕⊕⊕○: moderate level of evidence; ⊕⊕⊕⊕: high level of evidence. GRADE = grading of recommendations assessment, development, and evaluation; iAUC = incremental area under the curve; $\dot{V}O_{2peak}$ = peak oxygen uptake; SBAE = short bouts of accumulated exercise.

(20.0%), homes (20.0%), gyms or community centers (27.5%), laboratories (15.0%), and campuses (17.5%). The study populations consisted of healthy young adults (52.5%), middle-aged adults (30.0%), and older adults (17.5%).

7.1. Dropout and adherence and completion rates

Ninety-five percent of the studies reported the dropout rate of SBAE, while 65% reported the adherence and completion rates. Dropout rates ranged from 0% to 50% (11.9% ± 11.7%, mean ± SD; median = 11.8%, 25th (0%) to 75th (17.9%)). Completion rates ranged from 88.6% to 99.7% (95.8% ± 4.2%, mean ± SD; median = 96.9%, 25th (96.0%) to 75th (98.0%)). Adherence rates ranged from 55.5% to 115.1% (85.1% ± 13.5%, mean ± SD; median = 84.5%, 25th (73.3%) to 75th (89.7%)), whereby those with an adherence rate >100% completed more exercises than prescribed under supervised conditions. For example, Jansons et al.[161] reported that all participants were prescribed 8640 sessions but completed 9944 sessions (115%). These rates may be influenced by protocol type, the presence or absence of supervision, different age groups, and application scenarios (Fig. 2). As a comparative reference, a meta-analysis of 166 supervised HIIT studies reported an average dropout rate of 13% and a completion rate of 89%. Likewise, a meta-analysis of 70 supervised moderate-intensity continuous training (MICT) studies showed an average dropout rate of 12% and a completion rate of 93%.[244] Under unsupervised conditions, the dropout rate for SBAE was 12%, with a completion rate of 85%. A meta-analysis [244] of 30 unsupervised HIIT studies reported an average completion rate of 63%, while another meta-analysis of 17 MICT studies showed a completion rate of 68%.[244] These indirect comparisons suggest that SBAE is highly feasible in laboratory and real-world interventions. However, it is crucial to recognize that while investigating the potential of SBAE as a public health strategy, the observed dropout rate within the 11-week average intervention period provides insufficient evidence to assess long-term efficacy. Future research should prioritize longitudinal studies (typically spanning ≥ 6 months) with systematic follow-up to evaluate whether SBAE interventions can achieve sustained integration into daily routines, induce durable behavioral changes, and foster lasting health improvements.

7.2. Safety

Safety is assessed through reporting adverse events, with a reporting rate of 25% (10 reports[155,158,160–162,164,166,167,172,190]). Six studies[155,161,164,166,167,190] reported no adverse events during the study period, while 2 studies[158,172] reported 2 adverse events unrelated to the SBAE intervention (accidental deaths). Only two studies [160,162] reported adverse events that may have been related to SBAE. Liang et al.[160] conducted a 4-week unsupervised home-based resistance SBAE intervention for older adults and reported one adverse event: "A pre-existing knee injury worsened during sit-to-stand exercises". Fyfe et al.[162] conducted a 4-week unsupervised home-based fragmented resistance intervention for older adults. They reported that two participants experienced adverse events (one with plantar fasciitis and another with lower back/leg pain related to a spinal nerve/disc injury), allowing them to continue after adjustments. Fyfe et al.[162] also noted 8 minor musculoskeletal discomforts, none of which affected participation. Overall, the adverse event rates for young adults, middle-aged adults, and older adults were 0.0%, 0.0%, and 0.1%, respectively, representing the ratio of occurrences to total completed sessions. Most available safety data are from low- to moderate-intensity SBAE interventions, with limited research and safety data for vigorous-intensity SBAE. Meanwhile, considering that the current adverse event reporting rate is only 25% and that reporting methods and content vary, more objective and quantitative safety data are needed to further support the application of SBAE. Therefore, these findings should be interpreted 8 with caution.

7.3. Participant perspectives

Six SBAE interventions[155,160–162,166,193] and 3 short bouts of accumulated PA projects (Snacktivity™ and VILPA)[191,192,195] explored participant' perspectives on facilitators and barriers to implementation, as well as future practice recommendations, using semi-structured interviews and surveys. Barriers and enablers may vary depending on population characteristics, culture, life stage, socioeconomic factors, and city or neighborhood design. Behavioral determinants of SBAE are broadly categorized into external and internal domains. External facilitators include flexible scheduling, seamless lifestyle integration, and time efficiency, whereas internal drivers encompass perceived health benefits, enhanced self-efficacy, and sustained positive mood. Conversely, participation barriers involve external limitations such as programmatic gaps (e.g., insufficient upper-body-focused protocols), environmental constraints, and internal challenges like motivational deficits (e.g., boredom and habitual neglect of practice). Although current evidence derives predominantly from short-term interventions, these preliminary findings establish a foundational framework for understanding behavioral determinants. Future studies may further investigate longitudinal dynamics changes of SBAE behavioral determinants, examining temporal variations in determinants to optimize adaptive implementation strategies. The barriers and enablers to implementation details are summarized in Fig. 2 and Supplementary File 8, with future recommendations discussed in detail in Section 8.

8. Evidence-based practice applications

8.1. Summary of prescription variables

The recommendations for all specific motion variable parameters are summarized in Fig. 3.

8.1.1. Frequency (daily) and timing

The characteristic of SBAE being performed multiple times a day necessitates careful consideration of "timing"(i.e., daily frequency and density[245]) to maximize physiological benefits. Firstly, during periods of prolonged sedentary behavior (e.g.,

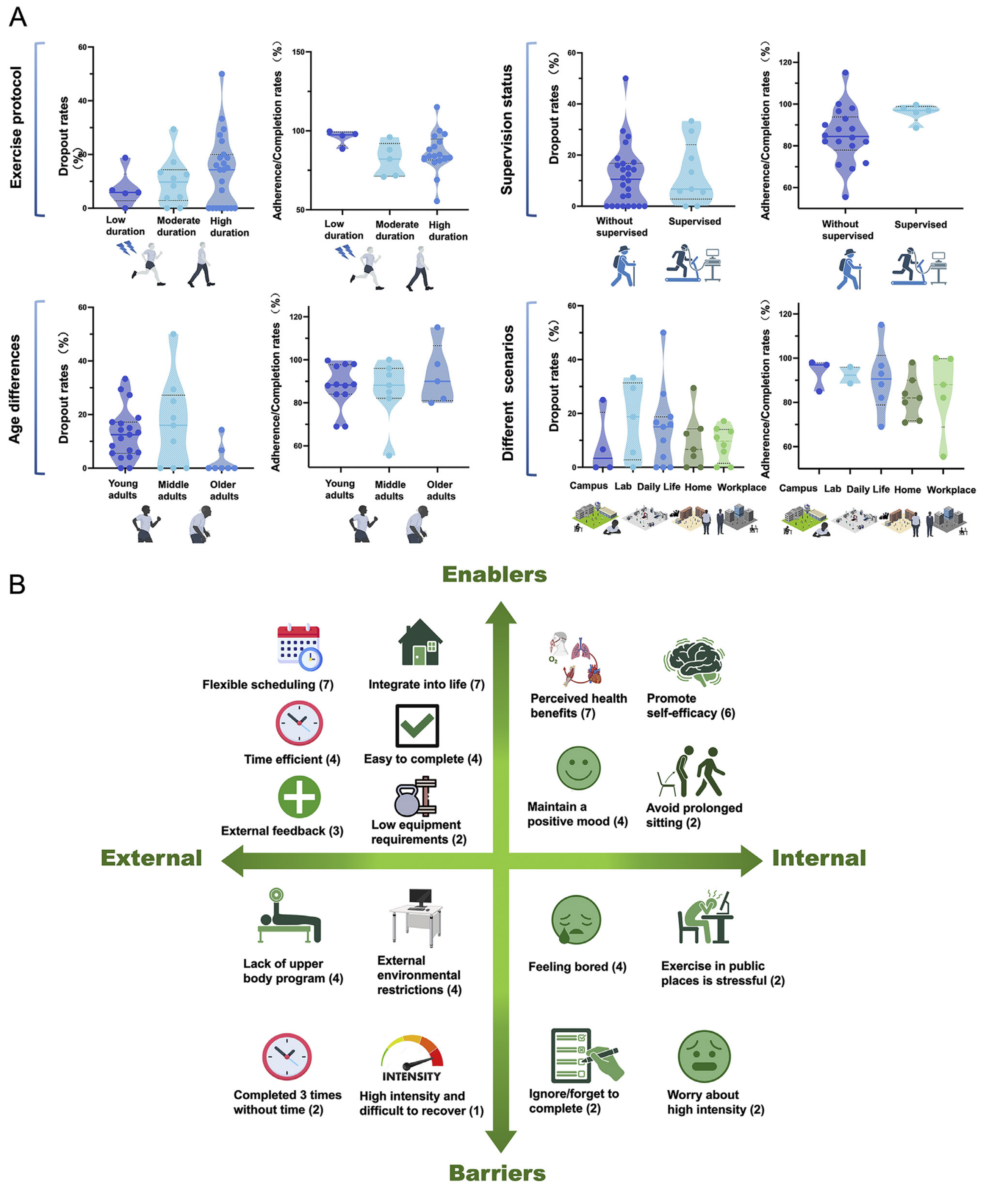

Fig. 2. Potential factors influencing dropout and adherence/completion rates of SBAE interventions, and summary of barriers and enablers. (A) This panel presents the distribution of dropout and adherence/completion rates of short bouts of accumulated exercise (SBAE) interventions under different influencing factors. It does not (and cannot easily) include statistical tests. Age categories: young adults (18−44 years), middle-aged adults (45−64 years), and older adults (≥65 years). (B) This panel summarizes the internal and external barriers and enablers influencing participation in SBAE interventions. The number (x) following each factor indicates the frequency with which it was reported across included studies. For example, “flexible scheduling (7)” under external enablers means that this factor was identified as an enabler in 7 studies—the most frequently mentioned in that category. SBAE = short bouts of accumulated exercise.

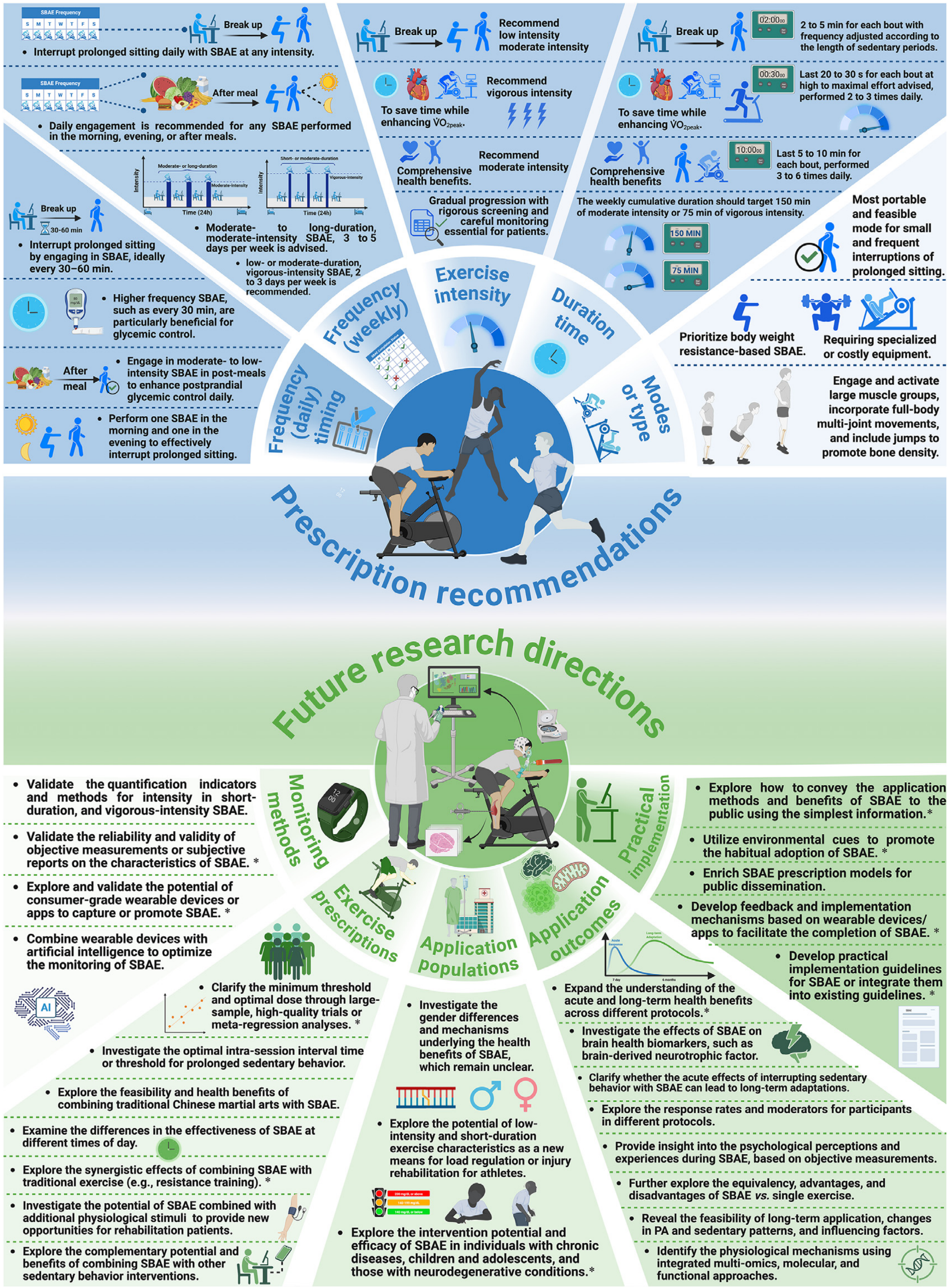

Fig. 3. Summary of SBAE prescription variables recommendations and future research directions. The top panel summarizes recommendations for each prescription variable of SBAE. The bottom panel outlines proposed future research directions for SBAE. The future research directions outlined above have all received a rating of "agree" or higher, with those marked with an * rated as "strongly agree". More detailed recommendation levels and scoring for each item can be found in Supplementary File 9. $\dot{V}O_{2peak}$ = peak oxygen uptake; SBAE = short bouts of accumulated exercise.

sitting, lying down), moderate- to low-intensity SBAE can intermittently break up sitting or reclining for 30–60 min, mitigating the harmful effects of extended sedentary behavior.[12,13,16,21,42,44–46,48–51,66] Specifically, an approach with higher frequency and shorter bout duration per session might be more effective for acute improvements in glycemic control compared to longer bouts performed with lower frequency.[92,112,130,142,144,150]

Meanwhile, one must consider the influence of meals and exercise timing throughout the day. Firstly, performing moderate- to vigorous-intensity SBAE before meals can aid acute and long-term glycemic control. Francois et al.[95] compared a single continuous treadmill exercise (30 min at 60%HR_{max}) before dinner to SBAE before each meal (6 × 1 min at 90%HR_{max}). Only the pre-meal short bouts significantly reduced postprandial glucose levels and the 24-h average glucose concentration, with benefits lasting into the following day. Secondly, sustained interventions can translate these acute benefits into long-term improvements in blood glucose indicators. Reynolds et al.[172] found that walking for 10 min after each meal significantly improved postprandial glucose iAUC and fasting glucose compared to a single 30-min walk at another time of day. Similar findings were also observed in fasting glucose and glucose tolerance tests.[178] Some studies have also compared the effects of exercise at pre-meal and post-meal time points. Engeroff et al.[246] included eight trials (116 participants) and found that post-meal exercise significantly reduced postprandial glucose but pre-meal exercise did not. These results suggested SBAE around post-meal time might be more beneficial to metabolic health.

Factors such as meal type (liquid *vs.* solid meals) and macronutrient composition might also affect the effect of SBAE. Bailey et al.[247] found that SBAE and lowering breakfast glycemic index each reduced postprandial glucose responses independently. However, there is currently very little evidence, and it is unclear whether SBAE combined with a glycemic index diet can have additional effects on improving metabolic health, nor is it clear whether various dietary strategies will interact with SBAE.

Finally, SBAE for older adults has been designed for morning and evening sessions, and these interventions have been validated as both feasible and effective.[157,158,160–162,166] However, it is important to note that prolonged sedentary behavior may still occur. Therefore, incorporating "small and frequent" bouts of PA of any intensity is recommended to interrupt sedentary behavior.

8.1.2. Frequency (weekly)

The weekly exercise frequency should be tailored to participant characteristics and the selected regimen. Firstly, it is feasible to interrupt prolonged sedentary behavior daily using small and frequent SBAE of any intensity and mode. Secondly, the feasibility and safety of performing one bodyweight SBAE session in the morning and evening[157,158,160–162,166] or engaging in low-intensity walking after meals[95,172,178] have been validated in older adults and individuals with T2D. These SBAE can be implemented daily. However, for moderate- to vigorous-intensity or long-duration moderate-intensity exercises, a frequency of 3–5 times per week is supported by current research. Additionally, for short-duration (<1 min), vigorous-intensity SBAE, the higher intensity requires more recovery time and motivation; evidence suggests that three sessions per week, with 48-h intervals between sessions, is feasible.[155,164,167,168,170] Notably, a study comparing short-duration maximal sprint cycling interval training (2 × 20 s, maximal sprints, one session per day) found no difference in $\dot{V}O_{2peak}$ improvements with a training frequency of 2–4 times/week, indicating that the frequency can be reduced to 2 days per week when intensity is maximal.[248]

8.1.3. Intensity

The intensity range of SBAE is broad, spanning from low intensity to all-out efforts. Additionally, "intensity" is not well characterized (or easy to define) for all types of exercises (e.g., elastic band resistance exercises or plyometrics). Research on the effects of varying exercise intensities within the same protocol is insufficient. Interrupting prolonged sitting by walking at different intensities (low *vs.* moderate) shows no significant difference in acute glycemic control.[91] Although network meta-analyses have found that moderate-intensity interruptions in sedentary behavior result in a statistically significant reduction in blood glucose compared to low-intensity interruptions,[51] the magnitude of difference would not be considered clinically meaningful.[51] However, increasing exercise intensity to moderate intensity is important for achieving broader long-term health benefits, including improved cardiovascular and endocrine function and favorable changes in body composition.[33,34] If the goal is to improve cardiorespiratory fitness and time is limited, vigorous-intensity exercise may be more effective, providing better improvements in cardiorespiratory fitness with shorter training durations (<1 min).[155,164,167,168,170] It is essential to adhere to the gradual progression principle when planning exercise intensity throughout the program. A cautious approach is necessary for individuals with chronic medical conditions, with careful medical screening and supervision recommended before establishing specific exercise prescriptions.[249]

8.1.4. Duration

A key characteristic of SBAE is its time-efficient nature, which reflects the idea that "every minute counts".[250] The exercise duration complements intensity, and both must be balanced for effectiveness. The choice of exercise duration depends on the purpose of the short bouts. For counteracting sedentary behavior, low- to moderate-intensity SBAE for 2 min to 5 min per session is supported by current evidence.[16,21,42–54,58–60,62,65,66] However, this range is broad, and large-scale meta-regression analyses to establish the minimum threshold for physiological efficacy and optimal duration are lacking. For comprehensive health benefits, evidence supports 5–10 min of moderate- to vigorous-intensity exercise performed 3–6 times daily (totaling 30 min daily).[33–35] For improving $\dot{V}O_{2peak}$, a single duration of 20–30 s performed 2–3 times daily at maximum effort[155,164,167,168] resembling short-duration HIIT[251–256] with an appropriate warm-up beforehand, is sufficient. Like intensity, exercise duration should be individualized and follow a gradual progression approach.[249] The weekly exercise duration targets should be set at 150 min of moderate-intensity or 75 min of vigorous-intensity exercise to reduce the risks for chronic disease morbidity and mortality.[1]

8.1.5. Mode

Due to their accessibility and integration into daily life, SBAE has demonstrated physiological efficacy and feasibility in unsupervised settings. Current evidence focuses primarily on walking, running, stair climbing, cycling, and body weight resistance exercises. While each mode generally improves key health biomarkers, there is limited evidence of the relative benefits of choosing one over another. Gao et al.[99] reported that brief walking and squatting interruptions during prolonged sitting effectively improve postprandial glucose control. They suggested that engaging large muscle groups could be a potential physiological mechanism underlying the effects of different modes of interruption on glucose regulation. Dempsey et al.[89] found that bodyweight resistance exercises (9×20 s, alternating between half-squats, leg raises, and knee lifts) significantly reduced postprandial triglycerides compared to continuous sedentary behavior, while low-intensity walking did not.

Long-term, body-weight resistance exercises improve muscle strength and function.[157,158,160–162,166] Additionally, dynamic movements with higher ground reaction forces applied rapidly and in novel directions are more osteogenic than static, slow movements (such as jumping).[40,257] Some types of jumping (e.g., jumping rope) may induce a significant cardiorespiratory stimulus, similar to HIIT, with the added benefit of greater neuromuscular stimulation,[257] and can be performed in a reduced space and with low-cost equipment (or no equipment at all[259]). Although running and cycling allow precise control of external loads through speed or power, they require specialized equipment. In contrast, all-out stair climbing achieves similar physiological intensities to maximal cycling sprints (perceived exertion, heart rate, and blood lactate) and offers long-term cardiovascular benefits (e.g., $\dot{V}O_{2peak}$).[259] Additionally, body-weight resistance exercises can vary in intensity based on movement speed, quality, duration, and difficulty (e.g., Shanghai University of Sport Worker Interval Exercise Guidelines[261]), which can be made more engaging with music. Beyond planned SBAE, individuals are encouraged to explore everyday opportunities for short bouts of accumulated PA (e.g., climbing stairs quickly, using a shopping basket instead of a cart) to increase daily PA.[191,196]

Additionally, we recommend incorporating varied multicomponent exercises that emphasize functional balance and strength training into SBAE. For instance, Liang et al.[194] developed a Tai Chi-based SBAE protocol for the elderly, which improved lower extremity strength, balance, and mobility. Given that previous studies have demonstrated the effectiveness of Tai Chi in enhancing cognitive function,[261] physical function,[262,263] and fall prevention[264] in older adults, integrating this approach into SBAE might offer a simple and practical strategy for improving elderly health.

8.2. Current evidence-based protocols available

Fig. 4 provides a visual summary of 3 distinct SBAE protocols identified through a comprehensive literature review, each characterized by varying intensities and durations of PA. These protocols are designed to be easily integrated into daily routines, balancing health improvement goals with practicality. Practitioners and participants can select protocols based on their specific health objectives.

For instance, participants with limited sitting time who engage in moderate- to vigorous-intensity PA but lack structured exercise time to improve cardiovascular function further can adopt a "low frequency, short duration, vigorous-intensity" protocol (Fig. 4A). This protocol involves short bursts of PA of ~20 s to 30 s (0.5 min total) every 1–6 h, 3 bouts per day, featuring maximal stair climbing or cycling sprints. These protocols are efficacious in improving cardiometabolic health, such as $\dot{V}O_{2peak}$,[155,164,167,168] in the short term (6 weeks) and have similar benefits to MICT as per traditional guidelines.[155] In contrast, Fig. 4A focuses on moderate-intensity and low-intensity exercise protocols. Moderate-intensity exercises lasting 5–10 min at 3–6 METs provide comprehensive health benefits across diverse populations, including cardiometabolic health and body composition.[33–35] For participants with persistent sedentary behavior and minimal PA, a "sitting less and moving more" strategy should be implemented.[12] This protocol reduces sedentary behavior and its associated health risks by interrupting prolonged sedentary periods every 30–60 min with low-intensity exercise or PA such as walking, which might be beneficial for acute glycemic control, vascular function, and cognitive performance.[16,21,42–54,58–60,62,65,66] These figures demonstrate the flexibility of exercise interventions, which can be tailored to different schedules and preferences while promoting overall health and reducing the risks of prolonged sitting and insufficient PA.

8.3. Recommendations of SBAE based on populations and scenarios

This study provides specific examples and recommendations for exercise prescriptions tailored to different populations and practical application contexts (Fig. 4B). Fig. 4B illustrates various populations and application scenarios, ranging from individuals engaged in structured exercise routines to patients undergoing treatment. The exercise prescriptions vary significantly in SBAE protocols (intensity and duration), depending on the target group.

For example, higher-intensity protocols, represented by vigorous activities such as stair climbing or cycling, are recommended for young people who do not sit for long periods every day and have accumulated a certain amount of moderate to vigorous PA (such as college students or workers) to enhance cardiometabolic health. These intensities and durations have been widely used in HIIT and are both effective and feasible in populations ranging from apparently healthy individuals to clinical populations.[251,253–255,265–275] In contrast, moderate- or low-intensity exercises, such as walking or simple resistance training, are prescribed for older adults or patients with chronic conditions like diabetes or cardiovascular disease.[43,59,86,89,108–110,140,172,178] These lower-intensity protocols are designed to ensure safety while still promoting recovery and physiological improvements. Finally, regular 2–5 min bouts every 30–60 min with low-

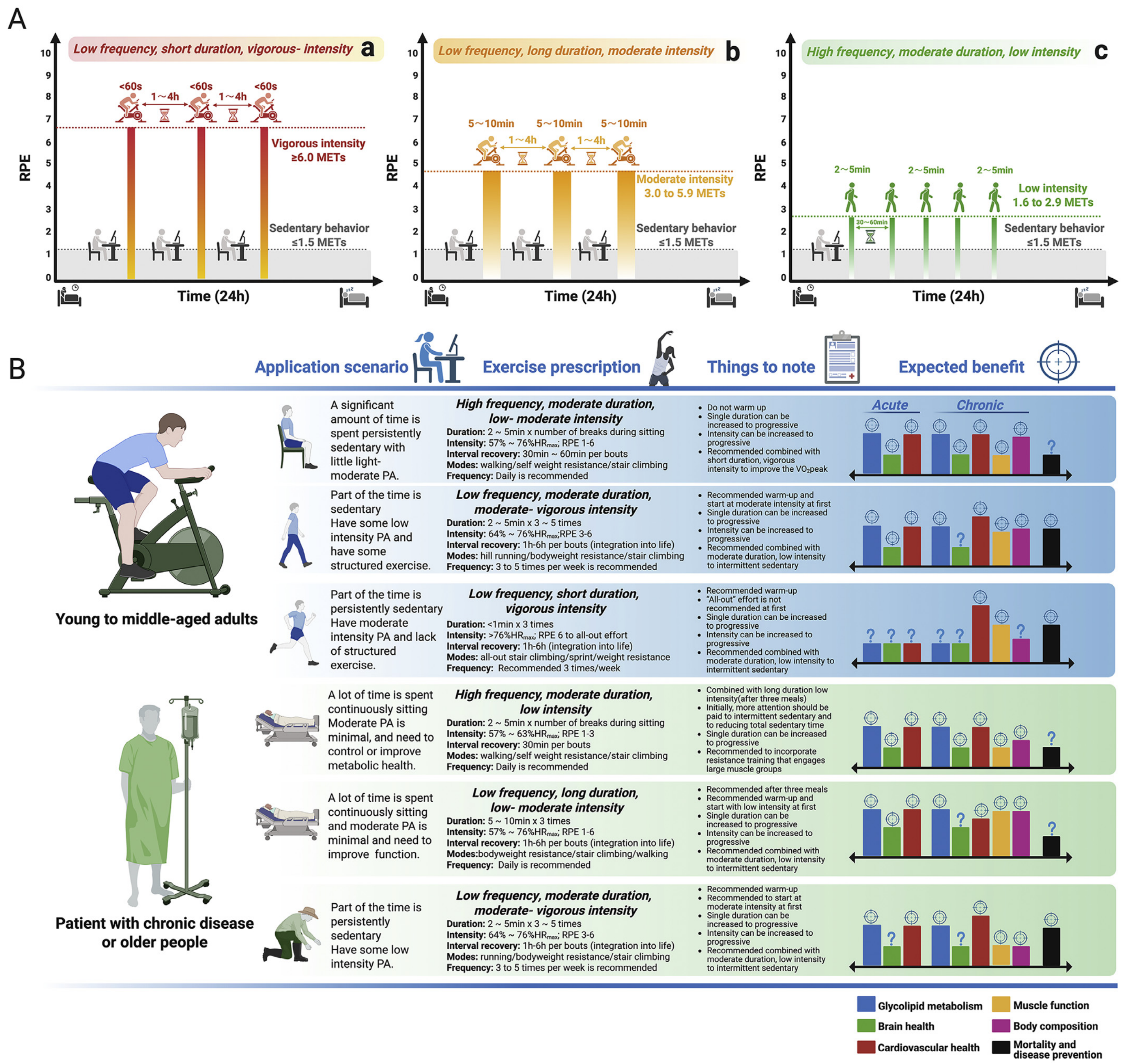

Fig. 4. Evidence-based SBAE protocols and recommendations with expected health benefits based on populations and scenarios. (A) The gray columns in the above figure represent sedentary behavior, the green columns represent low-intensity activity/exercise, the yellow columns represent moderate-intensity activity/exercise, and the red columns represent vigorous-intensity exercise. RPE is a scale ranging from 0 to 10, where 0 indicates rest, 1 represents very light activity, 2–3 corresponds to light activity that can be maintained for hours, 4–5 refers to moderate activity with heavier breathing but still manageable conversation, 6–7 indicates vigorous activity with difficulty holding a conversation, 8–9 reflects very hard activity near maximum effort, and 10 signifies maximal exertion where continuing feels impossible.[276] (B) The RPE is based on the Borg CR-10. The target icon refers to the magnitude and focus of the expected health benefits based on previous evidence. a = vigorous intensity; b = moderate intensity; c = low intensity; CR-10 = category-ratio 10-point scale; HR_{max} = maximum heart rate; METs = metabolic equivalents; RPE = rating of perceived exertion; PA = physical activity; SBAE = short bouts of accumulated exercise.

to moderate-intensity SBAE are employed to interrupt prolonged sitting.[16,21,42–54,58–60,62,65,66] This strategy is suitable for all populations, as it is simple, easy to implement, and can be integrated with other SBAE protocols or traditional exercise programs. This approach helps achieve the dual objectives of reducing sedentary time and increasing overall PA. Each exercise prescription is associated with a set of expected benefits, including improvements in cardiovascular health, muscular strength, blood glucose levels, and reductions in fat mass, as represented by the color-coded bars in Fig. 4B.

Vigorous-intensity exercise protocols deliver a broad spectrum of benefits, particularly enhancing cardiovascular and metabolic health. In contrast, moderate- and low-intensity exercises focus more on maintaining general health, preventing deconditioning, and aiding recovery. The "Things to note" section emphasizes the importance of exercise intensity regulation and monitoring,[1,217,223] particularly in clinical or rehabilitation settings. Exercise intensity, denoted by the rating of perceived exertion (RPE)[276] and METs,[277] ensures that the activity remains within a safe and effective range for the participant. In some cases, monitoring of physiological responses, such as heart rate and blood glucose levels, is necessary to avoid adverse effects and ensure that the exercise remains therapeutic rather than harmful.

Fig. 4 encapsulates practical implications for health and fitness professionals, particularly those working with varied populations, including sedentary and/or insufficient physically activity individuals and patients. It highlights the need for customizable SBAE prescriptions that consider an individual's health status, physical capabilities, and goals. Moreover, the division between vigorous-, moderate-, and low-intensity exercise prescriptions underscores the importance of matching exercise intensity to an individual's fitness level and specific health objectives. This personalized approach maximizes health benefits while minimizing risks, particularly in clinical settings.

In conclusion, Fig. 4 provides comprehensive recommendations for SBAE prescriptions that adapt to the needs of diverse populations. It balances the benefits of different exercise intensities and durations while emphasizing the importance of monitoring and regulation to achieve optimal health outcomes across various application scenarios.

8.4. Impact on policies or guidelines

As public awareness has grown, expectations for the precision, specificity, and practicality of exercise and sedentary behavior guidelines have also increased. This consensus aims to provide a scientific basis and guidance for developing and implementing relevant public health policies and guidelines for improving population health. This consensus is also critical for formulating and updating global PA policies and guidelines, as countries and regions can integrate these recommendations into their existing frameworks. Such integration allows for a more comprehensive and scientific approach to public health strategies. When incorporating these recommendations into policies, it is essential to reflect current evidence-based practices while aligning with local realities, including cultural, social, and economic factors, to ensure effectiveness and feasibility. This consensus can serve as a foundation for constructing a comprehensive public health management framework. For example, at the national level, promoting the benefits and methods of SBAE to combat sedentary behavior and insufficient PA can help increase public health awareness and motivate behavioral change. At the same time, policies that support conducive environments, such as providing urban pathways, staircases, and office spaces designed to facilitate SBAE, are critical to the successful implementation of this consensus.

9. Future research directions

Over the past 3 decades, SBAE has steadily gained scientific attention, with rapidly accumulating research evidence. This trend not only aligns with the international call for a "shift towards multidimensional forms of PA"[278] but also embodies the principle that "any movement is beneficial", as emphasized in the latest PA guidelines[1–3] and exercise prescriptions.[223] This consensus identifies several ongoing challenges in the field and summarizes participant perspectives on "future recommendations" to provide practical insights for applying and translating research findings. However, future research must address several key areas to enhance its rigor, scope, and relevance:

- Larger sample sizes and long-term studies: There is an urgent need for larger sample sizes and long-term RCTs to integrate behavior change techniques, further validating the current evidence on SBAE. These studies should verify whether the acute benefits of SBAE can lead to sustained long-term physiological adaptations, particularly regarding daily PA and reductions in sedentary behavior. Regular follow-ups should be included for primary outcomes such as changes in daily PA and sedentary behavior. These studies are crucial for updating and refining practical guidelines.
- Personalized, lifestyle-oriented SBAE: Future research should focus on personalized, lifestyle-based interventions to reduce sedentary behavior and promote SBAE, especially in clinical or everyday settings. Currently, most SBAE studies primarily focus on simple, repetitive movements (e.g., walking). It is essential to explore the potential of incorporating multicomponent exercises that emphasize functional balance, resistance/muscle strength, and combined strategy (such as blood flow restriction[279]) within the SBAE framework. Meanwhile, a key part of this research field will involve identifying the best activities to replace sitting, considering factors such as frequency, duration, type, and health outcomes. It is essential to understand which activities provide the most health benefits both in the short term (1–7 days) and long term (weeks to months). Furthermore, understanding when these activities may not fully counteract the negative effects of prolonged sitting is crucial. Exploring how these interventions function in real-world environments (e.g., workplace, home) alongside controlled settings is necessary, particularly for diverse populations such as women, individuals with obesity, and those in poor health. Additionally, exploring the physiological and psychological factors that might influence adherence and effectiveness, such as motivation and stress levels, will contribute to tailoring interventions more effectively.
- Diverse populations and contextual tailoring: Large-scale, multicenter RCTs are needed to account for potential confounding and/or moderating factors such as ethnicity, geography, medication status, and demographic variables like income and education. These studies should include diverse populations, such as individuals with disabilities

(e.g., those unable to perform lower limb exercises), patients with various conditions (e.g., diabetes, hypertension), and people across different age groups (e.g., children, adolescents, young adults, middle-aged adults, and older adults). Additionally, studies should involve women at various stages, including premenarcheal, premenopausal, and postmenopausal women. This approach would enhance the generalizability of the research and ensure that interventions are effective across diverse contexts. Additionally, research should focus on when and how individuals engage in sedentary behavior and SBAE in specific contexts (e.g., timing, meal-type/timing,[280,281] stress levels, energy intake, or sleep deprivation). Finally, considering that some workers might have high occupational PA and the ongoing debate about whether higher occupational PA benefits health,[282−286] it is crucial to explore whether SBAE can enhance health in workers with high occupational PA. This would expand the potential applications of SBAE and offer valuable insights into its role in improving health outcomes for individuals with high occupational PA. Tailoring interventions to personalized circumstances will improve both effectiveness and outcomes.

- Exploring non-traditional cardiometabolic risk markers and mechanisms: Future research should aim to identify non-traditional cardiometabolic risk markers (e.g., biomarkers of inflammation and muscle metabolism) and explore the cellular, molecular, and organ-specific mechanisms influenced by both acute and habitual sedentary behaviors. Understanding how local factors (such as muscle and fat tissue) and systemic factors (like metabolism and inflammation) interact is critical for unraveling the complex pathological consequences of sedentary lifestyles. Simultaneously, a deeper understanding of the behavioral and biological determinants or modulators of SBAE is essential. Furthermore, the acute responses and long-term beneficial adaptations of cancer biomarkers to SBAE[291] should be thoroughly explored to enhance the cancer-suppressive effects of exercise.[287,288] This knowledge can ultimately optimize the benefits of SBAE as part of an overall strategy to mitigate the effects of sedentary behavior.
- Research paradigm: A systematic research paradigm should be adopted, beginning with cross-sectional studies to reveal correlations, followed by longitudinal studies to establish causality. Mixed-methods studies will evaluate the feasibility and real-world applicability of interventions, particularly in targeted populations (e.g., patients with T2D). Longitudinal intervention studies should be conducted to assess the long-term effects of SBAE on various health markers, such as metabolic health, cardiovascular function, and quality of life.
- Detailed reporting of intervention variables and feasibility data: Accurate documentation of intervention variables, such as when SBAE is performed throughout the day (e.g., once every 2 h), is essential. Researchers should also report dropout rates, adherence and completion rates, and any adverse events in detail to enhance the transparency and reproducibility of the research. Meanwhile, dietary conditions should be objectively monitored and quantified, especially given their independent acute and long-term effects on markers such as metabolic health. Integrating semi-structured interviews into longitudinal SBAE interventions would yield valuable insights into behavioral determinants of adherence. Additionally, it is important to consider interviewing participants who drop out of the intervention rather than only surveying those who complete it. This approach can help evaluate the effectiveness of the intervention and identify barriers to long-term adherence.
- Balancing methodological rigor and real-world feasibility: Future research should prioritize a stricter methodological design while ensuring that studies maintain real-world applicability. While it is crucial to minimize bias through measures such as preregistration of trial protocols, transparent randomization, monitoring of PA and nutrition, and the use of triple-blind designs (for implementers, evaluators, and analysts), these efforts must be balanced with the need for more practical studies. This includes investigating the responses of individuals with lower exercise motivation and adherence to SBAE in real-world settings, especially considering the barriers individuals face in their daily routines (e.g., work schedules and family obligations).

Fig. 3 outlines urgent future research directions in 5 key areas: quantitative monitoring of SBAE, study populations, intervention prescriptions, application effects, and practical translation.

10. Conclusion

This summary of research on SBAE over the past 3 decades represents the most extensive and comprehensive integration of global evidence to date. Additionally, it marks the first international expert consensus on the operational definition, program classifications, health promotion effects, practical applications, and future research directions related to SBAE. The consensus offers insights for the public and fitness professionals while providing robust evidence for researchers and policymakers to help optimize the application of SBAE. We recommend that future research adhere to the operational definitions and protocol classifications of this consensus. SBAE shows potential as an emerging strategy to address the challenges of insufficient PA and sedentary behavior while promoting improvements in national health literacy. Significantly, SBAE should complement rather than compete with traditional structured exercise; we encourage the public to engage in structured, continuous PA options when feasible, while also incorporating SBAE throughout the day. Finally, while a consensus has been reached, the scientific promotion and implementation of SBAE still require further refinement through high-quality evidence. Continued research efforts should focus on eliminating barriers to implementation, particularly in policy development, environmental support, and public health promotion. Policymakers should consider integrating SBAE into national health strategies, and further attention should be given to the tools and environments that make such interventions feasible to ensure the transition from expert consensus to public consensus.

Author's contributions

YL proposed and designed the overall research topic and supervised the execution of the project; MY drafted the original manuscript and prepared all figures and tables; PC and LM jointly supervised the research design, provided strategic and constructive suggestions throughout the study, and approved the final manuscript. All members of the author participated in the online consensus survey and/or provided substantial intellectual feedback, including critical revisions and suggestions on the manuscript, figures, and tables. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Declaration of competing interest

The authors declare that they have no competing interests. Given their roles as Editor-in-Chief, Deputy Editor-in-Chief, and Editorial board members, Peijie Chen, Lijuan Mao, George P. Nassis, and Weimo Zhu had no involvement in the peer review of this article and had no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor.

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Supplementary materials

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