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Perspective

The Q4-Mood Framework: A Stratified Movement Intervention Model for Late-Life Depression

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ABSTRACT: Late-life depression (LLD) represents a significant public health challenge within global ageing societies, substantially impacting older adults' quality of life and health status. Despite the widespread application of pharmacological and psychotherapeutic interventions, their efficacy is frequently constrained by individual variability and treatment adherence issues. In recent years, exercise behaviour intervention (MBI) has garnered increasing attention as a low-side-effect, highly accessible therapeutic approach. This study proposes an innovative exercise intervention model—the Q4-Mood framework—aimed at stratifying older adults based on their motivation (self-efficacy) and physical capacity (fitness level), providing a personalised, progressive exercise intervention pathway for each stratum. The Q4-Mood framework categorises exercise interventions into four tiers: Sedentary Behaviour Interruption (SB), Exercise Snacks (ES), Physical Activity (PA), and Regular Exercise (RE). This model not only enhances exercise adherence among older adults but also effectively alleviates depressive symptoms. Through personalised intervention strategies, it facilitates dual physical and psychological improvements. Through a systematic review of existing exercise intervention studies, this paper demonstrates the Q4-Mood framework's potential in treating geriatric depression and offers novel perspectives for future research. We contend that Q4-Mood provides a comprehensive, flexible, and actionable framework for geriatric depression interventions, paving the way for its future application in clinical practice.

Keywords: late-life depression, movement intervention, regular exercise, physical activity, exercise snacks, sedentary breaks

1. Introduction

Depression is highly prevalent and severely harmful among the elderly worldwide. It is estimated that approximately one-fifth to one-third of individuals aged 60 and above experience varying degrees of depressive symptoms [1]. Late-life depression (LLD) not only impairs quality of life, increases physical functional decline, and healthcare utilization, but also significantly elevates the risk of mortality. It has become a critical public health issue that requires immediate attention in aging populations. However, LLD is often not diagnosed and treated in a timely manner. Statistics show that nearly half of LLD cases are not diagnosed in primary care settings (Mental Health & Aging Facts | Psychiatry | U of U School of Medicine). This is largely due to the atypical and concealed nature of LLD symptoms: unlike younger patients, older adults are less likely to directly report feelings of sadness, often presenting with somatic complaints, memory decline, or changes in sleep and appetite, which may be misinterpreted as normal aging or physical illness. Additionally, LLD frequently coexists with chronic physical diseases, forming a vicious cycle where one exacerbates the other. Research shows that elderly patients over 70 years old, especially those with severe chronic diseases like stroke, coronary artery disease, Parkinson's disease, and Alzheimer's disease, have a much higher incidence of depression compared to the general population (for instance, depression occurs in 30–60% of stroke patients) [2]. These characteristics

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make LLD prone to being overlooked or misdiagnosed, presenting several challenges in its prevention and treatment.

There are diverse intervention methods for LLD, including pharmacotherapy, psychotherapy, and social support interventions. Antidepressants (such as SSRIs) are the first-line treatment for LLD, but attention must be paid to the risks of adverse drug reactions in the elderly, and their effectiveness is not always reliable. Studies have shown that nearly half of the elderly patients receiving pharmacotherapy for LLD do not achieve full symptom remission. Psychotherapy (such as cognitive behavioral therapy and interpersonal therapy) is also effective for the elderly population, but cognitive impairment, difficulty in accessing resources, and other factors may limit its application [3]. Given the limitations of both pharmacological and psychological interventions, "lifestyle interventions" have gained attention in recent years, with physical activity interventions being an important approach to preventing and treating LLD due to their high safety and wide-ranging benefits. A large body of epidemiological evidence suggests that maintaining appropriate MBI over the long term can reduce the risk of depression. For example, a global prospective study that included 3 million adults found that regular moderate-to-high-intensity physical activity reduced the risk of depression by about 31%. In elderly individuals, sufficient exercise is also significantly associated with a reduction in depressive symptoms. Furthermore, clinical trials and meta-analyses on exercise interventions have shown clear antidepressant effects. A recent network meta-analysis [4] that included 47 RCTs on elderly exercise interventions showed that walking, aerobic exercise, Tai Chi, and strength training were all effective in improving LLD symptoms, with "walking" being evaluated as the most effective type of exercise. Another study that consolidated 15 RCTs reported that mind-body exercises (such as yoga and Tai Chi) had large effect sizes (SMD values ranging from 0.9 to 1.4) for improving LLD, while aerobic and resistance exercises also showed significant advantages compared to controls. Compared to pharmacotherapy, physical activity produces almost no side effects and also improves cardiovascular function, muscle strength, and balance, thereby enhancing the overall health of the elderly. Therefore, incorporating physical activity into the comprehensive management of LLD not only directly alleviates psychological symptoms but also helps break the depression-physical illness cycle, making it an economically effective adjunctive treatment. It is important to note that "physical activity" itself is not a singular, homogeneous concept (Physical activity, www.who.int/news-room/fact-sheets/detail/physical-activity). Based on purpose and form, it can be further divided into several types, as shown in Table 1:

Table 1. Definitions, needs, and examples of the four intervention types.

	SB	PA	ES	RE
Description	Break long periods of sitting with short, low-intensity activity every 30–60 minutes	Low to moderate-intensity physical activity, such as walking or household chores, accumulated weekly for overall health	Break exercise into multiple short, high-intensity bouts throughout the day	Structured, moderate to high-intensity exercise, such as aerobic or resistance training, performed at fixed frequency and duration.
Intensity	Low	Low	High	High
Ability	Low	Low	High	High
Motivation	Low	High	Low	High
Frequency	1–3 minutes every 30–60 minutes	600–800 MET-min per week	1–3 minutes per session, 6–10 sessions per day	3–5 times per week, 30 minutes or more per session
Examples	Standing, walking	Walking, household chores	Climbing stairs, high knee lifts	Aerobics, resistance training

The physiological goal of SB is to support individuals with limited physical ability or those who spend extended periods sitting. PA is aimed at individuals with some physical ability who can sustain daily activities. ES is designed for individuals who can engage in short bouts of high-intensity exercise, while RE targets individuals with higher physical ability who can engage in structured exercise.

First, regular exercise (RE), which refers to planned, structured, and repetitive physical training with controlled intensity and fixed frequency, such as 30 minutes of moderate-intensity aerobic exercise or resistance training three times a week [5]. Second, broad physical activity (PA), which includes all bodily movements performed in daily life, such as household chores, leisure walking, climbing stairs, gardening, and other recreational activities. PA emphasizes integrating exercise into daily routines, without focusing on high intensity or professional expertise. Even low- to moderate-intensity activities, if performed frequently and consistently, can provide health benefits (Physical activity, www.who.int/news-room/fact-sheets/detail/physical-activity).Third, the recently popular "exercise snacks" (ES) concept, where exercise sessions are broken into multiple short bursts throughout the day, similar to eating snacks. Each ES usually lasts 1–3 minutes of moderate-to-high-intensity activity (such as jogging in place or a set of quick squats), and repeated sessions can accumulate to the same total exercise volume as continuous activity. The World Health Organization's latest guidelines now emphasize that "any physical activity counts," no longer requiring each activity to last at least 10 minutes, and encouraging frequent but short bouts like ES. For elderly individuals who cannot spare a continuous block of time for exercise, ES provides a flexible option that increases the total daily activity while avoiding the fatigue or discomfort of prolonged exercise, potentially improving intervention sustainability [6]. Lastly, sedentary breaks (SB) refer to regularly standing or moving for a few minutes during prolonged periods of sitting to interrupt sedentary behavior. For example, standing or walking for 2–3 minutes every 30 minutes of sitting [7]. Reducing sedentary behavior itself is considered an important goal for healthy aging. The latest WHO guidelines explicitly recommend that all age groups should "limit sedentary time" and take as many activity breaks as possible. Sedentary breaks, as a low-barrier intervention, only require simple standing or moving to gain health benefits, making it particularly appealing for elderly individuals who are unwilling or unable to participate in regular exercise. While this behavior was previously seen as a "transitional" or trivial activity, increasing evidence suggests that frequent SB not only improves metabolic markers and inflammatory states in the elderly but also helps enhance subjective mood and well-being (Fig. 1).

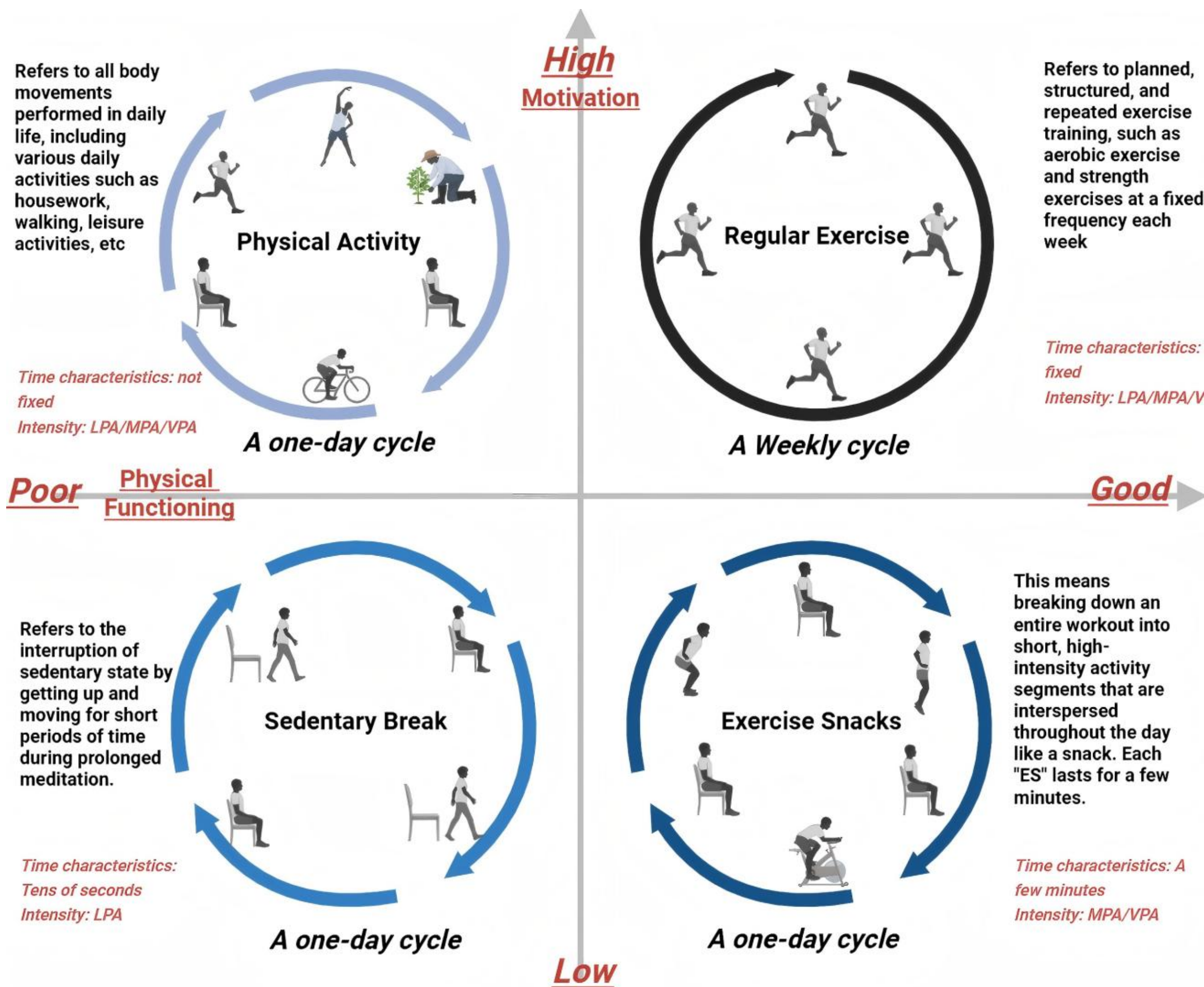

Figure 1. Q4-Mood Quadrant Model: Motivation × Capacity–based Stratification and Step-up Pathways. LPA: light intensity physical activity, MPA: moderate intensity physical activity, VPA: vigorous intensity physical activity.

As mentioned earlier, the core idea of this study is to propose a comprehensive, flexible model that allows different elderly populations to find their corresponding position in the model and apply the corresponding intervention strategy to manage LLD. The Q4-Mood framework is an exercise prescription model based on the motivation and physical capacity of elderly individuals, aiming to help elderly populations effectively alleviate depressive symptoms through personalized exercise interventions. The core concept of the framework is to categorize elderly individuals based on two dimensions: motivation (self-efficacy) and physical function (fitness level), and to provide an exercise intervention form suitable for each group's capacity and needs. Specifically, the Q4-Mood framework divides exercise into four types: SB, ES, PA, and RE. Each exercise type corresponds to different physical capacities and motivation levels, from the most basic sedentary breaks to progressive exercise snacks, daily activities, and regular exercise, ensuring that every elderly person can start exercising at their current capacity and gradually increase exercise intensity as their physical strength improves. This framework not only increases adherence and sustainability in elderly exercise interventions but also provides practical solutions based on individual needs, thus offering a personalized, scientific pathway for managing LLD.

Given this background, this study aims to comprehensively analyze and compare the effects of regular exercise, daily physical activity, exercise snacks, and sedentary breaks on LLD. We will systematically review relevant literature to explore the extent of these interventions' effects on LLD symptoms and their potential mechanisms, focusing on the differences in adherence, physiological and psychological effects, and applicable populations. By summarizing the advantages and limitations of each, we hope to provide evidence for the development of a classification intervention strategy for LLD and offer valuable reference and suggestions for researchers and clinical practitioners when selecting exercise interventions for different elderly populations.

2. Regular Exercise and Its Research Evidence

RE typically refers to a healthy lifestyle involving sustained physical activity at a certain frequency and intensity. For middle-aged and older adults, regular exercise can partially reverse the physiological aging process, enhance the body's reserve functions, and serve as an effective means of preventing and assisting in the treatment of depression. Therefore, regular exercise is widely recognized for its significant benefits to both physical and mental health, including reducing the risk of depression (Fig. 2).

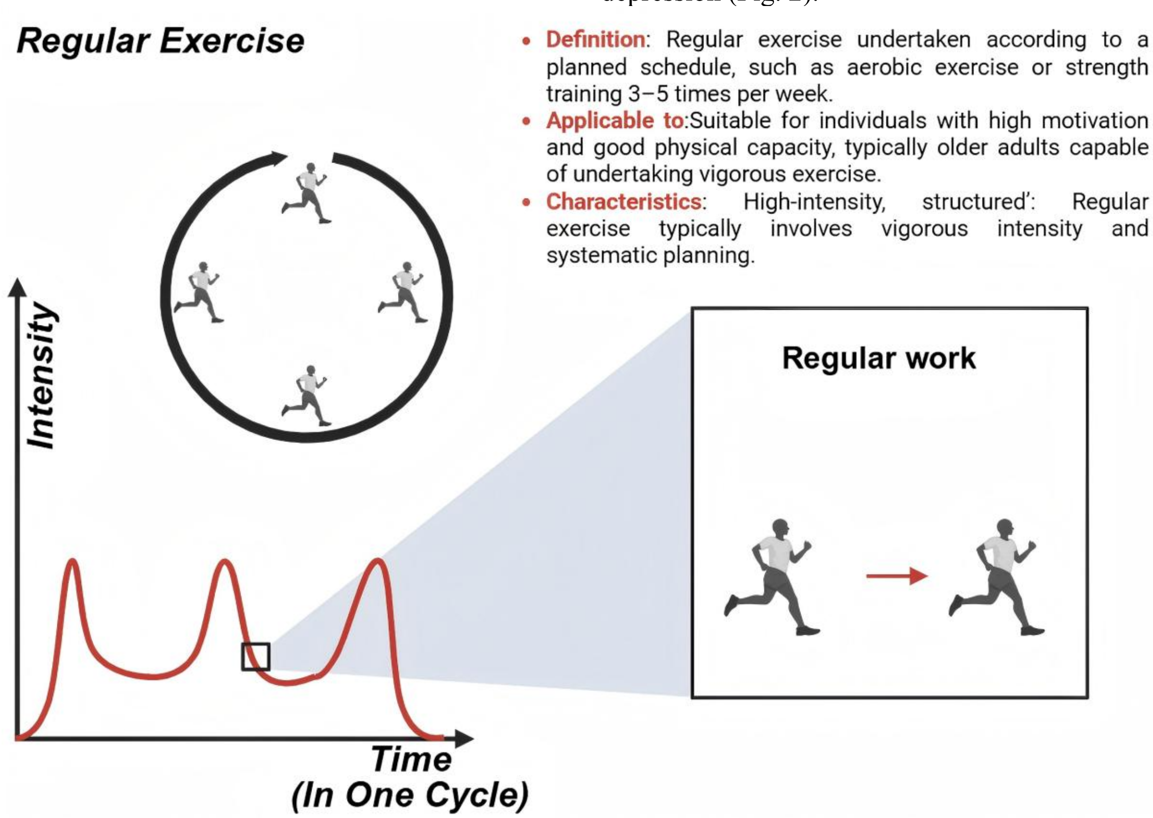

Figure 2. Regular Exercise Prescription: Weekly Layout of Intensity–Frequency–Time and Modalities.

In elderly populations, the effectiveness of RE in alleviating depression has been supported by a range of evidence from early to recent studies. Early systematic reviews and meta-analyses involving participants aged 60 and older showed a moderate overall effect size (SMD ≈ −0.34), consistent regardless of whether participants were grouped based on clinical diagnosis or symptom scales. This finding provides direct evidence for the notion that "structured exercise tailored to ability can reduce the severity of depression." Updated meta-analyses focusing on LLD (Late-Life Depression) RCTs show significantly larger effect sizes, indicating that moderately intense, group-based, mixed-supervision programs often yield better results, suggesting that prescription design and progression may determine clinical outcomes [8]. A head-to-head comparison of various exercise modalities by Schuch et al. in a network meta-analysis showed that aerobic, resistance, and mind-body exercises (such as Tai Chi and yoga) produced similar overall effects, with no single modality demonstrating stable superiority. This aligns with the clinical approach of prioritizing accessibility and preference in exercise prescriptions. This conclusion has been replicated across different databases and review platforms, enhancing its generalizability and transparency [9]. In a more clinically applicable network meta-analysis by Miller et al., 47 RCTs (n=2895) revealed that walking ranked highest in overall outcomes, and in terms of dosage, aerobic exercise at approximately 1000 MET·min/week achieved the best improvement in depression, while 600–970 MET·min/week reached the clinical significance threshold. Notably, walking at as low as 650 MET·min/week showed significant benefits, offering a "low-barrier starting point" and "gradual progression" approach for elderly individuals with functional limitations or low initial motivation [10]. Classic research by Tang et al. found that high-intensity progressive resistance training (PRT) yielded higher response rates in LLD patients compared to lower-intensity PRT and standard care, with improvements in muscle strength correlating positively with reductions in depression, suggesting that safe management of intensity and progression can bring additional benefits [3]. Furthermore, integrating exercise with medication also proves viable in managing LLD, as demonstrated by Singh et al., who found that Tai Chi, as a mind-body exercise, enhanced the effects of escitalopram, further improving symptoms and functional outcomes [11]. Lastly, an authoritative review covering different age groups and comorbidity spectra confirmed that walking, jogging, yoga, and strength training have good effects and tolerance in treating depression, being less sensitive to comorbidities, and offering flexibility in prescribing for elderly patients, which strengthens the external validity for elderly populations [4]. Our umbrella review also shows that RE can significantly reduce depression in middle-aged and elderly populations (SMD: −0.70, 95% CI: −0.83 to −0.57, $P < 0.001$, I2 = 49.3%, see supplementary materials).

Why does regular exercise exert its antidepressant effects? The underlying mechanisms involve complex physiological and biochemical pathways. First, exercise triggers a series of neuroendocrine changes beneficial to emotional regulation. During exercise, the brain releases endorphins, endogenous opioid-like substances that enhance feelings of pleasure, alleviate pain and discomfort, and promote positive emotional experiences [12]. Exercise also promotes the central release of neurotransmitters such as serotonin, norepinephrine, and dopamine, which play key roles in alleviating depressive moods and regulating emotions. Additionally, regular physical activity can reduce the excessive stress response of the hypothalamic-pituitary-adrenal (HPA) axis, as evidenced by lower cortisol levels at rest, improving the body's threshold for responding to stress. Stabilizing HPA axis function helps reduce chronic stress-related brain damage, thus mitigating the physiological burden associated with depression [12].

Secondly, neurotrophic and plasticity mechanisms also play an important role in exercise's antidepressant effects. Regular exercise significantly increases brain-derived neurotrophic factor (BDNF) levels, a protein that promotes neuronal survival, growth, and synaptic plasticity, which plays an important role in the occurrence of depression. Research has confirmed that both acute and long-term exercise can increase central and peripheral BDNF levels, benefiting the formation of new neurons in brain regions such as the hippocampus and promoting neural network remodeling [13]. This is particularly crucial for the middle-aged and elderly population, as the aging process is accompanied by reduced neuroplasticity and accelerated neurodegenerative changes. The neurotrophic pathways activated by exercise help delay the neurodegenerative processes associated with aging.

Thirdly, anti-inflammatory effects and improvement in overall metabolic health are also potential mechanisms by which exercise alleviates depressive symptoms. Depressed individuals are often observed to have mild chronic inflammation (e.g., elevated pro-inflammatory cytokines), which is believed to be associated with the onset and development of depression. Regular exercise modulates immune function and reduces systemic inflammation. Moderate exercise promotes the release of anti-inflammatory cytokines and reduces pro-inflammatory mediators, counteracting the biological triggers of depression. Additionally, exercise improves cardiovascular function and brain blood supply, providing more oxygen and nutrients to the brain, thereby enhancing metabolic levels in brain tissue [14]. Good cardiovascular health and brain perfusion contribute to better emotional regulation and cognitive function, producing positive effects on alleviating depressive symptoms.

Although this study and previous literature clearly show that regular exercise provides significant benefits for LLD, there are still some shortcomings that need to be addressed in future research. First, there is considerable variation across studies in terms of exercise type, intensity, frequency, and duration, and subgroup results in meta-analyses are not entirely consistent. This prevents clear conclusions regarding the optimal "exercise prescription" parameters for LLD. For example, we found that >12 weeks of moderate-to-high-intensity aerobic exercise is most effective, but practical application must consider the adherence and safety of elderly individuals. Some studies do not report detailed exercise prescriptions or patient adherence, limiting the interpretability of the results. Therefore, future research should focus on optimizing exercise intervention programs, comparing the relative effects of different exercise modalities (aerobic, resistance, Tai Chi, yoga, etc.), and exploring the dose-response relationship between intensity and duration. Second, many existing studies have intervention durations ranging from several weeks to months, and there is a lack of long-term follow-up on the effects of exercise interventions. Depression is a chronic disease prone to relapse, and it is still uncertain how strong the maintenance effects of exercise interventions are and whether symptoms will rebound after cessation of exercise. Furthermore, elderly individuals face realistic challenges in maintaining long-term regular exercise, such as chronic illnesses and insufficient motivation for exercise. In fact, some studies report that LLD patients have low attendance rates during exercise interventions, with a high dropout rate. This suggests that more support is needed to enhance exercise adherence in elderly patients during real-world implementation. Third, most current studies group middle-aged and elderly individuals together, but differences in physical functions and the causes of depression across age groups (e.g., "young elderly" aged 60–75 vs. "older elderly" over 75) may lead to different exercise effects. There is insufficient stratified evidence in this regard. Moreover, many LLD patients have comorbid chronic physical diseases or cognitive decline, but research on the specific effects and considerations of exercise interventions for these individuals with multiple comorbidities is lacking. Finally, although we have outlined several possible pathways for exercise to alleviate depression, direct research on the mechanisms in elderly populations is still scarce.

In conclusion, introducing regular exercise interventions for middle-aged and elderly individuals with LLD is feasible and beneficial. This study consolidates high-level evidence from RCT-based meta-analyses, providing strong support that regular physical exercise can effectively alleviate depressive symptoms and improve mental health in middle-aged and elderly populations. Given that exercise interventions are safe, have few side effects, and provide multiple health benefits, we recommend incorporating exercise as an essential part of the comprehensive management of LLD.

3. Physical Activity and Its Research Evidence

PA refers to any movement that involves skeletal muscle contraction, including household chores, walking, commuting, recreational activities, and other daily activities. Unlike structured exercise training, PA typically involves low-to-moderate intensity and emphasizes incorporating activity into daily life for sustained periods. For many elderly individuals with limited mobility or a lack of exercise habits, increasing daily physical activity (such as walking more or doing household chores) is a practical approach. Although its intensity may be lower, the cumulative effect of consistent activity is significant (Fig. 3).

It is essential to clarify and emphasize the distinction between RE and PA, as some non-experts may confuse the two. PA can be classified into three types: occupational PA (activities performed during work or household chores), commuting PA (walking or cycling for transportation), and recreational PA (leisure activities like sports or swimming). PA refers to any natural activity that engages skeletal muscles, whereas RE requires more intentional effort, time commitment, and motivation for non-natural exercise routines. Research has indicated that adherence to RE is generally lower for older adults compared to PA. In a 6-month supervised exercise intervention, only about 42% of elderly participants completed all prescribed sessions, attending an average of 18.9 out of 48 sessions [15].

In RE studies, researchers typically focus on using RE to intervene in depression among elderly individuals. In contrast, the goal of PA research is to observe its impact on depression risk in elderly populations. Numerous studies confirm that higher levels of PA are associated with lower depression risk in older adults. A meta-analysis of 49 studies indicated that PA offers protective benefits against depression in the elderly (adjusted odds ratio = 0.79, 95% CI = 0.72–0.86), and this effect is consistent across different regions, irrespective of ethnicity or geography [16].Longitudinal cohort data from multiple countries corroborate this, with studies from CHARLS showing that PA not only provides protection against LLD risk but also improves cognitive scores. Notably, a 9-year follow-up study found that elderly individuals who transitioned from low PA to moderate-to-high PA experienced significant reductions in LLD [17]. Evidence from ELSA further supports the idea that higher PA adherence correlates with a lower risk of LLD, highlighting that greater PA is associated with reduced LLD severity and risk [18].Similarly, SHARE data reveals an interesting finding: cross-lagged analyses show that higher PA reduces LLD, but conversely, higher LLD leads to lower PA levels in older adults, reinforcing ELSA's conclusions about adherence [19].

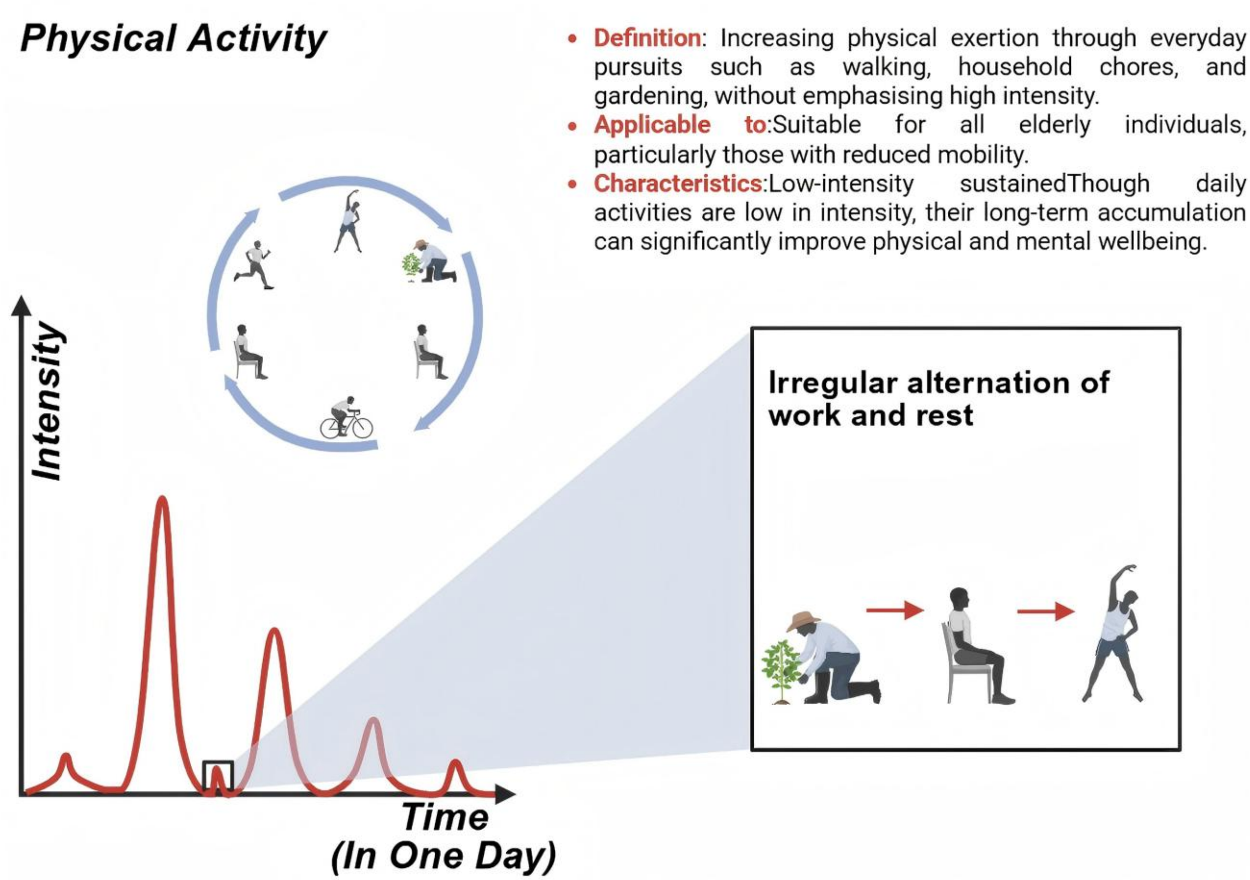

Figure 3. Daily Physical Activity Pattern: Weekly Distribution and Accumulated Dose of LPA–MPA.

Studies suggest that various types of physical activity can mildly increase neurotrophic factors like BDNF, IGF-1, and VEGF, promoting neuroplasticity and reducing apoptosis [20]. Although the intensity of a single activity is lower than that of aerobic exercise, the cumulative long-term effects are significant. Consistent moderate-intensity activity plans can reduce serum CRP, IL-6, and other pro-inflammatory cytokines while increasing anti-inflammatory cytokines like IL-10 [20]. Furthermore, daily physical activity can reduce oxidative stress and repair vascular endothelium, improving cerebrovascular function, which has protective effects against vascular-related LLD. PA also has a mild regulatory effect on the HPA axis, lowering resting cortisol levels and enhancing stress tolerance. Regarding autonomic nervous function, regular physical activity can improve heart rate variability (HRV), enhancing parasympathetic tone and thus improving the balance between sympathetic and parasympathetic systems [21]. At the neurotransmitter level, light activity slightly increases dopamine and serotonin release while promoting endorphin secretion, which stabilizes mood and enhances well-being. It's important to note that as individuals age, their responsiveness to exercise stimuli decreases. Therefore, maintaining continuous PA is crucial for preserving neurofunction. Overall, general PA through moderate upregulation of neurotrophic factors and suppression of inflammation can help alleviate LLD to some extent [22].

Despite the clear evidence supporting the positive impact of PA on LLD, several issues remain. First, the measurement methods for PA are subjective. Unlike RE studies that measure the effects of exercise on LLD, many PA studies rely on subjective self-report methods, such as the IPAQ questionnaire. While convenient, this approach is prone to recall biases and inaccuracies. Second, there are issues with measuring the intensity or amount of PA.

While the IPAQ provides a method for calculating PA volume, it still carries the potential for inaccurate results. Future studies should recommend more objective methods, such as accelerometers or smartwatches, to provide more accurate assessments of PA levels and minimize subjective biases. Third, more personalized PA recommendations are needed. While large-scale studies offer valuable insights, they may overlook individual differences, particularly in studies that exclude confounding factors. Future research should delve deeper into exploring PA interventions for individuals with varying lifestyle habits or health-related factors, such as smoking, drinking, diet, or comorbidities, to offer richer and more tailored PA strategies instead of one-size-fits-all recommendations.

In conclusion, PA is a low-barrier, highly accessible non-pharmacological intervention with great potential in the prevention and management of LLD. Compared to drug treatments, PA has virtually no side effects and provides multiple health benefits, such as improving cardiovascular metabolism, enhancing balance, and reducing the risk of chronic diseases. Numerous studies have demonstrated that incorporating PA as part of a comprehensive treatment strategy is both beneficial and feasible. Appropriate PA can not only alleviate LLD symptoms but also improve the quality of life and physical health of elderly individuals. As such, there is increasing support for the inclusion of PA as a routine intervention in LLD management guidelines. Looking ahead, there should be a stronger focus on advocating for and supporting elderly people to engage in physical activity, creating an environment and culture that fosters sustained participation. By leveraging coordinated efforts across individuals, families, and society, we can unlock the preventive and therapeutic potential of physical activity, paving the way for safer, more widespread, and sustainable approaches to LLD prevention and control.

4. Exercise Snacks and Its Research Evidence

ES is an innovative form of exercise that involves breaking up a continuous workout into multiple short bursts of activity, much like "snacking" throughout the day. Each ES typically lasts a few minutes (e.g., climbing stairs or jogging in place for 1–2 minutes), and these short bursts accumulate to provide the same total exercise benefit as continuous activity. Notably, the World Health Organization (WHO) has included ES in its guidelines for breaking sedentary behavior. Previously, the guideline recommended at least 10 minutes of continuous physical activity or 150 minutes of physical activity per week. However, the introduction and promotion of ES now offer an alternative for those who cannot commit to extended sessions of exercise (Fig. 4).

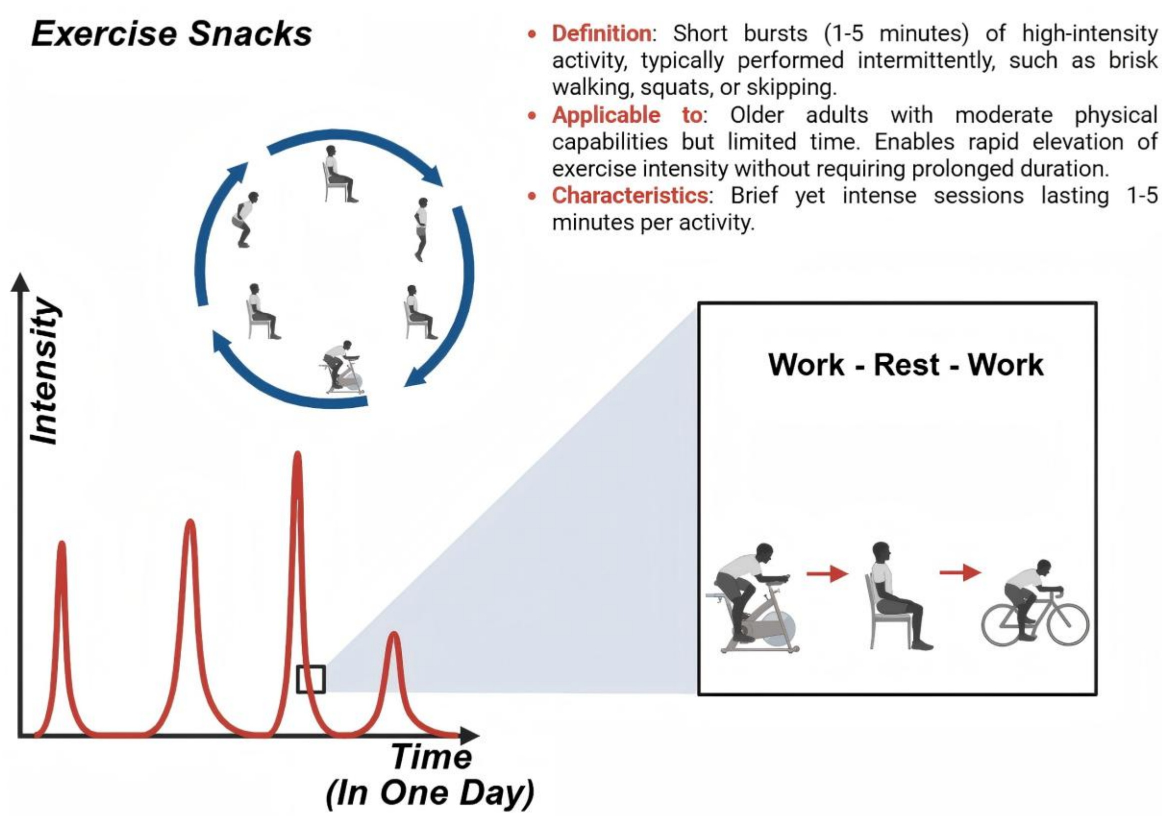

Figure 4. Exercise Snacks Pattern: Time–Intensity–Frequency Map of Brief MHI Bouts Across the Day.

As previously noted, the detrimental impact of sedentary behaviour among older adults on health-related outcomes cannot be overlooked. Breaking sedentary patterns and maintaining physical activity levels is particularly crucial for healthy ageing. Although the preceding section found that participation in RE or PA can improve depressive symptoms in older adults, it must be acknowledged that there are significant differences in physical function between older adults and middle-aged or younger individuals. Physiological ageing may lead to discomfort during concentrated, sustained exercise or physical activity, resulting in poor adherence. This may prevent sustained participation and thus hinder the realisation of associated benefits. A recent meta-analysis examining older adults' perceptions and acceptance of exercise programmes revealed [23], middle-aged and elderly individuals with reduced physical capabilities (underlying mobility impairments, diminished motor skill acquisition capacity, and lower health literacy) demonstrate greater receptivity to ES than conventional forms of RE or PA. This is primarily attributable to the ‘exercise opportunities’ provided by ES (such as familial support, rapid integration into exercise scenarios, and modern information technology support) and the ‘exercise motivation’ it fosters (enjoyable physical and mental experiences, immediate sense of accomplishment, and enhanced self-efficacy). In other words, compared to “blocked” exercise sessions, middle-aged and older adults may be more inclined towards “fragmented” exercise support.

After addressing the acceptance of ES among older adults, it is crucial to discuss its specific effects on LLD. A 12-week remote Tai Chi ES study found that participants had higher acceptance of ES compared to traditional RE, and the dropout rate was lower. After completing the 12-week intervention, participants reported improved self-efficacy and higher levels of joy, happiness, and motivation, suggesting that depression is a potentially modifiable factor [24]. Similarly, a multinational collaborative study also demonstrated the benefits of ES. Following the experimental period, interviews with participants revealed that the overwhelming majority held a highly positive attitude towards ES. Participants unanimously agreed that this ES delivered unprecedented levels of pleasure, with seamless integration into the group facilitating the restoration of lost interpersonal connections. Crucially, it induced a profound sense of mental relaxation, eliminating anxiety and preoccupation with trivial matters both during and after the session. Moreover, this format enabled them to engage anytime, anywhere, eliminating the perceived difficulty and procrastination associated with committing to extended periods for RE [25]. Indeed, anxiety among the elderly, coupled with diminished interpersonal interactions and reduced communication, constitutes a significant risk factor for LLD. The fact that ES ameliorates these aspects strongly supports its beneficial impact on LLD. The most recent public health event highlighting isolation's direct impact on depression in older adults was the lockdown policies during the COVID-19 pandemic. Relevant research indicates that anxiety about the pandemic itself, coupled with the social isolation resulting from home confinement, contributed significantly to LLD in this demographic. An ES study conducted during this period revealed that merely four weeks of remote ES improved the psychological state of these older adults. They developed a more balanced perspective on the pandemic and health concerns, Participants reported experiencing pleasure and relaxation during ES sessions, alongside reduced anxiety. This outcome has been confirmed to demonstrate a causal relationship. 26].The final point to address is the well-established strong correlation between cognitive impairment and LLD. A 28-day ES study recruiting elderly individuals with mild cognitive impairment from a cognitive clinic demonstrated that ES not only improved their cognitive function but also enhanced their perception of the exercise itself and their experience of participating in it [27].

In-depth analysis of the physiological mechanisms behind ES and its impact on LLD suggests that the effects are likely linked to the repeated activation of exercise-related neural and metabolic pathways. A study proposed that several 3–5-minute stair climbs during workdays, as part of ES, significantly increased BDNF and other neurotrophic factors, similarly to RE. This repeated stimulation also triggers the release of adrenaline and endorphins, rapidly improving mood and vitality. Despite the short duration of each session, the cumulative effect is substantial [28]. A meta-analysis of similar intermittent exercises showed a decline in serum CRP and IL-8 levels, suggesting that ES may have a suppressive effect on chronic inflammation [29]. Additionally, short bursts of high-intensity activity significantly increase cerebral blood flow and metabolic rate, improving neuronal oxygen supply and energy utilization, which promotes neuroplasticity [30]. It is worth noting that ES offers a feasible exercise option for older adults with limited mobility or endurance. Short, efficient exercises can provide multiple exercise benefits without causing excessive fatigue. These brief physiological changes can instantly enhance brain function and mood.

However, there are still some unresolved issues regarding ES. First, most studies have conducted ES in controlled settings such as labs or homes, and there is limited research on its application in open environments (e.g., public sports venues or outdoor areas). Future research should focus on examining the applicability of

ES in these unsupervised settings. Second, the standardization and population promotion of ES remain unclear. As a novel exercise model, ES is yet to be precisely recommended for different age groups or stages of illness. Further exploration and research are needed to tailor ES for specific populations. Notably, ES is not restricted to high-intensity activities. For instance, Tai Chi-based ES, a moderate-intensity form of ES, can be highly beneficial for elderly populations. Future research should focus on designing appropriate ES intensities based on the physiological characteristics of specific groups. Finally, there is limited exploration of the precise physiological mechanisms of ES in improving LLD. Future studies can delve deeper into how ES works, using animal models to explore molecular mechanisms, which could enrich evidence for establishing clinical guidelines. In conclusion, ES, as a fragmented, high-frequency, short-duration exercise model, has proven its potential positive effects on LLD in several empirical studies. Compared to traditional continuous exercise, ES is more easily accepted by older adults, showing higher adherence and allowing integration into daily life. The immediate enhancement of self-efficacy and social participation provided by ES is a critical psychological mechanism in alleviating depression and anxiety. ES not only offers a feasible alternative for elderly individuals unable to engage in long-duration concentrated exercise but also presents a simple, enjoyable, and sustainable approach for non-pharmacological intervention for LLD.

5. Sedentary Breaks and Its Research Evidence

SB refers to the act of staying seated for extended periods and the regular interruption of this inactivity by short bursts of physical activity. For instance, standing up and moving for 30 seconds to a few minutes every 30 minutes of sitting can help break prolonged sedentary states. Traditionally, such brief interruptions were not considered exercise or interventions but rather viewed as transitional or trivial behaviors between bouts of sitting. However, this overlooked aspect of SB has become its strength, offering a simple, accessible method to break sedentary behavior. For those who are unwilling to engage in regular exercise (RE), SB provides an easily adopted alternative, requiring only a minimal effort to stand up or move, thus offering health benefits even to those with limited physical activity (Fig. 5).

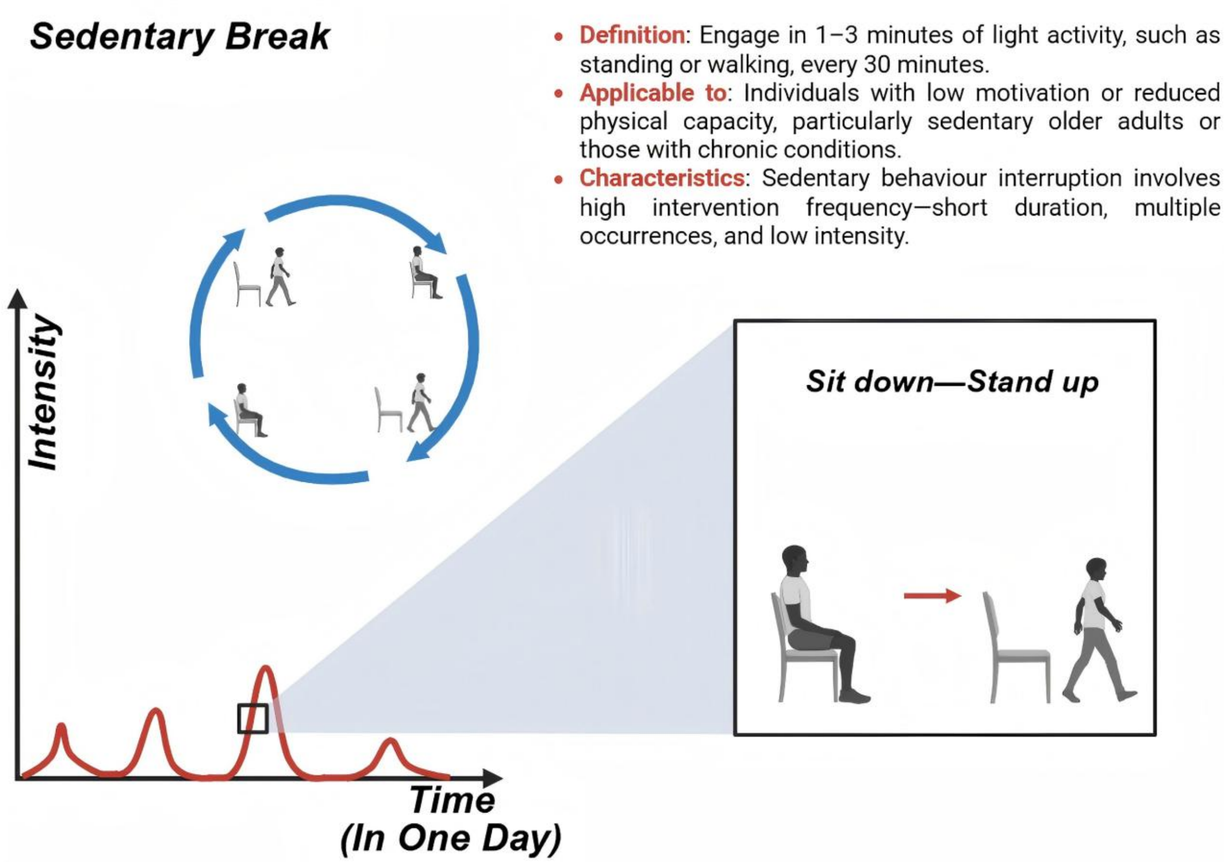

Figure 5. Breaks in Sedentary Time: Sequence and Intensity Trace of 1–3-min Interruptions Every 30–60 min.

Extensive epidemiological evidence has linked sedentary behavior to various diseases, including type 2 diabetes, metabolic syndrome, cardiovascular disease, cancer, and all-cause mortality, with a causal relationship between SB and depression (as proven through Mendelian randomization studies) [31]. Older adults, who spend the longest hours sedentary daily (8-11 hours), remain at risk for these conditions, even if PA or RE are increased. This reinforces the need to focus on reducing or interrupting SB alongside increasing PA to mitigate its harmful effects.

Similar to ES, SB is a new intervention derived from PA. Several pilot studies have found that reminding participants to stand and break their sedentary time can improve metabolic and inflammatory markers and positively influence physical function. While most studies have focused on the beneficial effects of increased RE or PA for LLD, SB, with its simplicity, presents a promising alternative for elderly individuals who may not be able to sustain high levels of PA or RE. Despite its simplicity, SB remains under-researched, particularly in older populations. Unlike younger adults, older individuals typically engage in "passive" sedentary behaviors (e.g., watching TV, resting), which are more harmful than "active" sedentary behaviors, such as studying or office work. A Swedish study found that passive sedentary behavior is more strongly associated with depression and anxiety than active sedentary behavior. Moreover, frequent interruptions in sedentary behavior were linked to reduced depression and anxiety rates [32]. Interestingly, older adults with depression tend to engage in more extended bouts of sedentary behavior. A UK community-based study found that older adults with mild or severe depression were more likely to engage in sedentary behavior lasting more than 30 minutes compared to those without depression [33]. This highlights the vicious cycle where prolonged sitting may lead to LLD, and individuals with depression may tend to sit for longer periods, exacerbating their symptoms. To address this issue, a 12-week pilot study recruited 60 older adults, randomly assigning them to either an intervention or control group. Both groups received biweekly education on the dangers of sedentary behavior, while the intervention group wore wristbands that vibrated after 30 minutes of sitting, reminding them to stand. The intervention group showed greater self-efficacy and happiness, with self-reported reductions in anxiety and depression [34]. This exciting result suggests that even without formal diagnosis, interrupting sedentary behavior could reduce depression risk and act as a preventive strategy for LLD. Additionally, a year-long observational study involving 67 older adults showed that prolonged sitting was closely related to worsening LLD and cholesterol levels, but increasing PA and SB reduced these associations over time [35]. These preliminary findings indicate that breaking up prolonged sitting or simply increasing SB frequency can reduce the risk and severity of LLD.

Physiologically, prolonged sitting increases blood glucose and insulin levels, reduces glucose tolerance, raises inflammation, and limits brain blood flow [36]. By standing, walking or stretching for several minutes at regular intervals (such as every 30–60 minutes), skeletal muscles are activated, glucose uptake and fat metabolism are promoted, thereby stabilising blood sugar levels and improving metabolic function. Physiologically, interrupting prolonged sitting significantly increases vascular endothelial shear stress, enhancing cerebral blood flow and perfusion. This provides the material basis for the generation of BDNF and neurotrophic factors within the brain [36]. Simultaneously, brief periods of standing and walking trigger sympathetic nervous system responses, increasing the release of adrenaline and noradrenaline. This enhances glucose supply to the brain, thereby reducing cognitive and emotional fatigue. Regarding immune regulation, observational studies indicate that SB can elevate levels of the anti-inflammatory hormone adiponectin [37], while some intervention studies also suggest a downward trend in inflammatory markers such as CRP and IL-8. Although the intensity of each activity is low, the repeated minor physiological changes help maintain HPA axis homeostasis, suppress excessive stress hormone secretion, and gradually restore sympathetic-parasympathetic balance. Furthermore, an interesting point of discussion is that sedentary behaviour primarily occurs indoors, particularly among the elderly. This results in limited exposure to sunlight, preventing vitamin D from functioning optimally. It is well known that vitamin D influences depression.

Despite the promising results of these pilot studies, there are still areas that require further investigation. First, the optimal duration and frequency of SB may vary based on individual physiological conditions, necessitating tailored recommendations for different groups. Second, while self-report measures are commonly used to assess the effects of SB on depression, they may be biased. Future studies could combine standardized questionnaires and recognized biological markers to provide more accurate results. Lastly, SB's potential for widespread use is one of its greatest strengths. Nearly everyone incorporates standing or moving into their daily activities, and modern technology allows for automatic tracking and reminders, such as through smartwatches. However, future research should explore how to optimize and personalize these interventions.

In conclusion, SB, as a simple and easily implemented intervention, has been increasingly recognized for its potential to alleviate LLD in older adults. By breaking up prolonged sitting periods, SB helps interrupt the negative behavior patterns associated with depression while triggering positive physiological changes. SB is highly accessible, making it particularly suitable for older adults with limited mobility or lower adherence to traditional forms of exercise. This intervention presents a low-barrier, high-acceptability solution for preventing and managing LLD. Future research should integrate standardized measurements, biomarkers, and smart technology to further optimize SB interventions and provide a sustainable, convenient mental health support strategy for aging societies.

6. Perspective: Application and Future Outlook of the Q4-MOOD Framework in LLD Intervention

The Q4-Mood framework offers a personalized and progressive intervention pathway for LLD. The key to implementing this framework is selecting appropriate interventions based on an individual's motivation and physical function, gradually increasing exercise intensity in a stepwise manner to enhance accessibility and effectiveness.

6.1. What is Q4-Mood?

Q4-Mood maps older adults onto four quadrants based on two core dimensions—motivation and physical function—matching each quadrant to one of four interchangeable and progressive exercise interventions (SB → ES → PA → RE). Unlike traditional "all or nothing" approaches to exercise, Q4-Mood focuses on "how to start with minimal resistance and progress sustainably." Every individual can begin in the quadrant corresponding to their current ability and motivation, and through the cycle of assessment, prescription, support, and re-assessment, they can gradually move upward or downward. This framework translates the guideline-level concept of "any activity is beneficial" into an executable prescription pathway and aligns with evidence that "various types of exercise are overall equivalent and complementary."

6.2. How to implement the Q4-MOOD framework?

As illustrated in Figure 6, we present a feasibility operational flowchart designed based on the Q4-Mood framework, encompassing several key steps that progress sequentially (Fig. 6).

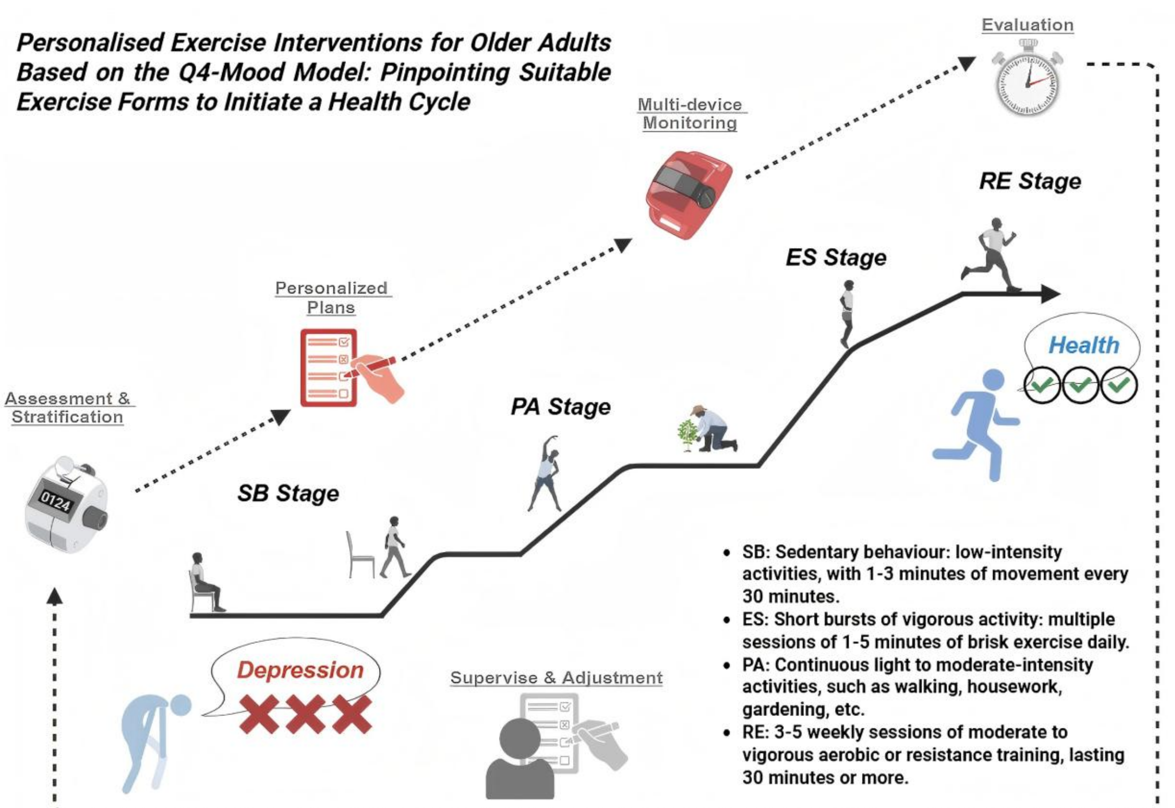

Figure 6. Q4-Mood Implementation Cycle: Assessment/Stratification → Personalized Plan → Multi-device Monitoring → Evaluation/Adjustment.

6.2.1. Step One: Applying validated testing to create stratified profiles for the elderly population

As part of the stratification process, we utilise a 10-15 minute rapid baseline assessment to categorise individuals into four quadrants based on their motivation levels and physical capabilities. Standardised tools are employed: motivation assessment utilises the Exercise Self-Efficacy Scale, BREQ-2/3 scale, and PAM scale; physical capability assessment employs the SPPB scale, TUG test, and grip strength test. These tools assist clinicians in devising the most appropriate intervention plan for each patient. The flowchart (Fig. 7) provides clinicians with a clear decision tree for stratification based on specific thresholds (e.g., TUG score ≥10 seconds indicating fall risk). This ensures interventions are both personalised and applicable to real-world clinical settings.

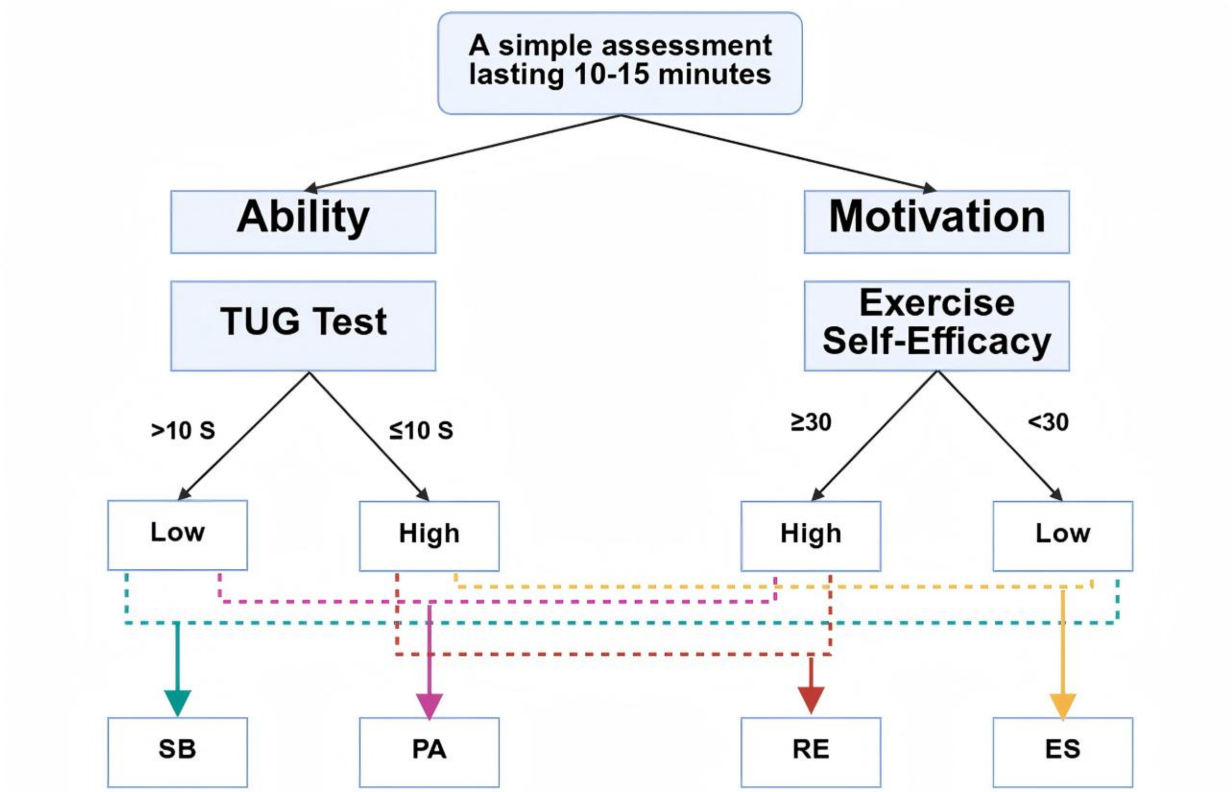

Figure 7. Proposed plan for clinical practitioners to stratify populations.

Numerous established scales and methods exist for assessing motivation and ability; the Timed Up and Go test and motivational scales are provided here as examples.

6.2.2. Step Two: Formulating an initial prescription, translating the four quadrants into comprehensible dosage ranges.

As shown in Table 2, the following key factors—intensity, frequency, and duration—require careful attention during future practical implementation.

6.2.3. Step three: Initiating implementation process: Perform positional anchoring according to stratification.
When both motivation and physical function are low, start with SB: Stand, walk, or stretch for 1-3 minutes every 30-60 minutes, aiming for ≥10 times per day. The physiological aim is to break the "sitting-inflammation-poor perfusion" chain, improving brain blood flow and endothelial shear stress with minimal burden, yielding "immediate tangible" psychological benefits. If time is fragmented or sustained exercise is difficult, transition to ES: Distribute 1-3 minutes of moderate-high intensity micro-exercise (e.g., brisk walking, stair climbing, chair squats) throughout the day, 6-10 sets per day. Short, repeated stimuli can provide immediate emotional uplift and self-efficacy enhancement, often serving as a stepping stone to PA/RE. When either motivation or physical function is adequate, choose PA: Accumulate light-moderate intensity through walking, housework, or commuting, initially aiming for 600-800 MET·min/week (e.g., walking 650-1000 MET·min/week) and gradually increasing by small steps each month. This dosage range has been consistently associated with depression improvement in older adults. When both physical function

and motivation support it, enter RE: Start with walking, jogging, aerobic equipment, progressive resistance training, or Tai Chi/Yoga, first entering the "effective range," then adjusting for optimal intensity. Aerobic exercise should be ~1000 MET·min/week, resistance training 2-3 times/week (with 6-10 exercises per session, increasing load progressively), and mind-body activities ≥2-3 times/week. Use RPE or heart rate zones to monitor intensity, including intuitive descriptions like "comfortable—talkative—slightly out of breath" for easier understanding by older adults.

Table 2. The key factors of future practical implementation.

	SB	PA	ES	RE
Frequency	Every 30–60 minutes	≥5 days/week	6–10 sets/day	3–5 days/week
Time	1–3 minutes	600–800 MET-min/week	1–3 minutes per set	30–40 minutes per session
Intensity	RPE 9–11 (0–10 scale, approx. 2–3)	LPA → MPA (talking comfortably, slightly breathless)	RPE 13–15 (0–10 scale, 5–7)	Aerobic: ~1000 MET-min/week, Resistance: 2–3 sessions/week
Type	Standing, walking in place, arm swings, heel raises, simple stretches	Walking, household chores, gardening, commuting cycling	Brisk walking, stairs, chair squats, wall push-ups, resistance band rows	Aerobic, resistance training, mind-body exercises (e.g., Tai Chi, yoga)
Example	Stand for 2 minutes during each TV commercial break + walk 3 minutes after lunch	Walk 20 minutes in the morning and evening + 15 minutes of gardening in the afternoon	Do 2 sets of chair squats every hour + climb 2 flights of stairs before dinner	Monday, Wednesday, Friday: 35 minutes on the elliptical machine + Tuesday, Saturday: 30 minutes full-body resistance with resistance bands + Thursday: 40 minutes of Tai Chi

6.3.4. Step four: Conducting rigorous reassessments and implement appropriate prescription escalation and de-escalation.

Cycle: Re-assess every 4-8 weeks. Indicators: Changes in PHQ-9/GDS-15, adherence (active days/week, SB/ES frequency, steps/MET·min), physical function (walking speed/sit-stand time), safety (pain, blood pressure, abnormal heart rate, adverse events).

Clinical Significance Thresholds (Examples): PHQ-9 decrease ≥5 points, GDS-15 decrease ≥2-3 points; walking speed increase ≥0.1 m/s; daily SB increase ≥4 times; weekly MET·min increase ≥150-300.

Progression: Once standards are met and tolerated, progressively increase frequency/time first, then increase intensity/complexity (e.g., PA → RE; increase sets then intensity in ES).

Regression: In case of intolerance, symptom flare-ups, or life events (hospitalization, caregiver stress), regress by one level and switch to "micro-prescriptions" (shorter time/lower intensity/more feasible type) to stabilize continuity.

Safety Tips: All plans should include 5-10 minutes of warm-up and 5-10 minutes of relaxation; adjust for temperature extremes to indoor alternatives; follow-up to track subjective enjoyment alongside dose to prevent "dose increases, enjoyment decreases."

6.3.5. Step five: Employing support systems: Utilising digital and social means to keep people engaged

The key to adherence lies not only in the prescription but also in the supporting structure. Digitally, a dual mechanism of "event-triggering + weekly goals" is recommended: SB reminders when sitting exceeds 30-60 minutes, and weekly goals quantified by MET·min/week, steps, active days, or SB/ES frequencies, using trend graphs and continuous streaks for instant feedback. Behavioral change techniques (BCTs) should be embedded in follow-up scripts: goal-setting, implementation intentions ("If I feel sluggish after lunch, I will do 2 sets of chair squats"), self-monitoring and feedback ("Weekly dose-emotion chart"), rewards (unlocking "milestone" badges/family rewards), cues (phone widgets, fridge stickers, standing prompts by the TV). Socially, prioritize peer/family support and group activities (walking groups, community Tai Chi/Yoga), using peer comparison and mutual help to maintain motivation. For individuals with "low motivation/lack of social support," start with "joyful small wins" (e.g., 1-minute ES + music) before discussing progression. Consider the digital divide and cognitive load, offering low-tech alternatives (e.g., paper activity book + weekly phone follow-ups) for those less familiar with digital devices, ensuring "elderly-friendly" design in fonts, contrast, and instructions.

6.3 Why Q4-Mood May Be More Applicable?

In clinical pathways, Q4-Mood works in parallel with medication and psychotherapy to enhance their effects. It is not a replacement, but an "addition": it clarifies "where to start, what dosage to use, and how to escalate," making exercise behavior interventions naturally integrated into collaborative care. The specific approach is as follows: a team consisting of psychiatry/general medicine, exercise prescription specialists/physical therapists, and nursing/ health coaches generate "preferred starting points + adjustable/escapable" prescriptions based on the four quadrants, aligned with the medication and psychotherapy follow-up cycles (e.g., 4–8 weeks).

In terms of timing, if a patient is undergoing CBT, moderate to low-intensity PA or short ES can be scheduled 1–2 hours before the session to enhance alertness and attention. If SSRIs cause insomnia/agitation, the main activities should be arranged in the early part of the day to avoid high-intensity exercise in the evening. If medications like Mirtazapine cause morning fatigue, a morning SB→ES "wake-up chain" can be used as a transition.

For comorbidities, low-impact PA, aquatic exercise, or Tai Chi should be prioritized for osteoarthritis or pain; intermittent aerobic exercise combined with breathing training for heart failure/COPD; foot care and low-impact alternatives for diabetes with peripheral neuropathy; and avoiding high-risk or confrontational activities for those on anticoagulation therapy. For those using benzodiazepines, balance challenges should be strictly controlled, with ES/PA and seated resistance exercises prioritized.

Safety "red flags" include chest pain, shortness of breath at rest, uncontrolled hypertension (≥180/100 mmHg), acute arrhythmias, fever/infection, recent cardiovascular events, or falls—if any of these occur, exercise should be immediately paused and medical evaluation conducted.

With this approach, Q4-Mood in clinical settings is neither overly invasive nor lacking: medication stabilizes emotional baseline, exercise builds sustainable physiological and behavioral improvements, and psychotherapy provides leverage for changing beliefs and motivation. The three elements support each other.

6.4. Current shortcomings and future recommendations

One limitation of this study is the absence of empirical data validating the Q4-Mood framework in real-world or clinical settings. While the conceptual model is grounded in existing literature and established guidelines, the framework has yet to undergo rigorous testing through feasibility trials or RCTs. Therefore, further empirical validation is necessary to assess its effectiveness, applicability, and impact on long-term outcomes for individuals with late-life depression LLD.

Another potential limitation is the generalizability of the Q4-Mood framework across diverse populations, particularly in settings with varying socioeconomic status, digital literacy, and access to resources. While the model is designed to be flexible and adaptable, its applicability may be limited in low-resource environments, such as rural or underserved areas, were access to healthcare professionals, digital tools, or appropriate facilities may be restricted.

To address these disparities, first, RCTs stratified by "motivation × function" should compare "initial preferred strategy" vs. "step-up strategy" in terms of symptom relief, relapse rates, adherence, and adverse events, ensuring sufficient samples for typical older subgroups (e.g., cardiovascular/bone disease comorbidity, mild cognitive impairment, high age ≥75). Second, the dose-response and threshold of objective measures need refinement: using accelerometers and MET·min to fine-tune SB/ES/PA/RE dosage curves, confirming the effective range of 600-970 MET·min/week, the optimal aerobic dose of ~1000 MET·min/week, and the reproducibility of benefits from walking at lower doses. Third, mechanism profiling: collect biomarkers like BDNF, inflammatory markers (CRP, IL-6), autonomic nervous function (HRV), and HPA axis for individual prescription tailoring. For SB, near-infrared or transcranial Doppler monitoring of cerebral blood flow/oxygenation with immediate emotional feedback can validate the "small-step-fast-effect" hypothesis. Fourth, combining digital health with social prescriptions in implementation research: investigate the impact of sit-to-stand reminders, timed push notifications, and peer group dynamics on progression success rates and long-term adherence, focusing on feasibility and cost-effectiveness while ensuring accessibility and fairness.

7. Conclusion

Q4-Mood's significance lies not in declaring any one exercise type to be "miraculous," but in providing a clear, executable framework from initiation to progression, from individual to system: starting in the right place, advancing with visible dosages, and improving within safe boundaries. By combining objective measurement, mechanism profiling, digital support, and social prescriptions, Q4-Mood can turn "knowing it works" into "effective, accessible, and sustainable," offering a replicable pathway for managing LLD.

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Conflict of Interest statement

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author's contributions

Conceptualization, Writing-Original Draft, Investigation: LK; Formal Analysis, Methodology, Software: LK and HZ; Formal Analysis, Writing-review & editing: LK and LJ; Writing-Original Draft, Supervision & Resources.

Supplementary Materials

The Supplementary data can be found online at: www.aginganddisease.org/EN/10.14336/AD.2025.1208.

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