Review

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Pushing the Pedals: Is Outdoor Cycling a Feasible Activity for People with Parkinson's Disease?

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Abstract

Purpose: Physical activity levels tend to be lower in Parkinson's disease (PD) than in healthy age-matched controls, largely because of substantial gait impairment. Remarkably, individuals with PD often retain a remarkable ability to cycle. However, so far, no evidence exists regarding the safety of patients when cycling outdoors in daily life. Therefore, the aim of this review is threefold: 1) to compare the mechanisms of cycling to those of walking, 2) to examine the symptomatic effects of stationary cycling, and 3) to highlight the challenges and opportunities to ensure safe outdoor cycling in PD. Major findings: Compared to walking, making cycling movements likely engages alternative neural circuits that largely bypass the most affected parts of the striatum in PD. Stationary cycling programs are therefore feasible and consistently improve physical fitness and motor symptom severity. Outdoor cycling may further increase physical activity levels, social participation and mobility in PD. However, its feasibility and safety are poorly studied, while there exist significant safety concerns linked primarily to poor balance, but also axial rotation, motor initiation and cognitive impairments. The present review discusses these challenges and considers which may be modifiable through future cycling-rehabilitation interventions. Conclusion: The relatively preserved ability to make cycling movements in PD makes outdoor cycling an attractive form of physical activity and promising strategy to enhance quality of life. However, further research is needed to assess outdoor cycling skills and inform rehabilitation interventions to ensure safe participation in a population for whom maintaining physical activity is essential.

Lay language summary

Feasibility of outdoor cycling for People with Parkinson's Disease

Engaging in regular physical activity is crucial to avoid negative health effects. However, this is easier said than done for persons with Parkinson's disease (PD) who are often faced with severe gait impairments that restrict daily life mobility. Surprisingly, even patients with substantial walking difficulties are still able to ride a bicycle, probably because cycling movements engage alternative neural circuits that are relatively spared. Cycling thus offers an attractive mode of engaging in physical activity for people with PD. However, currently no evidence exists on the difficulties and challenges that patients likely face when cycling outdoors. The present review first describes the mechanisms of cycling versus walking, followed by a summary of the literature on the symptomatic effects of stationary cycling interventions. It then critically reflects on the difficulties that may occur during outdoor cycling in PD. It is currently unknown whether these difficulties are modifiable through targeted training aimed at improving cycling ability and road safety. With this review, we intend to inspire the development of future road cycling assessments and trainings in this population for whom engaging in physical activity is essential.

Keywords: Parkinson's disease; cycling; bicycling; rehabilitation; physical activity; exercise; neurophysiology

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Introduction

Parkinson's disease (PD) is the second-most common neurodegenerative disorder worldwide[1]. It has a progressive disease course that leads to worsening motor and non-motor symptoms and causes significant burden to patients, their families and society[1–3]. The pathophysiology of PD is mainly characterized by the progressive degeneration of dopaminergic neurons in the substantia nigra pars compacta. The resulting dopaminergic denervation affects basal ganglia processing, especially in the sensorimotor striatum, which is associated with increased motor inhibition and impaired automaticity of motor performance[1,4,5]. The cardinal signs of PD include bradykinesia, muscle rigidity and resting tremor, but are also expressed in complex motor signs, such as reduced trunk mobility, postural instability and gait impairment[1,4,6]. To compensate for de-automaticity, PD patients become increasingly reliant on sensory (visual, parietal) and attentional (prefrontal) circuits to facilitate goal-directed motor control[4,5,7]. This explains why during performance of a dual-task the competition between compensatory circuits may be increased, further compromising motor performance[4,5,7]. Inevitably, and with time, both the basal ganglia and the compensatory circuits become increasingly affected causing severe motor and non-motor disability[8] and functional dependence[9].

The primary therapy of PD aims to reduce motor inhibition through dopamine-replacement pharmacotherapy or deep brain stimulation, the latter most often applied to the subthalamic nucleus (STN)[6,8]. Despite strong symptomatic effects[6,8,10], gait impairments are among the most disabling refractory symptoms, significantly affecting daily life mobility[10]. Physical therapy has been shown an effective adjunct strategy to help patients manage their activities of daily living and to keep them mobile and independent for as long as possible[11,12]. Besides motor learning and exercise, one of the critical components of physical therapy comprises of promoting everyday physical activity, defined by any bodily movement produced by skeletal muscles that results in energy expentditure[13] and this in the most safe manner possible[14].

A recent qualitative study identified everyday mobility as an important treatment target for patients with PD[15]. However, in the later stages, mobility becomes severe restricted by gait impairment and freezing of gait (FOG), putting patients at a higher risk of falls [8,16]. Hence, considering other forms of physical activity and exercise than those involving walking seems indicated. Cycling lends itself particularly well as an alternative[17–19]. More and more nations are increasing their cycling infrastructure. Cycling is indeed a sustainable and healthy form of mobility and transport that is key for social inclusion and economic development, as postulated by the European declaration on cycling[20–23]. What is more, the portion of older adults that adopt outdoor cycling has risen substantially since the introduction of electronically-supported bicycles[24]. However, little is known about the difficulties PD patients experience when cycling outdoor without clinical supervision. In this position paper, we therefore address 3 critical aims. First, we describe the mechanisms underlying cycling and present conceptual evidence for why severely affected patients may still be able to cycle[25]. Second, we synthesize the effects of controlled cycling exercises in PD. Third, we critically reflect on the barriers for safe cycling in uncontrolled environments and whether outdoor cycling could feasibly serve as an alternative form of physical activity in PD. Finally, we provide future research directions to promote safe cycling in PD patients' daily life.

1) Underlying mechanisms of cycling and why people with PD may cycle better than walking.

Several studies have explored the neurophysiological and biomechanical mechanisms underlying cycling following the observation that individuals with PD often experience less motor impairments during cycling movements compared to walking[25]. Although we do not yet have a precise understanding of this phenomenon, multiple plausible and non-exclusive hypotheses have been proposed, each focused on the rotational cycling movements that may engage neural pathways or motor control strategies that are less affected by PD than those controlling gait. However, other differences should also be considered when comparing walking and cycling outdoors.

i) Walking versus rotational cycling movements

Several theories have been put forward to explain the compelling evidence that PD patients have a preserved ability to perform rotational cycling movements in the face of severe gait impairment[25–28]. A first possible explanation relates to the degree of automaticity. Activities of daily living range from highly automated (i.e. habitual) to more goal-directed actions, depending on the context and need for motor precision[4]. Habitual motor patterns, such as walking, are performed frequently in everyday life from an early age and therefore become highly automated, whereas cycling is typically learned later in development and practiced with a lower frequency, possibly resulting in a lower degree of automatization. Figure 1 presents some of the hypothesized differences between walking and cycling movements in people with and without PD. In healthy people, motor automatization is associated with a shift in neural activation from the anterior associative fronto-striatal circuit to the posterior sensorimotor striatum[4,5], along with reduced attentional cortical demands[4,17]. Simultaneously, neural connectivity increases between the sensorimotor striatum and key components of the motor circuit, including the primary motor cortex (M1), central pattern generators, and the cerebellum, leading to efficient motor execution when precision is less critical, such as in walking (see figure 1, upper left)[4]. In people with PD, the sensorimotor striatum is more severely affected than the anterior striatum, explaining why automated movements are particularly disrupted in PD, and why patients revert to a goal-directed mode of gait control visualized by the bold black lines in Figure 1 (lower left)[4,5]. Cycling movements, considered to be less automated than walking[25], rely more on relatively spared associative neural circuits for goal-directed motor control, even in healthy individuals (Figure 1, upper right)[4,5]. The use of these alternative pathways may underlie the relative preservation of cycling ability in PD (Figure 1, lower right)[25], albeit that this circuit may be over-relied upon (bold arrows) in the PD population.

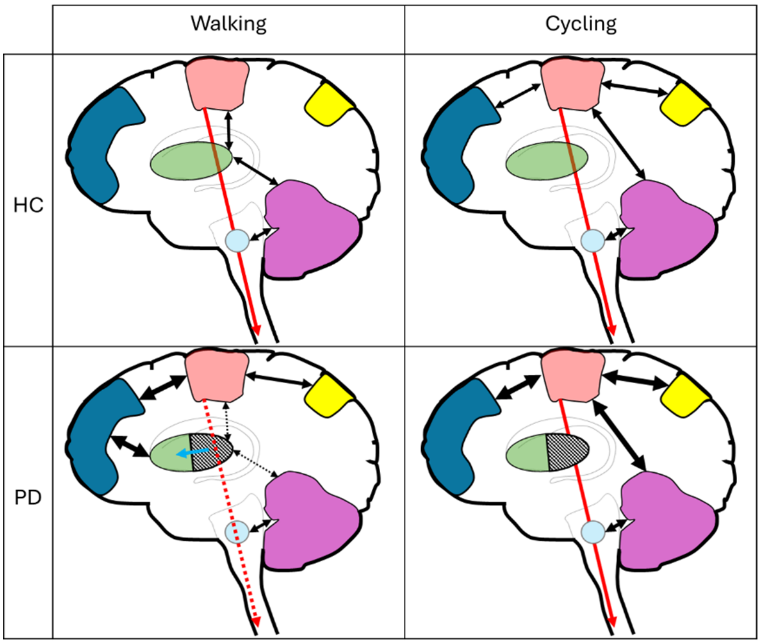

Figure 1. schematic models of hypothesized differences in sensorimotor pathways between walking and cycling in healthy persons (HC) and persons with PD (PD). Brain regions are indicated in different colors: frontal area (dark blue); motor cortex (red) including premotor cortex and primary motor cortex; somatosensory cortex (yellow); cerebellum (purple); basal ganglia (green), which are affected in PD (hatched); and central pattern generators (light blue). Black double arrows indicate involved network connections. The thickness of the lines

indicate connectivity strength. The red arrow indicates motor efferent output. Dashed lines suggest impaired pathways. When comparing HC and PD during walking, sensory processing (basal ganglia) and thus motor output are impaired. Patients therefore rely on compensatory networks, more involved in attentional motor generation. During cycling, people rely less on sensory information processing and more on feedforward movement prediction (cerebellum). The connection between cerebellum and basal ganglia is likely less engaged while cycling, and may contribute to preserved motor output during cycling.

Storzer et al. (2017) were the first to demonstrate that pathological beta-power in the Subthalamic Nucleus (STN) is significantly attenuated during cycling movements compared to over-ground walking[27], which may indicate that there is less pathological signaling to the STN during cycling (see also Box 1). Bougou et al. (2023) found a similar suppression of beta-activity through local field potential recording in the STN, but only compared active versus passive cycling. Interestingly, low frequency beta was most predominantly suppressed during passive cycling, and particularly in people with PD and FOG. These finding suggest that the somatosensory input of lower limb movements play a key compensatory role during cycling[28].

Box 1: Beta-band oscillatory activity

The primary pathophysiology of motor function in PD has been associated with over-activity in the indirect cortico-striatal-thalamo-cortical loop of the sensorimotor striatum leading to an over-inhibition of the striatal output structures and brainstem locomotor centers[29]. This over-inhibition has also been associated with alterations in beta-band oscillatory neural activity. Under physiological conditions, beta-oscillations help suppress unwanted movements and competing motor programs[30]. When a voluntary movement is initiated, beta power selectively decreases, thereby restricting the inhibitory striatal output and allowing selective movement generation. As such, beta-activity functions as both a neural “handbrake” by limiting unnecessary actions, and a funnel by appropriately initiating intended motor action[27,30]. Excessive and prolonged beta oscillations within the cortico-basal ganglia circuits, particularly in the STN and Globus Pallidus internus (GPi) correlate with bradykinesia, and gait impairment[26,27,30]. A lowering of beta activation as seen during cycling movements is therefore typically interpreted as a favorable outcome in PD[27,28].

It has further been suggested that the pedals of a bicycle act as external tactile cues and also facilitate goal-directed motor control[25]. Cues are external or internal stimuli to direct attention towards the execution of a specific movement[31]. Cueing has been extensively documented as an effective approach to temporarily improve movement initiation and execution in PD, alleviating gait impairments and FOG in particular[31–35]. We propose that bike pedals may serve as external cues in two distinct ways. First, for the pushing leg, the pedal may function as a proprioceptive target to guide foot placement and force direction. Second, for the non-pushing leg, the passive motion of the pedal may facilitate advancement through the movement cycle. Subsequently, the upward force generated beneath this foot may serve as ‘guidance’ to push the opposite pedal[25], thereby enabling movement continuation. As such, bradykinesia is counteracted during cycling and, on a moving bike, this will still contribute to meaningful forward progression.

Although gait patterns in themselves are run automatically[36], actual overground walking in daily life requires constant sensorimotor feedback to navigate and adapt gait parameters in an ever-changing environment with constant gravitational pertubations[37,38]. This imposes substantial load on the motor and cognitive circuits, as well as, requiring basal ganglia involvement, explaining why gait impairments are so prominent in PD[39–41]. Given the more constrained movement pattern of rotational cycling movements, these demands are likely to be lower[25]. During cycling, the feet remain fixed on the pedals and move along a fixed path length. Coordination between the pushing and non-pushing leg is also predetermined, occurring in a 360° phasic motion with a 180° delay between the legs. Gravitational perturbations are probably less prominent when seated in the absence of a swing phase[42,43]. Thus, cycling reduces the degrees of freedom and lowers the need for sensorimotor feedback. Rotational cycling movements are also substantially governed by feedforward movement generation[25](see Box 2), relying on predictive motor commands present at movement initiation, rather than by on-line adaptation. Feedforward control is mainly coordinated by the cortico-cerebellar circuit[39,44], which remains relatively intact in PD[39,45].

Box 2: Feedback versus feed-forward motor control

A feedback-regulated movement depends on afferent somatosensory input originating from internal and peripheral receptors, such as Golgi tendon organs and muscle spindles[38]. First, a motor plan is generated and executed in order to produce the intended movement. The somatosensory organs will continuously provide afferent information – reflecting both internal bodily state and external environmental conditions – of the performed movement to the central nervous system. The basal ganglia are involved in selecting, modulating and fine-tuning the motor responses whereafter the outcome is projected to the motor cortex[39,41,45]. Based on the incoming information, the motor system will refine subsequent motor commands to further optimize the next movement[37,38]. In PD, feedback -based processing is mostly affected, leaving a negative imprint on movement adaptation[37,39–41,45,46]. Feedforward movements, supported by consistent and predictable movement patterns, are primarily processed through cerebellar-thalamic pathways. In PD, these circuits remain relatively spared[25,39]. Because rotational cycling movements rely more on feedforward control than gait does, it may remain spared even in patients with severe gait impairments, including those experiencing FOG[25].

ii) Balance control differences between walking and cycling outdoors

A key distinction between walking and cycling outdoors relates to the mode of balance control. Walking predominantly relies on anterior-posterior balance control[47]. In contrast, cycling depends largely on mediolateral balance control, which is affected to a lesser degree in PD[25]. What is more, during walking, balance control is largely dependent on step width modulation in the same effectors that also produce the forward stepping motion (i.e. the legs). This regulation is impaired in PD, who typically adopt a maladaptive narrow base of support that increases risk for falls[48]. On the contrary, whilst the forward motion during cycling is also produced by the legs, balance control is regulated mainly by the upper body effectors through leaning and steering. This might allow PD patients to utilize different or more distributed neural circuits, thereby putting less strain on the already impaired control of the lower limbs. What is more, walking requires constant anticipatory postural adjustments (APA's), i.e., multidirectional weight shifts that underpin appropriate loading and unloading of the legs. Individuals with PD experience abnormally small APA's, leading to impairments in both gait initiation and continuation[49–51]. The rhythmic leg motions and upper-body balance corrections during cycling similarly demand a degree of APA's to ensure that he body remains balanced on the bicycle frame during movement[25]. However, the mechanical support of the frame and rotational movement of the pedals is likely to facilitate such mediolateral APA's and allow for greater gravitational control, also in PD[52]. Furthermore, turning during cycling is initiated by steering and leaning without requiring an asymmetric stepping pattern, known to worsen FOG and falls in PD[53–55]. Overall, current evidence indicates that several complementary mechanisms may underlie the relative preservation of cycling ability in people with PD.

Symptomatic Effects of Stationary Cycling Exercise in PD

The rationale to recommend cycling for PD is corroborated by converging evidence that cycling exercises result in symptomatic benefits. Unlike physical activity, exercise is defined as planned, structured and repetitive motor practice with a final or intermediate objective to improve or maintain specific outcomes of physical or mental fitness[13]. Mostly based on in-vivo animal studies, and to a lesser degree supported by human work in PD, exercise has been shown to stimulate neuroprotective mechanisms, as derived from brain-derived neurotrophic factor (BDNF), dendritic spine formation and metabolic pathway optimization for striatal dopamine release[56–60]. Exercise has also been demonstrated to induce neurostructural changes and strengthened connectivity between cortico-striatal networks, thought to support the slowing of disease progression[61,62]. However, the precise role of exercise as a potential disease modifier is still under ongoing investigation[63]. So far, aerobic exercise has shown the strongest potential to slow down motor symptom progression[60,61,64]. Various other exercise programs have been found to acutely improve aerobic capacity and muscular strength[60,61,65], motor symptoms[58,60,61,65] and generally enhancing the body's resilience and ability to compensate[60,61]. Hence, exercise has now become integrated into overall disease management.

Cycling on a stationary indoor bicycle is a popular exercise mode for PD, because of the seated stationary position that results in a low risk of falling. Indeed, indoor bicycles typically provide robust structural support and stability during mounting, dismounting and exercising, offering a means for safe home-based interventions too, whereby training parameters (e.g. speed, resistance, training duration) can be carefully controlled through therapist supervision or mobile health (M-health) technology[66]. A systematic review by Tiihonen et al. (2021) revealed consistent positive effects of indoor cycling on motor symptom severity, self-reported quality of life[67] and reduced symptom progression after 6 months[64,68]. Alberts et al. (2025, ClinicalTrials.gov ID: NCT04000360)[19] published a study protocol, which is investigating the impact of a 12-month cycling exercise program (the CYCLE-II study) on symptom progression based on the OFF-medication MDS-UPDRS III score[69] compared with usual care. Unpublished trial data indicate a mean change of -1.4 points in the cycling group versus +3.6 points in controls, suggesting a clinically meaningful benefit is likely[19]. The program was also safe and feasible with adherence exceeding 87% and few reports of serious (10/129), and non-serious (27/129) adverse events in the cycling group[70].

The scoping review of Palmieri et al. (2024)[71] further highlighted that positive effects of stationary cycling may translate to other activities, even if inconsistently, as one well-controlled RCT did not show any transfer[64]. Generally, clinically meaningful improvements of gait parameters were reported in 69% of the reviewed studies, while 60% demonstrated statistically significant improvements in balance-related outcomes which, however, did not surpass the corresponding minimal detectable change thresholds. Of note, a 6-week backwards cycling program resulted in transferable improvements in backward walking speed, backward reactive balance and overall postural stability[72]. The potential for transfer of cycling-related benefits may be attributable to the fact that individuals with low baseline physical fitness profiles[71] are particularly responsive to any form of exercise. In such individuals, even moderate increases in physical capacity can yield meaningful improvements in functional abilities, including walking[71]. Collectively, these findings indicate that stationary cycling-based exercise programs are safe, feasible, and effective within the broader menu of evidence-based rehabilitation option for people with PD.

Outdoor Cycling Challenges as Alternative form of Physical Activity?

Regular physical activity is linked to broad health benefits[73], which have likewise been observed in the PD population as along with improvements in gait, postural stability and cognitive functioning[14,74]. However, gait disturbances also form a major barrier for engaging in physical activity, as they put patients at a higher risk for falls[75]. Consequently, patients tend to adopt a sedentary lifestyle[76,77], setting off a detrimental spiral of secondary complications, and eventually increasing morbidity[14,78]. To counteract this vicious cycle, cycling can serve as a viable exercise modality, but also as a means to increase daily physical activity when used for transportation or recreation. Recreational cycling enables individuals to travel longer distances, enjoy natural environments, and participate more fully in community life, for example, by visiting family and friends and running routine errands, such as going to the bakery or grocery store. Through cycling, people with PD can substantially expand their social mobility, while simultaneously benefiting from regular physical activity. Moreover, cycling can be preserved in people with severe gait impairment, as illustrated by the video-supported case report of Snijders and Bloem (2011) displaying a gentleman with severe freezing but who could still ride a bicycle (figure 2)[25].

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On the down side, outdoor cycling comes with its own risks and difficulties. First and foremost, compared to walking at a slow pace, a fall or collision at a higher speed may give rise to more severe consequences, such as bleeds, fractures, concussions and worse. Besides an advice to wear a safety helmet75, patients must be able to safely execute cycling-specific tasks when navigating in traffic to avoid falls and accidents. This is not self-evident, as outdoor cycling introduces multiple challenges for people with PD. Some of these challenges are evident in the previously referenced case-report video.

Figure 2 displays six screenshots taken from the video illustrating the various egocentric difficulties. First, the initiation of the first cycling movements can be challenging (Figure 2A: note, the pushing of two people to advance the bike). Poor initiation of movement is a hallmark of PD that can be made worse by freezing[49,51,55]. Second, the patient does not fully look over his shoulder (Figure 2B). This might be the result of axial rigidity and poor axial rotation[79–81]. The shoulder check serves as a preparatory action for successive traffic maneuvers to determine whether it is safe to proceed and is therefore crucial for navigation in real-world traffic. Figure 2C shows difficulty with making tight turns within the border of a double-laned street, deviating into the parking space of cars. Making exaggerated wide turns may indicate deficits in balance[16,82], turning mobility and axial rotational control, known to be affected in PD[79,80]. It may increase fall and collision risks during public cycling. Figure 2D shows difficulty with making sharp-angled maneuvers and a near collision with a parked car. In figure 2E, the patient swiftly hops off the bike by jumping from the pedals. Intentionally or not, it could indicate a compensatory strategy to overcome difficulties with controlled disembarking.

After dismounting, the participant walks while holding the bicycle, but is restricted because of FOG (Figure 2F). Walking while maneuvering an object is a motor dual task with high balance requirement and a known trigger of FOG[4,5].The same difficulty is shown in another case video by the same group[83]. During traffic, prior to turning one should put out an arm to signal the intended travel direction. The gentleman in the video does not perform this maneuver. Such an action requires mediolateral balance control and single-handed steering, which the patient may have avoided as well.

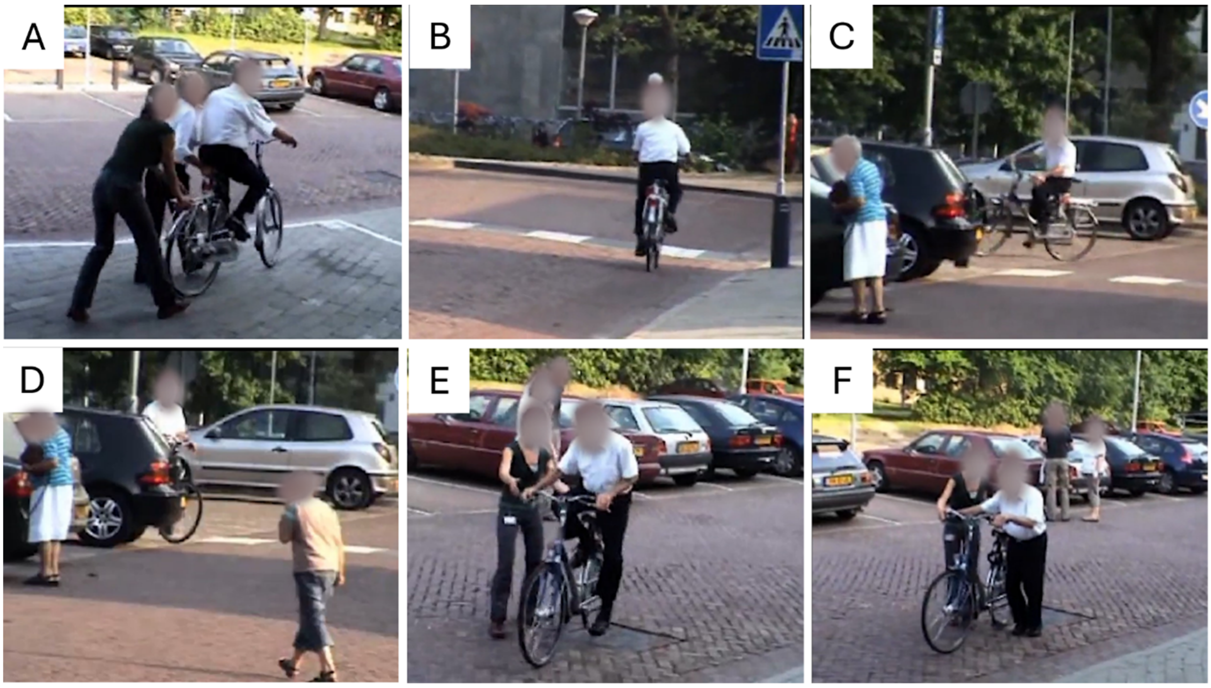

Figure 2. Screenshots from the case-report video of Snijders and Bloem (2011) entitled “kinesia paroxia”, illustrating six challenges the gentleman faced when cycling outdoors, namely: A) cycling initiation; B) performing a shoulder check; C) turning; D) making sharp-angled maneuvers; E) disembarking from the bicycle;

D) difficulty walking with the bicycle. Embarking the bicycle and hand raising are other challenges this gentleman might have experienced, but which is not shown on the video. Permission was obtained by the editor of the New England Journal of Medicine for re-use of the images following a face blurring de-identification procedure.

Figure 3 provides an overview of envisioned difficulties that people with PD may experience with handling a bicycle, including some of those shown in figure 2. The mechanisms that can possibly explain the depicted difficulties are indicated in writing under each subfigure. Figure 3A represents various egocentric problems that likely challenge people with PD given their dual-tasking, balance, transfer, axial rigidity, and motor initiation, some of which (Figure3A: panels 1-6) were also identified in the video of Snijders[25]. The other difficulties depicted include upper-limb motor skills needed for using the breaks and (un)locking a bike (panel 7)[84]; parking a bike on a kickstand involving unipedal balancing and unracking and unparking a bike, demanding retropulsion, a common difficulty in PD (panel 8)[85]; and recalling one's route, which requires spatial memory (panel 9)[86]. As for allocentric difficulties, figure 3B shows that navigating through traffic is likely to be challenging in the face of reduced cognitive ability and cognitive-motor dual tasking in PD[87,88]. Cycling outdoors indeed requires faster visual scanning of the environment and spatial awareness compared to walking. In conjunction, there is also a great demand on executive functioning to correctly apply the traffic rules, pay attention to other road-users and pedestrians, adapt one's movements and behavior to an ever-changing environment, and generate responses timely for (emergency) breaking (Figure 3B). Finally, figure 3C shows the primary concerns of outdoor cycling, namely the risk of falling, suffering an accident and the ensuing demotivation to engage in cycling. In conclusion, although cycling may offer a valuable form of physical activity in PD, safety remains the most important challenge.

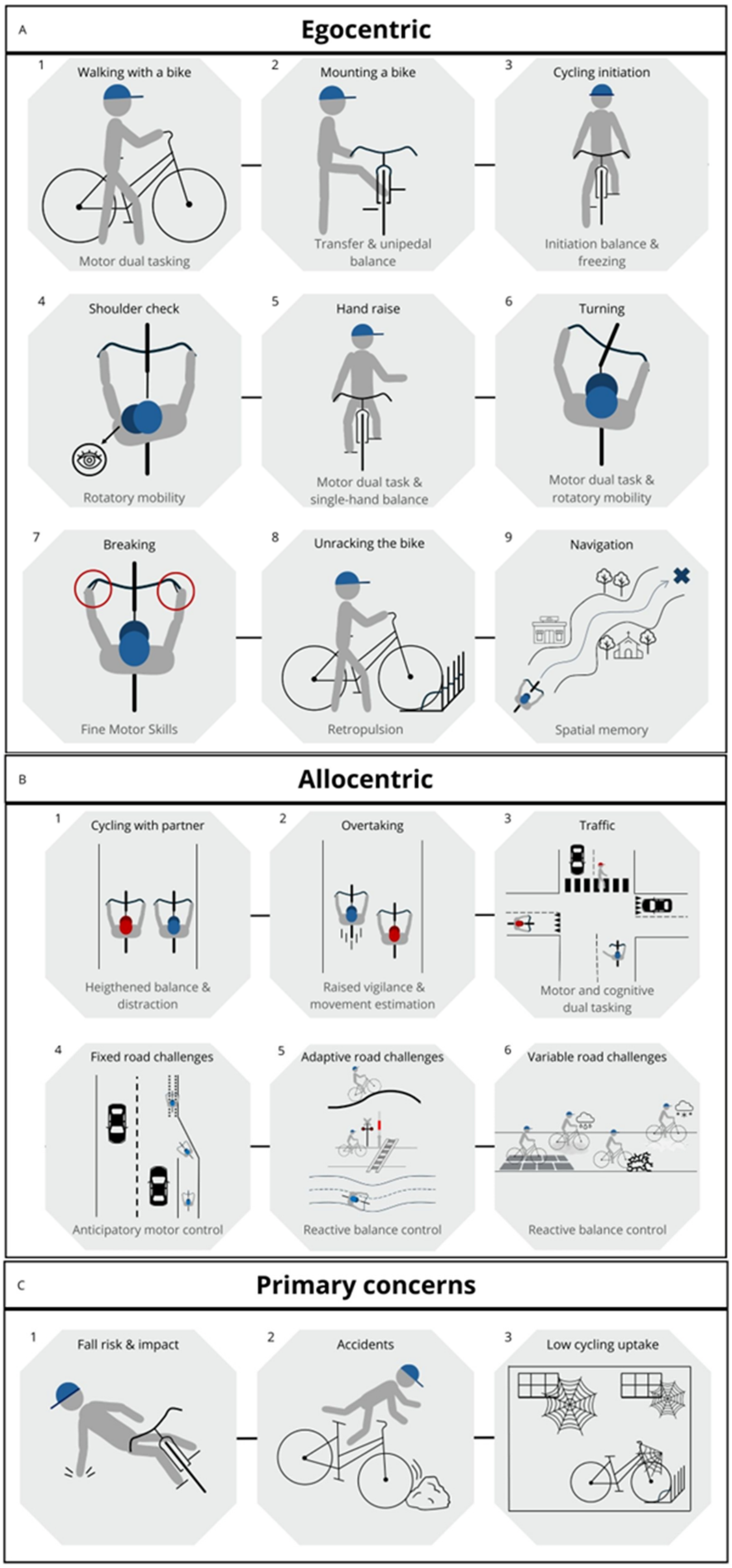

Figure 3. Envisioned challenges during cycling and primary concerns for cycling participation and safety. The challenges are divided in egocentric and allocentric categories. Egocentric challenges refer to an individual's level of both motor and cognitive functioning. Allocentric challenges reflect difficulties brought to the cyclist by the traffic and the environment, which includes predictable road changes, uneven surfaces and weather conditions. The primary concerns of outdoor cycling include falls, collisions and low cycling participation.

Gaps and Future Directions

In some countries, such as Belgium and The Netherlands, cycling is integrated in everyday life and cycling paths are widely available. However, even in these ‘cycling nations’, there are no studies on cycling uptake in people with PD specifically. A retrospective evaluation of spontaneous physical activity and exercise as reported on a diary as part of another study[89] in our group, showed that only one in four patients with mild-to-moderate PD cycled outdoor on a weekly basis, which was slightly lower than in healthy older adults living in the same area of Flanders, albeit not statistically significant (see Figure 4). Moreover, a recent survey (G-sport Vlaanderen (2024) of the Flanders regional sport association for persons with a disability[90] indicated that only 54% of people with chronic disease are weekly active. Within this group, seven out of 15 persons with PD reported to participate in weekly physical activity. Interestingly, cycling was listed as the fourth most popular sport in this group, after walking, swimming, and strength exercises.

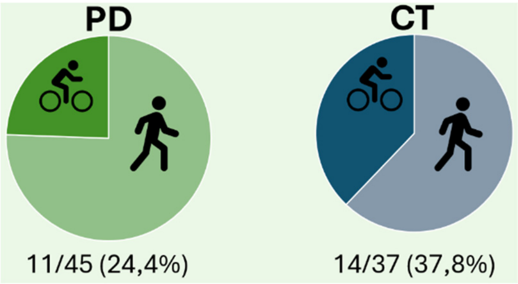

Figure 4. weekly cycling uptake in persons with PD and age-matched controls. Roughly one in four PD participants report to cycle at least once per week compared to a third in the control group. The difference between both groups was not significant (p=0.19). Ethical approval was obtained from the Medical Ethical Committee for this retrospective evaluation (ID: S70945).

This begs the question of how can we promote safe cycling in PD? First, the most important motivators and barriers for engaging in cycling must be identified. Next, a training program teaching cycling skills should be developed to enhance road safety and confidence. Multiple studies[91–93] already identified a diverse set of motivators and barriers to engage in physical activity and exercise in PD. Barriers included: 1) PD-symptoms and their resulting discomforts, 2) low baseline activity levels, 3) personal factors such as limited self-efficacy, fear of falling, depressive mood or lack of time, and 4) environmental obstacles (insufficient social support, unfavorable weather conditions, poor accessibility and financial burden). Factors that helped engagement were: 1) the perceived health benefits of exercise especially when indicated by health-care professionals, 2) tailoring an exercise program to the individual’s schedule, 3) education about exercise and 4) providing adequate feedback and reward. However, it remains unclear whether the same barriers and motivators apply to outdoor cycling. As for feedback and reward, mobile health (Mhealth) technology emerges as a valuable adjunct for optimizing adherence to exercise through monitoring tools, motivational features and low-threshold goal-setting strategies[91]. Future research should evaluate if Mhealth technology also benefits adherence to and clinical effectiveness of cycling interventions.

In this opinion paper, we identified important gaps in the literature to determine the exact difficulties that patients experience during real-life cycling. More specifically, which cycling tasks are particularly impaired in PD compared to their healthy peers? This understanding will aid in informing future training programs for increasing cycling skills.

Earlier, we espoused that the lack of balance, strength, cognition and fear of falling may impact on cycling proficiency. Equally, external factors, such as the amount of daylight, the weather, the bike type (e-bike versus conventional) and the bike’s size and weight, could also be important. Finally, intrinsic factors, including previous cycling experience and the person’s general agility and speed[94], could be important determinants of cycling ability. Adaptive forms of cycling can also be considered. While, two-wheeled bicycles are agile and appropriate for patients in the early to mid-stages, tricycles may be better suited for the later stages when balance control becomes markedly impaired. Tandem bicycles can also be considered given the potential benefits of (semi-)passive cycling movements. More research is needed to inform and advise patients and healthcare providers appropriately about which bike is best, as well as, on when to discourage cycling in traffic in the light of motor and cognitive deficits.

At present, we are conducting a cross-sectional observational study, the so-called MaestroPD study, to address some of these knowledge gaps (MaestroPD-preregistration)[95]. Using a standardized outdoor assessment, we will compare cycling skills between PD and healthy older adults during different cycling-specific tasks. Performance outcomes will be evaluated based on inertial measurement units and video footage of the bike's and the cyclist's movements. In the second phase of the study, we will be able to evaluate which clinical and personal determinants of the participants predict better outdoor cycling performance. Lastly, cycling-specific motivators and barriers will be rated through qualitative analysis of a population-wide survey to identify the key elements that could be addressed in future training programs and outdoor cycling promotion materials.

Conclusion

Given the relative preserved ability to perform rotational cycling movements in PD, it seems compelling to recommend outdoor cycling as an alternative form of physical activity. However, in contrast to the extensive gait-oriented literature, much less is known about outdoor cycling performance and safety in PD, despite the many anticipated challenges. These knowledge gaps must now be addressed to inform the development of cycling-specific rehabilitation programs and to optimize safe and sustainable cycling uptake in people with PD.

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