Learning to cycle: a constraint-led intervention programme using different cycling task constraints

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Background: Cycling is a foundational movement skill which represents an important motor milestone to achieve in children's lives. The use of a bicycle with training wheels is the most common approach for learning how to cycle, although some evidence suggests that this approach is counterproductive. Purpose: Underpinned by an ecological perspective and Constraints-led approach, this study investigated whether learning how to ride a conventional bicycle in childhood can be shaped by the specific task constraints related to the kind of training bicycle used beforehand (i.e., balance bike or bicycle with training wheels). This comparison could guide pedagogical practice to facilitate children's learning in cycling and their independent riding. Methods: The Learning to Cycle intervention programme was introduced to 25 children (M=6.08±1.19 years) who could not previously cycle, divided into two treatment groups. One group trained with a bicycle with training wheels (BTW) and another with a balance bicycle (BB) for six sessions, followed by four sessions with a conventional bicycle (CB). The acquisition of independent cycling was assessed, based on established cycle learning milestone achievements, without help: (i) self-launch, (ii) riding for at least 10 (consecutive) metres, and (iii), braking. To be considered an independent rider, participants needed to achieve all these milestones, without any external help. During the CB sessions, the number of sessions that each child needed to acquire each learning milestone and independent cycling were recorded. Results: The programme led to a success rate of 88% for achievement of independent cycling on a conventional bicycle, differentiated by 100% success in the BB group and 75% in the BTW group. The BB participants were significantly faster in learning to self-launch, ride, brake, and cycle independently, compared to BTW participants. Conclusions: The Learning to Cycle programme was effective for facilitating learning in children from three years of age onwards. Using the BB instead of the BTW seems to lead to a more effective and efficient acquisition of independent cycling at earlier ages.

Keywords: learning to cycle, Ecological dynamics, self-organisation under constraints; affordances; system degrees of freedom

Introduction

Since its invention the bicycle has gained a prominent role in everyday life. Nowadays, this sustainable mode of transport is used everywhere for exercise, sports competition, travelling or simply for recreation. Recently, cycling was proposed as a foundational movement skill, because it promotes engagement in physical activity, leading to positive health trajectories throughout the lifecourse (Hulteen *et al.*, 2018). Indeed, the benefits of cycling are well documented in scientific literature, applicable across the whole lifecourse. In childhood, cycling promotes physical health benefits to promote better cardiorespiratory fitness, body composition with lower body fat, and less incidence of metabolic syndrome (Ramírez-Vélez *et al.*, 2017). It also promotes mental and social benefits, including a better development of social and emotional skills, supporting transport independence, greater activity and an expansive exploration of the environment, in children (Smith *et al.*, 2017). In summary, the perceptual-motor competence of cycling can support numerous mental, physical and social health benefits in children. For these reasons, learning to cycle represents an important achievement milestone in children's personal and motor development (Zeuwts *et al.*, 2020, Zeuwts *et al.*, 2015), which should be promoted as early as possible in childhood.

In the process of learning to cycle, different training bicycles can be used, and the most common is the bicycle with lateral training wheels. However, there are no consensus data available on whether this is the best approach in learning to cycle (Mercê *et al.*, 2021c, Shim & Norman, 2015). Recently, a systematic review was carried out to synthetize, compare and evaluate different interventions and strategies implemented to teach children to cycle (Mercê *et al.*, 2021c). This review discussed several methodological aspects of cycling learning programmes, including context and personal constraints, and presented a list of recommendations for future interventions.

One of these recommendations specifically concerned the variation of task constraints for learning to cycle, such as the type of bicycle used for learning. The review proposed ruling out the use of the bicycle with lateral training wheels (BTW), recommending instead the use of a balance bicycle (BB).

The use of the BTW allows children to first learn how to pedal without needing to regulate their posture and balance on the bike, negating the fear of falling. The training wheels are, in this way, a task constraint (Davids *et al.*, 2008) (i.e., a type of equipment constraint that may limit a learner's tendency to fall off a bike due to poor postural regulation). Training wheels are designed to overcome the rate limiter of fear of falling. Training bikes aim to decompose the task of learning to cycle, by addressing the capacity of the learner to regulate posture on a bike as a rate limiter. Training wheels do not require the learner to maintain posture on the bike *while* pedalling at the same time. With this training bicycle, children are only allowed to explore the synchrony of regulating posture between their body and bicycle *after* removing the training wheels.

Recently, the BB has become a more popular approach for learning to cycle. This bicycle does not have pedals, nor training wheels, and is scaled so that the children's feet can touch the floor from the sitting position, which allows them to use their feet to propel themselves forward and manoeuvre the bike. In contrast to the BTW, the BB task constraint allows children to overcome the rate limiter of fear of falling by being able to place their feet on the ground whenever they feel instability. Another advantage is having no pedals to get in the way when learners use their feet to facilitate motion. Simultaneously, the BB cycle design allows the child to couple their postural regulation actions with the bicycle movements. This equipment design for learning allows the child to learn to maintain balance on the bike from the first moment. A key issue is that the constraints for regulating posture and balance differ considerably between the BB and the BTW bikes. When using the BB, children first learn how to balance before pedalling, and integration of these two task components will only occur after pedals are added with use of a conventional bicycle (CB).

According to the studies reviewed by Mercê et al. (2021c), the BTW, by having pedals and lateral training wheels that limit lateral oscillations, may not invite children to explore balance in forming a system between their body and bicycle from the beginning (Hauck et al., 2017, Hawks et al., 2020, MacDonald et al., 2012, Temple et al., 2016, Ulrich et al., 2011). The BTW decomposes the cycling task because it only encourages pedalling behaviours without the challenge of maintaining regulating posture on the bike. Burt et al. (2007) sought to clarify this issue by explaining that, when the lateral training wheels are removed, children experience instability, activating ineffective defence responses, freezing their movements and making their upper torso and arms rigid and inflexible. The freezing of movement degrees of freedom has been characterised as an indicator of the initial stage of learning a new motor skill, which needs to be navigated in developing skilled movements (Bernstein, 1967).

This hypothesis was later supported by a recent survey study (Mercê et al., 2022), which looked at the different cycling learning trajectories, based on the different types of bicycles used for the learning process. The data from this study indicated that children who used the BB, followed by the conventional bicycle, learned to cycle significantly earlier (4.16±1.34 years) than those who used the BTW, followed by conventional bicycle (5.97±2.16 years).

However, there is a need for data to verify these plausible suggestions and it is important to investigate relevant strategies to help children to explore and learn how to cycle, as quickly as possible. The framework of ecological dynamics can help teachers better understand and guide the process of learning to cycle. Learning how to ride a bike, underpinned by key concepts in ecological dynamics, is not a linear process based on increasing and cumulative learning. On the contrary, this perspective advocates that learning is a nonlinear process that emerges as each individual adapts and self-organises to key task constraints framed by relations with each learner's unique personal dynamics (Chow *et al.*, 2022, Chow *et al.*, 2007). Ecological dynamics is based on the premise that information and movement become highly coupled as skills are acquired and to make this coupling more adaptable and functional, learning/teaching/training must take into account contextual variability of tasks and the effective manipulation of key constraints (Button *et al.*, 2020). The non-linearity of the learning process, may result in the individual presenting erratic and unpredictable performance as they explore their own movement solutions (Chow *et al.*, 2022).

In the present study, the aim is to consider the contribution of a Constraint-led approach (CLA) to learning how to cycle. The distinguishing feature of the CLA is that its learning design is grounded in ecological dynamics and in Newell's model of constraints (1986), providing a powerful theoretical rationale for didactically structuring the learning process in cycling (Chow, 2013). Those constraints are predicated on dimensions of Newell's model (1986), proposing that movement emerges from the interaction of the personal characteristics of each individual (e.g., a learner's anthropometry, motor competence, motivation to learn, previous experience on the bicycle), the task (e.g., riding a type of bicycle), and the environment (e.g., gravity or cycling surface to be navigated). The CLA advocates that learners should be challenged and guided to use information to self-regulate actions in adapting to changing task and environmental constraint (Davids et al., 2008, Renshaw et al., 2010). This interplay of interacting constraints must be taken into account in the learning process (Renshaw et al., 2010). A key challenge of pedagogical practice is to identify the major task and environmental constraints that can be manipulated during the learning process.

When a teacher designs a learning task, they seek to combine constraints manipulations that are aimed at introducing ‘noise’ (e.g., in the form of task variability) in the learning environment, creating instabilities and perturbations which promote exploration of functional and adaptive movement solutions (e.g., Renshaw et al., 2010). Introducing, reducing or increasing sources and levels of noise (influencing system instability/stability) enables, inhibits or promotes particular affordances (i.e., opportunities for action that can be perceived and utilised within the environment, (Gibson, 1979) during performance available in the perceptual-motor landscape, e.g., for independent cycling in the environment. To achieve this pedagogical aim, learning situations must be organized in such a way that manipulating task constraints guide the learner’s search for new goal-directed movement solutions (Chow et al., 2007). In teaching children to cycle, teachers should perceive which movement responses may be available or not to emerge from the specific set of constraints interacting for individual learners in cycling, and design learning contexts accordingly. Furthermore “decisions on manipulation must be also based on prior analysis by practitioners” (Correia *et al.*, 2019). This means that, planning an intervention, according to the tenets of the CLA, also benefits from gathering previously general information related to the task and environment constraints (e.g., materials and spaces available), and the children’s behavioural tendencies and dispositions (e.g., past practice experiences, physical condition and movement competencies) (Correia *et al.*, 2019). Another key aspect of planning, using CLA methodologies, is to identify rate limiters and manipulate task constraints to overcome their effects (Davids *et al.*, 2008). Based on an ecological dynamics conceptualisation, three possible rate limiters on learning to cycle stand out: fear of falling, inability to regulate posture on the bike and the type of training bicycle used for learning. In this sense, the present study sought to investigate and compare the process of learning to cycle using the most common, traditional approach, the BTW, compared to the most recent one, the BB, in a two-week intervention.

Methods

Study Design

This study was approved by the Ethics Committee of the Faculty of Human Kinetics (approval number: 22/2019). The study design (Figure 1) was composed of: (i) a **baseline assessment**, which was conducted in the week before the **intervention**; (ii) a two-week intervention divided into two phases, the first including six sessions with the training bicycle, and the second composed of four sessions with the conventional bicycle; (iii) a **Post-intervention assessment**, which was undertaken daily after each session in the second phase of intervention; and (iv), a **Follow-up assessment** two months after the end of the intervention.

Participants were recruited through two parent associations that showed interest in joining the project. The schools were contacted and authorized the programme's implementation within their school playgrounds. Informed consent from parents and children's assent were obtained.

[Figure 1 near here]

Baseline Assessment

The following assessments were undertaken as part of the research protocol: independent cycling assessment; parental survey, to collect information about previous bicycle experience and frequency of physical activity; measures to determine participant body mass index (BMI, see WHO, 2006); motor competence (MCA, see Rodrigues *et al.*, 2019); and motivation (pictorial scale, see MacDonald *et al.*, 2012)

Independent Cycling

The definition of independent cycling is not consensual. Some previous cycling interventions have considered children as independent riders if they could cycle for a previously defined distance, even with help to start (e.g., Hauck *et al.*, 2017, Kavanagh *et al.*, 2020, Temple *et al.*, 2016). Other assessments just required participants to perform a self-launch in the bike (i.e., being able to start pedalling without assistance) and braking without any help (Hawks *et al.*, 2020, MacDonald *et al.*, 2012).

In the present study, independent cycling was defined as the ability to perform, sequentially and without any outside assistance, the following cycle milestones: i) self-launch, when the child can propel themselves and maintain balance while placing both feet on the pedals to starting pedalling (the researcher could only stabilize the bicycle in the beginning if the feet of the child could not reach the ground due to their small stature), ii) ride, when the child can cycle maintaining balance for at least 10m consecutively, without touching the floor with a foot or both feet, and iii), braking safely, when the child uses the bicycle brakes to stop and rest their feet on the ground, without falling (Mercê *et al.*, 2021c). For all these assessments, children were invited to cycle on a conventional bicycle, and researchers observed and registered data on each cycle milestone.

In all independent cycling assessments, as well as in all intervention sessions, the bicycles were individually adjusted to properties of each participant. The seat height of the BB was adjusted to each participant's inner leg measurement (i.e., the measurement from the top of the inner leg to the ankle), minus 2,5 cm (one inch). The BTW and CB seats were fitted at a height that provided the same level of knee flexion for each participant. The handlebar height was established for all bicycles at belly button level for each participant.

Participants and Group Constitution

The initial sample included 101 children. However, due to the CV-19 pandemic situation (which led to the lockdown of one of the schools), as well as some dropouts, the final sample consisted of 25 children (Figure 2 shows the flow of participants). The final sample of participants had an age range of 3 to 7 years (1 child aged 3 years, 3 aged 4 years, 7 aged 5 years, 8 aged 6 years and 6 aged 7 years, M=6.08 years; SD= 1.19), consisting of both sexes (11 girls and 14 boys), from two kindergartens and public elementary schools in Alfragide, Portugal. None of the sample participants were able to cycle independently at the beginning of the intervention (Figure 2).

After collecting data on the initial measures, the two experimental groups were formed. Stratified random samples were constituted based on the variables: sex and age. No statistically significant differences were found between the groups regarding BMI, motor competence, bicycle previous experiences, and practice of physical activity (all $p_s > .05$).

[Figure 2 near here]

Intervention

The *Learning to Cycle* (L2Cycle) *Intervention Programme* consisted of a two-week programme, underpinned by key concepts in ecological dynamics, developed to teach children without disabilities to cycle independently using a conventional bicycle. The intervention was initially planned by a team of researchers in motor development and learning, which included two experts to provide a detailed conceptual basis for the study using a CLA; after this discussion and preparation, the intervention learning design was analysed by another specialist, who besides having deep theoretical and scientific knowledge , also had an extensive experience in CLA application in the physical education teaching and sports coaching. Within this framework, the L2Cycle Intervention Programme was designed, specifically, to examine how learning to ride a bicycle in childhood could be shaped by task constraints manipulations, related to the kind of bicycle used. It was also implemented to guide pedagogical practice to facilitate teaching of children's key riding capacities to facilitate independent riding.

While considering individual constraints (e.g., frequency of physical activity, motor competence, motivation), the application of CLA in this learning intervention programme was focused on manipulating bicycle task constraints, in order to afford children opportunities to explore how to use perceptual information to guide cycling actions. Furthermore, according to this theoretical framework, the teacher's role is to guide the learner's discovery, as they explored the task, and not prescribing their actions. Therefore, all sessions incorporated two components, one of free exploration and one with a more game-based approach. In both learning contexts, augmented (verbal) information was provided on external movement outcomes (Davids et al., 2008). In the free exploration component, the child could play with and explore the bicycle, without any specific augmented information, in several spaces including a

30x15 m training field and a 20x15 m ramped area with sand and grass. In the game-based component, racing and obstacle games were designed to create instability, and promote and guide the exploration of functional and adaptive movement solutions (Chow et al., 2007). For the running games, in a space clear of any obstacles, the starting and finishing lines were established, and the teachers only offered the following instruction to learners: "At the start signal, you must move with the bicycle as quickly as possible to the finishing line". This verbal guidance was designed to facilitate an increase in the velocity of displacement with the bicycle, rather than to specifically prescribe how to cycle it. The BB children could explore the use of various cycle patterns (e.g., walk, run or glide) while the BTW children could explore various pedalling velocities or even pedalling by raising their body from the saddle. For the obstacle games, objects (i.e., cones) that were presented as ‘bombs’ occupied the cycling space and the children were asked to play with the bicycle inside that space, avoiding touching the ‘bombs’. This play design was expected to lead children to use their imagination and explore the manipulation of the handle bars so as not to hit the ‘bombs’. To promote tighter turns, the teacher could either manipulate the number of cones (increasing it) or the available space between the cones (reducing it), see Appendix 1.

The programme included two experimental groups which used different training bicycles in the six sessions of the first intervention phase, with one group using a balance bicycle and the other using a bicycle with training wheels attached (Figure 1). The training bicycle, which was the task constraint under study, was the only relevant difference in the intervention between groups. Both groups experienced similar conditions of learning design and information delivery, being together in the same sessions with the same teachers. The intervention was carried out by the same teachers, who maintained the same communication style and motivational strategies (see Appendix).

For intervention delivery, this study relied on professional support of physical education teachers, with a ratio of teacher-learners of one-to-two or, at maximum, one-to-three. All teachers involved in the program's application were selected beforehand, considering their motivation and openness to apply a program based on CLA and NPL. (Denzin & Lincoln, 2005, Moy *et al.*, 2019). All teachers had received training on the CLA approach in their academic background, especially testing its application during their training experiences, under the guidance of the principal researcher. In addition, before starting the program, they specifically received training on the principles and methodology of the L2Cycle program. The main research responsible for field application had five years of experience in conducting bicycle training with children, and all the others had approximately one year. The intervention programme was set up in the school's playground, which was reserved only for this intervention, the interest and support of the school administration for allocating the necessary time, space and equipment has an important facilitator of this study. The daily sessions lasted approximately 40 mins each, with 10 mins for preparation (e.g., each child learning to adjust helmet and bicycle to their anthropometric characteristics), 30 mins of effective practice (i.e., time for the child to explore using the bicycle, with and without instructional or organizational tasks). The ratio of child-bicycle was one-to-one during practice. All children used a helmet in all sessions, for their safety and educate them on the future relevance of using helmets (Spinks *et al.*, 2005).

After the initial intervention (first phase) with the two groups using different training bicycles, the programme then involved a transfer phase of four sessions using a conventional bicycle (second phase) (Figure 1).

Post assessment

The independent cycling assessment was taken daily for each participant at the end of each session of the second phase of intervention (i.e., 4 sessions with the conventional bicycle) (Figure 1). This procedure allowed the evaluation of how many sessions were necessary for each child to acquire each of the defined cycle milestones, as well as being able to cycle independently. Children who could not learn to cycle independently during those four sessions were coded as having learned in five sessions, as they would need at least one more session with the conventional bicycle to learn.

Follow-up assessment

Two months after the end of the intervention a follow-up session took place. Children were assessed for independent cycling again and parents were asked whether their children had cycled after the intervention programme, and if so, with what frequency and volume. This information was used to interpret the dependent variables of the follow-up session, if there had been a regression in learning (Figure 1).

Data Analysis

The normality of the distribution was tested and not assumed. A Mann Whitney test was used to investigate differences between groups regarding age, height, weight, BMI, motor competence (MC) and sessions needed to achieve the cycling milestones and independent cycling, with estimation of effect size values, *r*. Participant differences interpreted by sex, previous experience, frequency of physical activity, and reported motivation levels, were investigated using Chi Square tests. For all tests, a statistical significance level of p=0.05 was adopted.

Results

Baseline characteristics and independent cycling

Before the intervention, all children included in the study were unable to complete any of cycle milestones.

There were no correlations in our sample between decimal age, BMI or MC and the number of sessions needed to achieve independent cycling. Regarding cycling milestones, only a moderate positive correlation was found between the number of sessions needed to achieve the ability to ride independently and the child's BMI (R_s=0.583, p=0.002).

The groups did not differ in relation to gender, age, height, weight, BMI, MC, previous experiences on different bicycles, practice of physical activity or motivation (all p_s>0.05). Descriptive statistics per group and for the total sample regarding age, body composition and MC scores are presented in Table 1.

[Table 1 near here]

Intervention effects on independent cycling

The post-intervention assessment procedures were applied daily after each of the four sessions in the second intervention phase (using the conventional bicycle). All participants in the BB group successfully acquired independent cycling within two sessions when transferring to the conventional bicycle. In the BTW group, three participants (one boy aged four years and two girls aged five years), did not achieve independent cycling after the four sessions with the conventional bicycle. Figure 3 presents the necessary sessions needed to achieve each milestone and independent cycling for each child by treatment group.

[Figure 3 near here]

Although all children in the BB group successfully acquired independent cycling (i.e., 13 out of 13 children), and 3 children in the BTW group failed to acquire it (i.e., only 9 out of 12 children), the number of participants who learned how to cycle independently was not significantly different between groups. However, children in the BB group all learned the cycling milestones in fewer sessions than the BTW group. The performance data showed that for self-launch, the BB children needed 1.3 sessions while the BTW children took 2 sessions; for riding the bikes, the BB children needed 1.15 sessions while the BTW children needed 2.58; for braking, BB children needed 1.15 versus 2.45 sessions of BTW children; and, finally, for the independent cycling the BB children needed only 1.42 while BTW children needed 2.92 sessions. These results revealed that BB children required significantly fewer sessions with the conventional bicycle to: self-launch ($U=19$, $z=-2.52$, $p=0.012$, $r=-0.56$), ride ($U=32$, $z=-2.84$, $p=0.005$, $r=-0.57$), brake ($U=34$, $z=-2.73$, $p=0.006$ $r=-0.55$), and achieve independent cycling ($U=31$, $z=-2.71$, $p=0.007$, $r=-0.54$), see Table 2.

[Table 2 near here]

Follow-up assessment

All children who learned to cycle independently during the intervention could still do so in the follow up session. Between the intervention and the follow up assessment, 44% of the children continued cycling at home. Most of them continued to cycle with the CB, and only three returned to using BTW in activities with their parents, who indicated safety issues as their main reason for the change. The other 66% of children never cycled again, the reasons for not having cycled were mostly related to not having a bicycle, and COVID-19 lockdown and vacations.

The three children who did not achieve independent cycling during the intervention did not try to cycle during the interruption, and they were still unable to achieve this milestone in the follow up session.

Discussion

The L2Cycle programme had an 88% success rate, since 22 out of 25 children learned to cycle independently, with a 100% success rate in the BB group. These data show that a ‘bicycle camp’ (as a learning intervention) of 10 sessions of 40 minutes each can be enough to help children from 3 years of age, without disabilities, to learn to ride a conventional bicycle, independently. Currently in Portugal, where this study was conducted, cycling is integrated as part of the elementary school curriculum (ENMA, 2019). However, our data suggest that programmes to learn to cycle can be successfully introduced even earlier, in kindergarten.

Balance Bike versus Training Wheels as key task constraints

Being able to cycle is an important motor milestone, but the process of learning can be complex, since children needed to learn how to start, turn, brake, pedal and regulate their body posture and the bicycle, while maintaining balance during all these tasks. Some studies claim that the most challenging aspect during the acquisition of cycling skills is mastering balance (Ballantine, 1992, Becker & Jenny, 2017, Shim & Norman, 2015). For this reason, some programmes (Balanceability, ICanShine, 2019), based on some research, avoid utilising the lateral training wheels approach (Burt *et al.*, 2007, Ulrich *et al.*, 2011). Despite being the most commonly used worldwide approach, training wheels do not afford children opportunities to explore their balance and their postural regulation on and with the bicycle, i.e., the bicycle becomes too stable and not "balanceable". By attaching the extra wheels to the bicycle, a bigger support area is ensured for the learner-bike system, and consequently, the levels of stability increase and demands on balance decrease. Also, with training wheels, no lateral movements of the bicycle are afforded, reducing the amplitude of movements that are needed when riding a conventional bicycle. But there are also advantages in promoting a greater stability, for example, when using the bicycle with training wheels (BTW). These advantages mainly exist in alleviating children's fear of falling by using stabilisers (Temple *et al.*, 2016). The use of stabilisers could be seen as helping children to overcome the rate limiter of learning to pedal when cycling (Davids *et al.*, 2008). In this way, children can start practising pedalling from the beginning. However, these benefits might not be enough to compensate for the disadvantage of what Burt and colleagues (2007) called "a counterproductive motor plan". They explained that, when the training wheels are removed, the lack of experience that children have in maintaining balance on bike without stabilisers, can promote ineffective defensive responses. This defensive movement strategy may lead to a reduction in use of movement system degrees of freedom in cycling (Bernstein, 1967). This response may be dysfunctional in the long term since, by freezing their movements and making their upper torso and arms rigid and inflexible, learners impair their postural orientation and control on the bicycle, hampering the process of learning to cycle.

The differences between the two groups when transitioning occurred from the BTW to the CB, may be due to the freezing responses referred by Burt *et al.* (2007). For children to learn how to cycle independently they must acquire and master balance and postural regulation on the bicycle; but they need to be able to 'unfreeze' the degrees of freedom (DOF) in their upper torso and arms to move to the next stage of skill adaptation in learning (Chow et al., 2022), which is a difficult challenge.

More recently, Berthouze and Lungarella (2004) updated Bernstein's (1967) ideas, suggesting that a single pathway of freeze and freeing DOF may not be enough for acquiring skill in complex coordination tasks. They argued that dynamic alternations between freezing and freeing DOFs could be the solution, and perturbations are needed to push the learner-bike system outside boundaries of postural stability, which could trigger these freezing and freeing explorations of system degrees of freedom.

All participants who did not learn to cycle during the intervention belonged to the BTW treatment group. By cycling with BB, children are constantly dealing with balance and postural regulation challenges. These task constraints act as perturbations, as referred by Berthouze and Lungarella (2004), which trigger the freezing-freeing dynamic and, consequently, allow children to progressively acquire the balance needed on the bicycle. On the other hand, the use of stabilising training wheels in practice, is indeed a possible pedagogical solution to reduce the degrees of freedom problem in the process of learning to cycle (Newell & Mcdonald, 1994). But children do not experience the challenges of balancing and postural regulation on the bike, since if no perturbations are created, the learner-bike system tends to remain too stable. For some children, when the training wheels are removed the perturbations and the complexity could be so big that they simply freeze, not exploring the freezing and freeing dynamics and hampering the learning process. In this way, it is also not surprising that children in the BTW group learned more slowly than children in the BB group, needing significantly more sessions to self-launch, ride, brake, and cycle independently, see Table 2. By observing these children, our findings are in line with comments of Burt *et al.* (2007), who observed that children who used training wheels become rigid and tense when transferring to the CB. From an ecological dynamics perspective, the participants' adaptations to the BTW task constraint may not be considered a "counterproductive motor plan", but rather "a restrained exploration strategy" for learners. Our data imply that not being able to explore balance and postural regulation on the BTW bike, delays the ability to adapt to a conventional bicycle. Indeed, this "restrained exploration strategy" was so restrained that it did not afford a representative learning environment for learners, therefore, not fulfilling a key pedagogical principle of nonlinear pedagogy (Chow, 2013). Indeed, the suggestion is that the BTW may have 'over-restrained' exploration of balance and postural orientation in learners, thereby inhibiting a smooth transition in learning to use the conventional bicycle.

In contrast, using bikes with the BB, the child is able to manage freezing and freeing degrees of freedom during the learning process, according to their own levels of motor competence and pace of learning, which is aligned with key assumptions of the Constraints-led approach (e.g., Renshaw *et al.*, 2010) and ecological dynamics (Araújo *et al.*, 2006). By not having pedals (which could limit the child to only pedalling or spatially hinder other forms of propulsion with the feet on the ground), or training wheels (which limit lateral oscillations), this bicycle affords exploration of different types of locomotion, and children can learn to walk, run, hop or glide in the learner-bicycle system (Mercê *et al.*, 2021a). When children glide, by lifting their feet off the ground and just controlling their balance on the bicycle, they are incorporating the balance of the new child-bicycle system (Heiman *et al.*, 2019). So, it is not surprising that these children can rapidly learn balance and ride when they are required to transit to the CB. Our results showed that, among the 13 children of the BB group, 11 of them (84.6%) were able to achieve the ride cycle milestone on the CB in the first session. These children ended up being able to ride on the CB during the second session. On the other hand, only 4 children (33.33%) of the BTW group were able to ride on the first session with the CB, and after the second session only 6 children (50%) did so (see Figure 3, panel B). It is important to note that one of the factors that influence balance stability during ride is ‘system velocity’, signifying that, when riders reach a requisite level of velocity, it’s easier to maintain balance on the cycle (Astrom *et al.*, 2005). Its possible that the BTW group may have had more difficulty in riding the CB due to lack of requisite velocity, despite these children possibly being able to explore higher velocity levels in practice, due to the safety of the lateral wheels. When they transited to the CB, they needed to implement balance control on the bicycle to perform the initial pedal strokes that allowed them to acquire velocity on the bike. It seems that the challenge of coping with postural freezing preceded the acquisition of system velocity. On the other hand, as the children in the BB training group already had the opportunity to explore and acquire balance on the bicycle, they may have been able to transfer it more efficiently to using the CB.

During the sessions with the CB, self-launch was also acquired earlier, i.e., in fewer sessions, by children transferring from the BB group. Self-launch is a dynamic balance task. When using the CB, children need to put their feet on the pedals to start riding in absence of contact with the ground. With the BB, self-launching is also dynamic and essential, because children do not have pedals to propel themselves, so they must manage balance as their feet are off the ground when they walk or run to start riding the bike. In addition, during learning they explore their balance and postural regulation, which is known to improve with BB practice (Shim *et al.*, 2021). On the other hand, using the BTW, children do not need to practise the bicycle's propulsion with their feet on the ground, they can just sit, rest their feet on the pedals without their balance being disturbed, and pedal. The greater practice of a dynamic balance task during the learning stage probably contributes to the greater success in self-launch of children in the BB group after transitioning to the CB (see Figure 3, panel A).

Learning to brake in the CB seemed to also be easier for participants in the BB group. To brake safely, the child must squeeze the brakes but also place both feet on the ground, to stop in a controlled manner without falling. Both groups had the opportunity to explore the brakes with their training bicycles. However, with the BTW, children can brake and keep their feet on the pedals. They do not need to place their feet on the ground, because the lateral wheels provide that stability. Inversely, with the BB there is no extra support when braking, so children have to place their feet on the ground to avoid falling. Thus, the use of BB, constrains children to explore the whole action of braking from the first session. In the BB group, 11 children (84.6%), safely braked in the first session with CB, whereas only four children (33.3%) of the BTW group did so (see Figure 3, Panel C).

According to our results, using the BB seems to be a more effective and efficient way to learn to cycle than using the BTW, which is in line with suggestions from previous research (Ballantine, 1992, Becker & Jenny, 2017, Mercê *et al.*, 2021c, Shim & Norman, 2015). In particular, the current data are well aligned with outcomes reported from a recent study that compared different cycling learning trajectories (Mercê *et al.*, 2022). That investigation verified that children who used the BB to learn to cycle learned significantly earlier (at an average age of 4.16±1.34 years), compared to those who used the BTW (5.97±2.16 years). These mean ages corresponded to the age band included in the present study.

That study also found that the single use of a CB led to a later learning age (7.27±3.74 years). This is an important finding because it implied that excessive complexity of the motor task of cycling with a CB may have led to a later learning age, probably because more time is needed to explore and control the motor system degrees of freedom. The BB, by not having pedals or side wheels, allows a greater exploration of a large part of these degrees of freedom from early in learning. Children can practice how to propel, travel and brake safely from the first session, because self-organization is preserved, i.e., each child can explore according to their perceived motor competence. This hypothesis can be tested in future studies, analysing the postural adjustments of children during the process of learning to cycle with the different types of bicycles, in order to better understand the process of freezing and freeing the degrees of freedom, and their exploration during this learning task (Bernstein, 1967, Berthouze & Lungarella, 2004).

The study's results highlight not only the success of the BB as a learning tool for cycling, but also the efficacy of the L2Cycle programme, which is encouraging for its future replicability.

Following up L2Cycle program

The current pandemic circumstances represented a historical threat for the implementation of this project, making it impossible for one school and for children from other schools to participate. Despite these circumstances, the follow-up seemed to verify the programme's success, since all the children who had learned how to cycle could still cycle in the follow up session. The cliché of never forgetting how to ride a bicycle was confirmed in this study, which is particularly important for the group of children who did not cycle between the intervention and follow-up.

Practical Suggestions and Future Studies

In terms of practical applications, these findings suggested that parents, teachers, coaches, and educators choose BB over BTW in learning to cycle. Studies have indicated that, when young children have the opportunity to explore using the BB early, they can learn how to cycle independently from the age of two and a half years (Mercê *et al.*, 2022). In the present study, we also verified this finding, the 3-year-old participant was included in the BB group and successfully learned to cycle. So, we suggest that parents and educators make a BB available to children as a playful toy for informal learning interactions as soon as possible. In this way, children will be able to play with a new, enjoyable toy and, simultaneously, improve their balance and postural regulation (Shim *et al.*, 2021), giving them the chance to achieve independent cycling earlier (Mercê *et al.*, 2021b).

One of this study's aims was to guide pedagogical practice to facilitate teaching children's key riding milestones and independent riding. After the L2Cycle intervention, there are some practical suggestions that could be considered for future interventions in this area. First, interventions should include ramps, since ramps seemed to promote the greatest exploration of the glide pattern in the BB group participants. Possibly, the increase in velocity gained when descending the ramps by accelerated under the constraint of gravity, acts as an inviting affordance (Withagen *et al.*, 2012) for children to lift their feet of the ground and simply glide. During the glide moments children seemed to be exploring how to maintain balance on the bicycle, so these moments should be promoted. Implementing a non-linear pedagogy approach, our findings support the idea that a teacher's role should be to guide self-discovery and self-organization in their learners, by manipulating constraints in order to create instability and promote the discovery of new motor solutions (Davids *et al.*, 2008, Renshaw *et al.*, 2010). In this sense, there is no need to instruct children to lift their feet, the teacher or educator could simply use ramps and other games to the discovery of this functional behaviour. The ramp's affordances may also mean that velocity is a key parameter for learning to glide, inviting further investigation in future studies whether changing the value of this cycling task constraint could lead to emergence of structurally different cycling coordination patterns. Second, due to this study's experimental design, all children transitioned to the conventional bicycle after the six sessions on the training bicycle. However, children who had mastered the glide in the first few sessions (e.g., in < 6 sessions being able to perform a glide while turning), could transit to the CB earlier.

Conclusion

The L2Cycle programme revealed that children learned to cycle independently significantly more quickly when using the BB rather than the BTW. A two-week bicycle camp can be effective for children from 3 years old, without disabilities, to acquire independent cycling. These results provided evidence supporting the inclusion of a series of BB cycling sessions in the school curriculum, starting at the kindergarten level.

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Response to Editor and Reviewers

Dear Editor,

The authors would like to thank both reviews. After this first round, we felt that the comments contributed to deepening our discussion and reflection on the data, which significantly improved the manuscript.

As requested, we leave below the comments and answers to both reviewers. We identified the changes in the manuscript requested by reviewer 1 with a yellow background, by reviewer 2 with a blue background and, in cases where the change was requested by both reviewers, with a green background.

The authors.