Universidade de Lisboa
Faculdade de Motricidade Humana

Learning to Cycle: the influence of individual constraints and of the training bicycle

Cristiana Isabel André Mercê

Orientadores: Professora Doutora Rita Cordovil de Matos e
Professor Doutor Marco António Colaço Branco

Tese especialmente elaborada para obtenção do grau de Doutor em Motricidade Humana, na especialidade Comportamento Motor

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Aos meus Pais. A minha fonte de inspiração e orgulho.

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Abstract

The present thesis aimed to investigate an important motor milestone in children's life, the process of learning to cycle, more specifically to: 1) systematically review the intervention programs for learning to cycle; 2) investigate different constraints that influence this learning process; 3) create and implement a learning to cycle intervention, and compare the learning process between the balance bike (BB) and the bicycle with lateral training wheels (BTW); 4) analyse the BB's cycling patterns and investigate if velocity is a control parameter; 5) compare the motor variability during the learning process with BB and BTW. The methodology included a systematic review, one web-survey, a longitudinal intervention, and two cross-sectional studies. The systematic review pointed that it should be adopted a progressive cycle learning strategy, primarily using training bicycles and simpler exercises. The survey identified differences in the age of learning to cycle (ALC) according to the: training bicycle used, with the BB's approach revealing the lowest ALC; birth decade, which has decreased since 1970-79; physical activity, with people more active learning to cycle earlier; and birth order, with the younger children learning earlier than only children. The "L2Cycle" program was applied to 25 children (6.08±1.19 years), having a success rate of 88% (100%-BB, 75%-BTW). BB's children needed fewer days to cycle independently (self-launch, ride and brake). Seven BB's cycle patterns were categorized. After six sessions, children explored more cycling patterns and increased their global velocities. The results support that velocity is a probable control parameter. During the learning process, the BB allowed a greater motor variability than the BTW, leading to a faster adaptation to the traditional bicycle, which is a potential reason for its greater learning efficiency.

Keywords: learning, bicycle, task constraints, affordances, variability.

Resumo

Esta tese teve como objetivo investigar um importante marco motor na vida da criança, o processo de aprender a andar de bicicleta, visando especificamente: 1) rever sistematicamente os programas de intervenção para fomentar esta aprendizagem; 2) investigar os diferentes constrangimentos que influenciam esta aprendizagem; 3) criar e implementar um programa de aprendizagem, comparando o processo de aprendizagem entre a bicicleta de equilíbrio (BE) e bicicleta com rodas laterais (BRL); 4) analisar os padrões de motores que existem na BE e investigar se a velocidade é um parâmetro de controlo; 5) comparar a variabilidade motora durante a aprendizagem com a BE e BRL. A metodologia incluiu uma revisão sistemática, um inquérito online, uma intervenção longitudinal e dois estudos transversais. A revisão sistemática apontou que deve ser adotada uma estratégia de aprendizagem progressiva, utilizando primeiramente bicicletas de treino e exercícios mais simples. O inquérito verificou diferenças na idade de aprendizagem (IA) de acordo com: a bicicleta de treino, com a abordagem da BE a revelar menor IA; década de nascimento, a qual decresceu desde 1970-79; atividade física, com pessoas mais ativas a aprendem mais cedo e; ordem de nascimento, com o irmão mais novo a aprender mais cedo que o filho único. O programa de aprendizagem “L2Cycle” foi aplicado a 25 crianças (6,08±1,19anos), revelando um sucesso de 88% (100%-BE, 75%-BRL). As crianças da BE necessitaram de menos dias para andar de bicicleta autonomamente (iniciar, pedalar em equilíbrio e travar). Foram categorizados sete padrões motores na BE. Após seis sessões as crianças exploraram mais padrões e aumentaram as suas velocidades globais. Os resultados suportam que a velocidade é um provável parâmetro de controlo. Durante a aprendizagem, a BE induziu uma maior variabilidade motora que a BRL, levando a adaptação mais rápida à bicicleta tradicional, o que é uma potencial razão para a sua maior eficiência de aprendizagem.

Palavras-chave: aprendizagem, bicicleta, constrangimentos da tarefa, *affordances*, variabilidade.

Publications

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136). Faculdade de Ciências do Desporto e da Atividade Física - Universidade de Coimbra.

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Tables

Abbreviations

ADHD – Attention-deficit/hyperactivity disorder

ASD – Autism spectrum disorder

BB – Balance bicycle

BMI – Body mass index

BTW – Bicycle with two lateral training wheels

B1TW – Bicycle with one lateral training wheels

BC – Body composition

BSG – Bike skills group program

CLA – Constraints-led approach

CRQA – Cross recurrence quantification analysis

CP – Cerebral palsy

DCD – Developmental coordination disorder

D&B – Downs and Black checklist

deg/s – Unit of measurement of angular velocity

DOF – Degrees of freedom

DS – Down syndrome

EC – Experimental group

g – Unit of measurement of gravitational acceleration

IMUs – Inertial measurement units

ISAK – International Society for the Advancement of Kinanthropometry

L2Cycle – Learning to Cycle

LA – learning age

LyE – Largest lyapunov exponent

LED – Light Emitting Diode

MC – Motor competence

MCA – Motor Competence Assessment Battery

MR – Mental retardation

NLP – Nonlinear pedagogy

O1 – 1st observation moment

O2 – 2nd observation moment

O3 – 3rd observation moment

PA – Physical activity

PCF – Portuguese Cycling Federation

RCMDE – Refined composite multiscale dispersion entropy (RCMDE)

RCT – Randomized controlled study

RQA – recurrence quantification analysis

T12 – 12th thoracic vertebral

T2 – 2nd thoracic vertebral

TB – Traditional bicycle, with pedals and no training wheels

USA – United States of America

WHO – World Health Organization

Chapter 1

1. Introduction

1.1. Rationale for the Investigation

Cycling is a mode of transport culturally acquired, which was invented to be more efficient, economic and less tiresome than our natural modes of locomotion, such as walking or running. The bicycle allows people to move during more time, for longer distances and with less effort (Ballantine, 1992; Herlihy, 2004). Recently, riding a bicycle has been considered as a foundational movement skill (Hulteen et al., 2018), and as an important motor milestone in children's lives due to its various benefits (Zeuwts et al., 2020; Zeuwts et al., 2015). Children who cycle to shool regularly have better cardiorespiratory fitness, less body fat and lower incidence of metabolic syndrome (Ramírez-Vélez et al., 2017). Besides these health related benefits, cycling has social benefits for children, such as allowing for a greater exploration of the environment, and making new friends (Karabaic, 2016; Orsini & O'Brien, 2006). Considering its benefits, cycling should be promoted as early as possible. To ride a bicycle, people need to learn a new way of moving, which requires pedaling and controlling the balance simultaneously in a new instrument (the bicycle). Cycling is, in this way, a complex task, and investigating the process of learning to cycle can be a key element to promote an earlier cycling onset.

Motor learning is a dynamic process (Kelso, 1995), which occurs within a complex system of interactions and relationships between the person and their environment. Framing the learning to cycle process in Bronfenbrenner's (Bronfenbrenner, 1979, 1995) bio-ecological model, different variables, from the different layers of the environment (proximal to distal), should be investigated to better understand what factors positively impact and what factors hamper the age of independent cycling onset. From a more proximal level (microsystem), the participation in intervention programs to learn how to cycle will influence the learning process. So, to better understand this learning process, it is important to know which intervention programs for learning to cycle exist, and which are their characteristics and levels of success. Although several systematic reviews have focused on the effect of interventions to promote cycling frequency, skills and safety (Richmond et al., 2014; Sersli et al., 2019; Spinks et al., 2005; Yang et al., 2010; Zeuwts et al., 2020), the key aspects of a successful program to learn how to cycle still need to be further explored. Other proximal and more distal variables that can also influence the process of learning to cycle should also be investigated, such as the child's characteristics (e.g., morphology, level of physical activity and level of motor competence), the family characteristics (e.g., only child versus having siblings), the task characteristics (e.g., type of bicycle(s) used for learning), or the decade of birth (i.e., chronosystem), which might be related for example with different strategies used for learning and with different levels of importance given to cycling.

At a microsystem level, while children learn how to cycle, they are influenced by the interaction between the existent individual, task and environmental constraints (Newell, 1986). In the process of learning to cycle, task constraints have recently been deserving more attention due to the increasing popularity of the balance bike (BB) (Becker & Jenny, 2017; Shim & Norman, 2015). The BB, also called run bike, glider bike or pedal less bike, consists in a two-wheels bicycle without pedals nor training wheels, in which the child self-propels with feet on the ground. The basic principle is to allow the child to explore the body-bicycle stability from the beginning of the learning process rather than focusing in acquiring pedalling first. Some authors (Hilpern, 2016b; Martins, 2017) and entities, namely the Portuguese Cycling Federation (PCF, 2020b), claim that children who practice with a balance bicycle can make a quicker and smoother transition to the traditional bicycle than children who ride a bicycle with training wheels (BTW). The idea is that the BTW creates a limited sense of stability control, which seems to trigger defensive and postural freezing responses when children try to cycle in a traditional bicycle (TB) (Burt et al., 2007). On the other hand, the BB allows children to explore the body-bicycle stability autonomously and at a individual pace, leading to a lower probability of falling when they transition to the TB (Ballantine, 1992; Hilpern, 2016b).

The arguments in favour of the BB's use have been mainly based on empiric experiments and manufacture's information. For a deeper understanding of the process of learning to cycle, it is important not only to determine which is the most effective and efficient training bicycle (i.e., the one that helps most children to cycle autonomously with shorter periods of practice), but also to understand why a certain training bicycle might be better than the other. Despite the above-mentioned arguments in favour of the BB, to our knowledge, no study has specifically addressed and compared the process of learning to cycle using different learning bicycles. The fact that the BB allows an inherent exploration of the children body-bicycle stability may imply a greater movement variability and exploration during the learning process, which seems to be a promising argument for its greater success. The same coordination task, like cycling, could be performed by multiple elements or degrees of freedom (e.g., motor units, muscles, joints, limbs, movement axis and planes), and by a wide variety of combinations between them (Latash et al., 2002). The exploration of this movement variability affords adaptability, which in turn allows the system to deal and overcome with unexpected and challenging situations as, for instance, to transit from the training bicycle to the traditional bicycle (Kedziorek & Blazkiewicz, 2020; van Emmerik & van Wegen, 2002).

1.2. Thesis general and specific goals

The primary aim of this thesis was to investigate the influence of individual constraints and type of training bicycle, more specifically the BB and BTW, in the process of learning to cycle. The following specific aims guided our studies:

1. To systematically review the intervention programs that aim to teach children to ride a bicycle, in order to identify and compare specific methodologies and protocols (Chapter 2);
2. To investigate different constraints that influence the process of learning to cycle (Chapters 3 and 4);
3. To create and implement a learning to cycle intervention program, with two groups of children using two different training bicycles, the BB and the BTW, in order to analyse and compare the learning process between them (Chapter 5). The influence of specific individual constraints, such as motor competence, body composition and physical activity will also be explored as secondary aims of this study;
4. To analyse children's cycle patterns when riding a BB and to test the hypothesis that velocity as a control parameter that drives the system along those different cycling patterns (Chapter 6),
5. To investigate and compare the motor variability during the process of learning to cycle with the BB and with the BTW (Chapter 7).

1.3. Structure of the thesis

The present thesis addresses the process of learning to cycle, according to the specific aims previously defined.

First, a systematic review regarding the intervention programs that aim to teach children to cycle is presented in chapter 2. This chapter characterizes the current state of the art regarding learning to cycle interventions, by presenting several protocols and methodological considerations, which were later considered to develop the Learning to Cycle Program (L2Cycle).

Chapters 3 and 4 explore the influence of different constraints in the process of learning to cycle. The Learning to Cycle Survey was created for data collection in these two studies. The influence of different constraints on the age of independent cycling onset is explored, more specifically the type of training bicycle and the decade of birth are analysed in chapter 3, and the influence of physical activity and birth order are analysed in chapter 4.

To corroborate a suggestion of the systematic review (chapter 2) and one of the results of the survey (chapter 3), which pointed out the balance bicycle as the most efficient training bicycle to acquire an earlier independent cycling onset, the L2Cycle intervention program was created an implemented (Chapter 5). This intervention analyses and compares the learning process in two groups of children using either the BB or the BTW. The influence of motor competence, body composition and physical activity are also explored.

In chapter 6 and 7 a more specific analysis of the learning to cycle process is presented. In chapter 6, an observation tool to characterize cycling patterns is suggested. This tool was created based on the qualitative analyses of the patterns observed during the L2Cycle intervention. Also, velocity is proposed as a control parameter that drives the system through its different states, leading to the emergence of progressively more complex cycling patterns. In chapter 7, a non-linear analysis is performed to study the variability of the child-bicycle system according to the type of training bicycle used. This analysis highlights the existence of a greater variability provided by the BB than by the BTW, which seems to have a positive effect on the learning process.

Finally, the chapter 8 presents the thesis general discussion and conclusions, methodological considerations, practical implications and suggestions for future studies.

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Chapter **2**

2. Training programmes to learn how to ride a bicycle independently for children and youths: a systematic review

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2.1. Abstract

Background: The bicycle is a popular means of transportation, exercise, recreation and also socializing for children worldwide, allowing them several physical and psychological benefits. Several methodologies and types of bicycles have been used for learning how to cycle, however, the best approach is still unclear. Purpose: The purpose of this study was to review and summarize the existent studies of programmes that aim to teach children how to ride a bicycle independently, in order to identify which possibilities lead to a more efficient intervention. Methods: A comprehensive search was performed in seven electronic databases (TRID, CENTRAL, Web of Science, SCOPUS, EBSCO, ProQuest Dissertations and Theses and Google Scholar), including grey literature and the citations of relevant articles, from their inception to April 2020. Studies were included according to the eligibility criteria: children and youths aged 18 or less, with and without disabilities; intervention programmes that aimed to teach how to ride a bicycle with a pre- and post-intervention assessment regarding the ability to ride. The Downs and Black checklist was used for quality assessment. Results: Nine intervention studies, including a randomized controlled trial, were included. The mean quality score was 11.8±3.6 points. Just one of the included studies was targeted at children without disabilities. Different facilitating constraints and barriers were identified, which resulted in a list of tips for future intervention programmes to teach children how to ride a bicycle. The facilitating constraints were using a progressive learning strategy; using an individualized approach; making bicycle adjustments; having motivated children and having family support throughout the learning process. The barriers were: the fear of falling; lack of parents' support; and lower leg strength. Learning to cycle was also associated with a decrease in sedentary time, increase in physical activity, improvement in leg strength, and a positive influence on body composition, indicating that it can be a solution to disrupt the cycle of consistent weight gain over time in children with disabilities. Conclusions: There is a gap concerning intervention studies to teach children without disabilities how to cycle. The best strategy is probably a progressive learning strategy by using simpler training bicycles that enable the child to explore balance from the beginning, and simpler exercises first. Teaching programmes should adopt an individualized intervention, feedback and motivation, considering each child's specific characteristics.

Keywords: children, learning, bicycle, intervention, disabilities.

2.2. Introduction

The bicycle is a popular means of transportation, exercise, recreation and also socializing for children worldwide (Macarthur et al., 1998). Besides its utility component, cycling has several health benefits for children, such as improving cardiorespiratory fitness, body composition, and decreasing the chances of having metabolic syndrome (Ramírez-Vélez et al., 2017). Cycling also promotes the development of relational and emotional skills (Karabaic, 2016; Orsini & O'Brien, 2006), and it facilitates the exploration of the environment, enabling children to become more independent and active (Smith et al., 2017). In addition, a recent study showed a positive association between active transport by cycling and academic achievement (Phansikar et al., 2019). For all of these reasons, learning to ride a bicycle is an important milestone (Zeuwts et al., 2020; Zeuwts et al., 2015).

Despite its benefits, cycling might also cause some injuries, and cyclists sometimes get involved in road accidents (Richmond et al., 2014). Since the proficiency of children's cycling skills is an important component of bicycle-related accidents (Corden et al., 2005), a range of policies and programmes were developed worldwide to promote safe cycling, e.g. 'Bikeability' from the UK, 'Cycle Skills for School Kids' from New Zealand, 'Master on your bike' from Belgium, 'Cycle for Health' from the USA, and 'Bike Ed' from Australia (Ducheyne et al., 2013; Imberger et al., 2007). The programmes aforementioned usually aim at two targets: (i) to create the favourable conditions to increase cycling in children and youths; and (ii) to promote safer cycling by increasing cyclists' traffic knowledge and improving their cycling behaviour on the road. Most of these programmes take place in schools, sometimes they have an 'on road traffic component', and the participants already possess the basic skills to ride a bicycle.

Due to the importance of cycling benefits and the need to prevent injuries and road/cycling accidents, cycling has been largely studied in the literature. There are five systematic reviews, which address programmes for children, related to cycling: two of those reviews focused on programmes to promote cycling frequency (Sersli et al., 2019; Yang et al., 2010); one focused on the promotion of bicycle helmets (Spinks et al., 2005); one on injury prevention (Richmond et al., 2014); and another one focused on the development of the intrinsic factors in young cyclists (Zeuwts et al., 2020). However, to our knowledge, none of the published revisions or ongoing ones (already registered) aimed to address programmes designed to teach children how to ride a bicycle.

Several methodologies and types of bicycles have been used for learning how to cycle (Cain et al., 2012). The most traditional approach consists of using lateral training wheels to increase the stability of the bicycle, enabling children to explore and acquire pedalling. Most recently, the balance bike has been used. This bicycle has no chain, pedals or training wheels, and children use their feet directly on the floor to propel themselves (Becker & Jenny, 2017; Shim & Norman, 2015), which allows children to first train and acquire balance before starting to use the traditional bicycle. The roller bicycle, with one or two rollers instead of the wheels, is also used and promotes a progressive challenge in balance using rollers progressively tapered on the ends. Usually, this bicycle is targeted towards children with disabilities (Klein et al., 2005). A less frequent option is the Gyrobike Gyrowheel (Murnen et al., 2009), which uses a rotating gyroscope in the front wheel to provide additional stability.

Although there are different approaches to teaching children how to ride a bicycle, until now, some questions remained unanswered, such as the best type of bicycle or the best pedagogical or methodological options regarding the programme and session's duration, the session's frequency, the participant/instructor ratio, or the programme contents and exercises.

It is fundamental to identify the best methodologies to teach children how to ride a bicycle. The sooner children learn to cycle independently; the sooner they will be able to take advantage of all its benefits. Thus, in this study, we aim to review and summarize the existing intervention programmes on learning how to ride a bicycle, to compare their protocols and outcomes, and identify the best options and efficient interventions for children and youths with and without disabilities.

2.3. Methods

2.3.1. Protocol and registration

The present review was conducted according to the PRISMA guidelines (Moher et al., 2009). The review protocol was registered in PROSPERO (International prospective register of systematic reviews) with ID number CRD42020153871.

2.3.2. Eligibility criteria

The research question in this was framed by the PICOS acronym (Moher et al., 2009), which stands for: Population (children and youths up to 18 years of age, who participated in a bicycle training programme and who could not cycle in the beginning of the programme); Intervention (bicycle training programmes that aimed to teach how to ride a bicycle independently, which had to include face-to face training where participants have a 'hands-on' component to ride one or more kinds of bicycles); Comparator (pre/post-training evaluation to assess participants' ability to cycle); Outcomes (being able to ride a conventional two-wheel bicycle independently after the intervention, evidence relating to effects on overall physical activity, body composition, well-being or health was also considered); and Study design (experimental studies with pre/post assessment of the ability to ride a bicycle).

Inclusion criteria were: (i) children and youths aged up to 18 (included); (ii) participants with and without disabilities; (iii) interventions with a hands-on training component; (iv) intervention studies; (v) studies with a pre- and post-intervention assessment regarding the ability to ride a conventional two-wheel bicycle independently. Studies were excluded if: (i) participants knew how to ride a bike prior to the intervention; (ii) intervention studies did not aim to teach children how to ride a conventional two-wheel bicycle; (iii) studies did not evaluate whether participants learned to ride a conventional two-wheel bicycle; and (iv) intervention was solely based on stationary bicycles or bicycle ergometers. No time or language limitations have been established.

2.3.3. Search strategy and sources

A comprehensive literature search was conducted applying multiple strategies: (i) search for literature indexed in academic databases; (ii) search for grey literature including reports, evaluations, and theses; and (iii) and hand search in the reference lists of the included papers and in systematic reviews that approached bicycle intervention programmes (Sersli et al., 2019; Spinks et al., 2005; Yang et al., 2010; Zeuwts et al., 2020) to identify potentially relevant studies. The search was conducted between March and April of 2020, in the following databases: TRID, CENTRAL, Web of Science, SCOPUS, EBSCO, ProQuest Dissertations and Theses and Google Scholar. Databases were selected based on previous systematic reviews which approached bicycle intervention programmes (Richmond et al., 2014; Sersli et al., 2019; Spinks et al., 2005; Yang et al., 2010). The search expression used was: (toddler* OR child* OR youth* OR teenager* OR adolescent*) AND (Bike* OR cycle* OR bicycle*) AND (training* OR programme* OR course*) AND (teach* OR learn* OR ride*). Only keywords in English were used; however, no language restrictions were defined. All documents in other languages that included the selected keywords were considered for review, e.g., documents in German and Turkish. The search dates covered the period from the inception of the databases until 30 April 2020.

2.3.4. *Study selection*

Relevant identified papers were entered into reference management software EndNote X7 (Thomson Reuters, Philadelphia, PA, USA). After removal of duplicates, based on title and abstract matching, one reviewer screened the titles and two reviewers independently screened the abstracts and the full articles according to the eligibility criteria. Disagreements were resolved through discussion, with the intervention of a third reviewer when needed (Richmond et al., 2014; Sersli et al., 2019). See Figure 1 for a flowchart illustrating the selection process.

2.3.5. *Data extraction*

The following information was extracted from each study: (i) author(s) and year of publication; (ii) participants description; (iii) staff characteristics and ratio staff/participant; (iv) programme duration, session frequency and duration; (v) evaluation moments; (vi) training bicycles used; (vii) intervention rationale and description; (viii) bicycle adjustments; (ix) exercises and sequence progression; (x) definition of independent riding; (xi) main results, percentage of children who learned to cycle and health benefits; and (xii) conclusions. In cases where the paper did not contain all the information needed; the authors were contacted for more details.

2.3.6. *Quality assessment*

Quality assessment was also conducted by two independent reviewers, according to Downs and Black (D&B) quality assessment checklist (Downs & Black, 1998). Disagreements were solved through discussion with a third reviewer (Richmond et al., 2014). The D&B checklist scores range from zero to 28 points, with bigger scores representing a higher quality. In previous studies the following cut points were considered to categorize the studies: excellent 26–28, good 20–25, fair 15–19, poor <15 points (Hooper et al., 2008; Silverman et al., 2012).

2.4. Results

The initial search retrieved 2646 records from the different databases and 17 records were added from grey literature. After the reviewing process, eight articles met the inclusion criteria and were included in the review (see Figure 1).

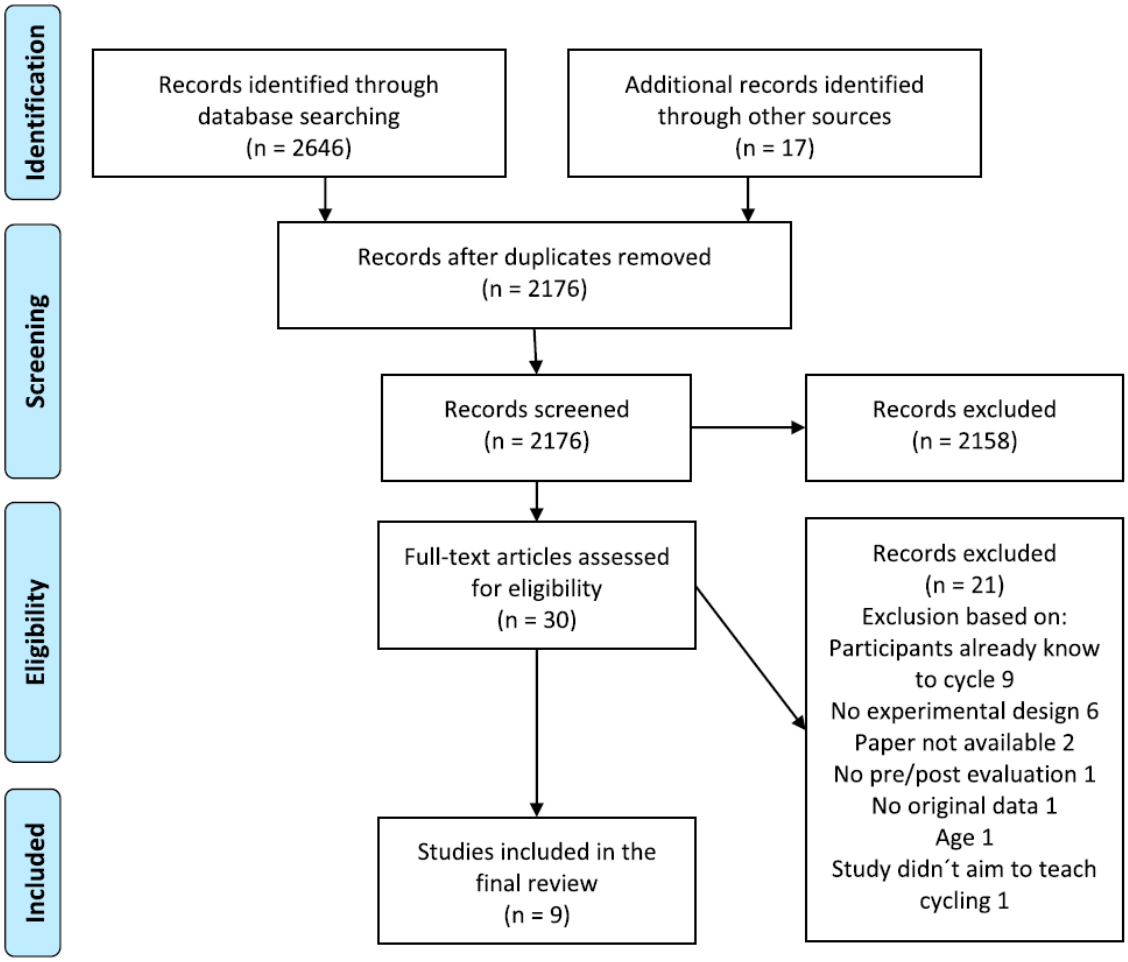

Figure 1. Flow diagram of study selection in the systematic review.

2.4.1. *Studies' characteristics*

Six of the nine studies in this review (Table 1) applied the iCan Bike intervention (Cain et al., 2012; Hauck et al., 2017; Hawks et al., 2020; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011), which consists of a programme that teaches individuals with disabilities to ride a traditional two-wheel bicycle (TB). The majority of the interventions took place in the USA, one occurred in Canada (Temple et al., 2016), another in the UK (Dunford et al., 2017), and other in Ireland (Kavanagh, Moran, et al., 2020). Most of the interventions included children and youths with disabilities, just one included children without disabilities (Kavanagh, Moran, et al., 2020). Regarding quality assessment, there was an excellent interrater reliability for the D&B (ICC = 0.98). Scores varied between 5 and 18 points (M= 11.8 ± 3.6 points), eight articles were classified as having poor quality and two as fair quality.

Table 1. Studies quality score, participant description, criteria for independent ridding and percentage of cycle acquisition

Authors and Year	Country, Quality Score	Participant Description	Criteria for Independent Riding with TB	Cycle acquisition (%)
iCan Bike				
Ulrich et al., 2011	USA, 18	72 DS, ages 8-15 years EG, 12±1.9 years; CG,12.4±2.2 years	Ride for 9 meters (30 feet), even when helped to start	56%
Cain et al., 2012	USA, 11	3 DS; 5 ASD; 1 CP; 1 ADHD; no CG	Ride for 9 meters (30 feet), even when helped to start	60%
MacDonald et al.2012	USA, 12	30 DS, 41 ASD, ages 9-18 years DS, 11.42±2.09 years; ASD, 11.69±2.38 years	Ride for 30.48 meters (100 feet) and perform self-launch and brake	80.3%
Temple at al., 2016	Canada, 9	4 DCD; 4 ASD; 1 ADHD; 1 DS; 1 cognitive delay, ages 7-11	Child can cycle in a controlled outdoor environment. Can have help to start but must be able to develop and maintain speed, steer, and brake without assistance	45%
Hauck et al., 2017	USA, 12	44 DS and ASD, ages 9-18 years EG, 11.8±2.4 years; CG, 12.2±2.1 years	Ride for 30.48 meters (100 feet), even when helped to start	64%
Hawks et al., 2020	USA, 13	15 ASD, ages 7-16 years, 10.8±2.54 years	Ride for 21.34 meters (70 feet), without the rollers or any assistance	60%
Others				
Burt et al., 2007	USA, 11	7 MR, ages 7-11 years, mean 9.3	Ride for 12m on 3 out 5 consecutive trials with a 2BW, with the possibility of instructors assisting with launching	100%
Dunford et al., 2017	UK, 5	20 DCD; 11 ASD; 5 no diagnosis; 3 CP; 2 learning difficulties; 2 hearing deficits; 1 several impairments, ages 6-15 years	Child pedals independently, consistently, on at least five separate occasions	89%
Kavanagh, Moran, et al., 2020	Ireland, 15	74 pre-schoolers with typical motor development; 4.04±0.48 years	Child could cycle for more than 3 revolutions without no holding of either handlebars or saddle, but the cycling is not smooth. The child did not initiate alone	64,9%

Notes: EG- experimental group; CG- control group; DS- down syndrome; ASD- autism spectrum disorder; CP- cerebral palsy; ADHD- Attention-deficit/hyperactivity disorder; DCD- developmental coordination disorder, MR- mental retardation, TB- traditional two-wheel bicycle, BSG- bike skills group program

2.4.2. *Intervention's characteristics*

Most interventions occurred both indoors and an outdoors, except for Burt et al. (2007) and for Kavanagh, Moran, et al. (2020) studies, which took place only indoors; and for Dunford et al. (2017) study, which took place only outdoors. The different authors mentioned that the training space should be free of obstacles or containing few obstacles; safe, on an enclosed level floor; and preferentially large.

In all studies with children with disabilities, which represented the majority of them, the ratio between instructor and participants was always one-to-one, and Dunford et al. (2017) even used two instructors per participant during balance learning, one on each side of the participant to minimize the risk of falling. In the only study with children without disabilities, the ratio was one instructor for four or five participants Kavanagh, Moran, et al. (2020).

The iCan Bike programmes occurred in a four- to five-day bike camp with 75 minutes sessions. Burt et al. (2007) opted to extend it until all the children acquired independent cycling using 45 minutes sessions, the child who took the longest to learn needed seven sessions. Dunford et al. (2017) opted for a four consecutive morning intervention of approximately two hours per session. Kavanagh, Moran, et al. (2020) opted for two cycling sessions a week for five weeks, each session lasting 45 minutes.

Regarding evaluation, some studies assessed children daily (Burt et al., 2007; Cain et al., 2012; Dunford et al., 2017). Cain et al. (2012) quantified learning as a function of the correlation between the bicycle steer rate and roll rate, and claimed that this methodology could be used to evaluate the effectiveness of other training techniques and to develop new methods for teaching. The authors highlighted that learning to steer in the direction of leaning is an essential skill in learning to cycle, and conclude that adapted bicycles are an effective tool for some riders, but they are possibly too stable for some riders. One study assessed children's cycling ability weekly (Kavanagh, Moran, et al., 2020). Two studies included a follow-up to analyse the transition to the home context (MacDonald et al., 2012; Temple et al., 2016), and two studies also assessed related physiological outcomes (Hauck et al., 2017; Ulrich et al., 2011).

Most studies used adapted bicycles, while Dunford et al. (2017) used clothes with handling belts. The iCan Bike programmes used an adapted bicycle created by professor of engineering Klein with a specially designed roller in the rear wheel (Klein et al., 2005). This roller is included in a series of eight rollers which are progressively tapered on the ends, each one becoming more balance challenging. Burt et al. (2007) used a set of four Klein's adapted bicycles. Dunford et al. (2017) used conventional bicycles and children wore handling belts to help prevent falls. Although the authors just claim to have used conventional bicycles, they refer to have removed the pedals in the initial stage of learning. So, in fact, they also used a balance bike. At least, Kavanagh, Moran, et al. (2020) divided children into two groups, one used balance bikes and another used bicycles with lateral training wheels.

Regarding bicycle adjustments, all studies reported lowering the saddle so that children could touch the ground with both feet while seated, and all but Dunford et al. (2017) and Kavanagh, Moran, et al. (2020) elevated the handlebars in order to promote a more upright posture, allowing children to look in the direction of motion and preventing falls.

All interventions analysed in this review combined a progressive sequence of exercises and/or training bicycles. The iCan Bike programme progressively changed the rollers, decreasing the support area. This change only occurred when children proved to have good control of the bicycle with the previous rollers. Burt et al. (2007) used a progressive sequence of bicycles and also bicycle control criteria to decide when to change the bicycle. The control criterion was set at 12 m of independent cycling on three out of five consecutive trials. Dunford et al. (2017) used the balance bike first and then the conventional bike with a progressive sequence of exercises and stages. Initially children performed easy tasks manoeuvring the bicycle by their side, after that they handled the bicycle while seated but without pedals (i.e., balance bike), and finally, they manoeuvred it while seated with pedals (i.e., traditional bicycle). In this study, the manoeuvring in each phase was also sequential, first in a straight line, second in a sweeping curve and third in a slalom course of cones. Lastly, Kavanagh, Moran, et al. (2020) based their intervention in fun games ordered by an increase in difficulty. The first games were the most linear and focused more on stopping, starting and gaining speed. After children became more comfortable in these games, the instructors proposed games that improved agility on the bike and further braking after picking up speed. The most complex games that required agility and balance (e.g., football on the bicycle) were the last ones to be introduced.

2.5. Main results and conclusions

Studies' success rate in teaching children how to ride a TB varied between 45% and 100% (see Table 1). However, the criteria for the acquisition of independent riding were different between studies, inclusively between studies with the same intervention programme. Some studies using the iCan Bike intervention considered the child as an independent rider if he/she could ride for a previously defined distance even when helped to start (Cain et al., 2012; Hauck et al., 2017; Temple et al., 2016; Ulrich et al., 2011), whereas others just considered the child to be an independent rider when he/she could also perform the self-launch and braking without any assistance (Hawks et al., 2020; MacDonald et al., 2012). Kavanagh, Moran, et al. (2020) developed the KIM cycling scale to monitor and access the development process of cycling learning. This scale is composed of eight stages, and it is considered that the child can ride a bicycle independently from stage five. Which consists in performing more than three revolutions without any help during the cycling but with help to start. This criterion turns out to be more flexible than the previous ones, since it does not consider the self-launch, braking, and that the three revolutions fall short of the minimum distance of 9 m reported in the other articles. Despite the differences in the independent rider criteria, all studies sustained that children with and without disabilities can learn to ride if they receive the suitable help and intervention (Burt et al., 2007; Cain et al., 2012; Dunford et al., 2017; Hauck et al., 2017; Hawks et al., 2020; Kavanagh, Moran, et al., 2020; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011).

Besides the acquisition of independent riding, some studies also showed several health-related outcomes (Hauck et al., 2017; Ulrich et al., 2011). In the follow-up, after seven weeks and one year of the intervention, Ulrich et al. (2011) found a decrease in the sedentary time (p=.035 after seven weeks, p=.004 after one year), and an increase in moderate to vigorous physical activity time (p=.009 after seven weeks, p=.023 after one year) in children that had participated in the bike camp when compared to the control group. The bike camp children also revealed greater leg strength after one year (right knee flexion p=.041, left p=.026). Additionally, body composition was positively influenced over time, with a decrease in body fat percentage (p=.004 after seven weeks, p=.006 after one year). Hauck et al. (2017), in the follow-up after one year, also found greater leg strength in bike camp children (right leg extension p=0.002, left p=0.016; right leg flexion p=0.032) compared to the control group. They also referred a trend to improve balance and to decrease body mass index, although these differences were non-significant. The authors conclude that riding ability can influence leg strength and potentially disrupt the cycle of consistent unhealthy weight gain over time in children with disabilities.

2.6. Discussion

The aim of this systematic review was to review and summarize the programmes for learning to ride a bicycle, comparing their protocols and outcomes, in order to identify the best options for efficient interventions. The nine studies included presented poor to fair quality, ranging between five and 18 points in a total of 28 possible points of the D&B scale. The lack of a representative population, control group or power analysis, are aspects considered and scored in D&B checklist that were not met by most studies in this review. The fact that almost all studies were conducted on children with disabilities might pose a greater difficulty in meeting some of these criteria. It is essential for future studies to clearly identify their reports, explain their methodological options, and consider the possible bias and confounding variables in order to ensure a better quality.

2.6.1. Studies and participant characteristics

Although we set no beginning date for the systematic search, articles included in this review were published between 2007 and 2020, and eight of them in the last decade. The recent increased interest in these programmes might be related to the various and continuously proven health-related outcomes associated with being able to cycle, like improvements in cardiorespiratory and muscular fitness, social interaction, emotional and relational development, independence and mobility (Karabaic, 2016; Orsini & O'Brien, 2006; Phansikar et al., 2019; Ramírez-Vélez et al., 2017; Smith et al., 2017).

Just one of the interventions was targeted at children without disabilities. And this intervention was conducted in the scope of the development and reliability of a cycling scale, being the cycling learning a secondary objective. Cycling is a functional, culturally normative activity valued by most families (MacDonald et al., 2012; Ulrich et al., 2011). So, probably children without disabilities usually learn how to ride a bicycle in their normal course of development, without enrolling in a specific learning programme. Despite the existence of several national programmes to promote safer cycling (e.g., ‘Bikeability’ in the UK or ‘School Bike Ed’ in Australia), in Portugal the inclusion of learning to cycle in the physical education school curriculum is being debated. This may indicate a need to develop and implement more cycling programmes for children without disabilities to ensure an early cycling acquisition. Consequently, the importance of identifying the best teaching strategies to learn how to cycle remains, for both children with and without disabilities. The sooner the child learns to ride a bicycle, the faster he/she will enjoy its benefits. The age span of participants in these studies ranged from four to 18 years. In typically developing children, the intervention age could probably be even lower, since some studies indicate that many three-year-old children can learn how to ride a bike (Mercê et al., 2022).

2.6.2. Intervention features: ratio, scheduling, session duration

In all studies with children with disabilities the ratio instructor/participant was one-to-one, or even two-to-one (Dunford et al., 2017). This approach seems to be the best choice for children with disabilities considering the percentage of children that learned how to cycle in the different interventions. Perhaps, for children without disabilities, this ratio could be less demanding. However, in the only study that included children without disabilities the ratio was one-to-four or five and the success percentage was just about 64.9%. Probably, a more individual approach could lead to faster learning, especially in younger children, which was the last case.

All studies except Burt et al. (2007) and Kavanagh, Moran, et al. (2020) opted for an intensive intervention including four to five consecutive practice days, due to its similarity to the normal process of learning how to cycle (Dunford et al., 2017). Dunford et al. (2017) revealed concern for the proximity of the sessions, stating that it could cause fatigue and become a confounding variable. However, in that study, parents reported that children were tired after the intervention, but seemed to have recovered by the next day. Some authors felt that the four to five consecutive days could not be enough for all children to learn to cycle (e.g., MacDonald et al., 2012; Ulrich et al., 2011). In Dunford et al. (2017) study, most children learned to ride in four hours, which corresponds approximately to the four 75 minutes sessions of the iCan Shine. In spite of that, some of those children needed 16 hours to learn, which would correspond to approximately 13 sessions. Burt et al. (2007) also report an average need of five sessions to acquire independent cycling, however one of their participants needed seven sessions. Hawks et al. (2020) verified that the training time, in days, was a strong predictor of cycling motor skill acquisition. On the other hand, it is also interesting to denote, that the only article with children without disabilities (Kavanagh, Moran, et al., 2020), who supposedly would learn a new motor task more easily, included 10 sessions (almost twice as many sessions as the others offered). And revealed a learning percentage of just 64.9%, even with an independent cycle criterion more flexible by not included self-launch or braking. It's also important to denote that this article also included the lower age, which can in some way compensate the greatest ease of learning in children without disabilities. It seems that a more intensive intervention may be more beneficial than a more widely spread intervention with only two weekly sessions. According to most reviewed articles, an intensive five-session intervention should be enough for most of the children aged over six years, to learn this skill (Burt et al., 2007; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011). To increase learning success more practice days are recommended (Burt et al., 2007; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011).

The session duration of these studies varied between 45 minutes and approximately two hours. Unfortunately, as the criteria for the cycling acquisition wasn't uniform across studies, it's impossible to compare the efficiency of the session duration. Yet, considering the studies' success rates and knowing that fatigue should be avoided, we believe that each session should last between 45 and 75 minutes.

Like any other motor task, the greater the practice the greater the skill acquisition. The question of how much practice is needed to learn and of the existence of a possible ceiling effect during long interventions can be analysed in future studies. However, it is important to note that there are various factors that influence the success rate of the different interventions (e.g., number of adults per child, having or not having children with disabilities, type of disabilities, age of the children). So, the efficacy of the different programmes should be compared with caution.

2.6.3. Training bicycle: training wheels, balance bike, roller and tandem bicycle

It is possible to use different types of bicycles in the process of learning to ride a bike, the most typical are the training wheels and the balance bike (Cain et al., 2012). In Europe, especially in southern countries, the use of the balance bike is relatively recent, e.g. in Portugal, there was a significant increase after 2000, and using training wheels remains the most common learning method (Mercê et al., 2022). Despite its popularity, using training wheels for learning is not considered to be a good method in almost all the analysed studies.

Using training wheels allows a bigger support area, so the child can learn how to pedal without having to solve the balance challenge and this also reduces the fear of falling. However, according to the iCan bike programme, training wheels lead to the acquisition of a counterproductive motor plan (Cain et al., 2012; Hauck et al., 2017; Hawks et al., 2020; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011). When children perceive that the bicycle is unstable, they activate ineffective defence responses, and by using the training wheels they don’t experience this instability. So, when the training wheels are removed, the rider’s response to the bicycle’s action is the opposite of what would be needed to maintain control. Burt et al. (2007) also refute the training wheels, claiming that when novice riders use them, the tendency is to use the upper torso as a balance mechanism, and when the training wheels are removed, the arms often remain rigid and inflexible, impairing their use in the control of balance. Dunford et al. (2017) and Kavanagh, Moran, et al. (2020) were the only authors that did not mention training wheels directly.

Dunford et al. (2017) used the conventional bicycle during learning removing the pedals in the initial stages, which is the equivalent to using a balance bike (BB). The idea of the BB is to allow children to first acquire balance before pedalling. Different authors (Ballantine, 1992; Becker & Jenny, 2017; Shim & Norman, 2015) argue that the BB is the most effective way of learning to cycle and promotes an earlier and smooth transition to the TB.

Kavanagh, Moran, et al. (2020) opted to use two different instruments, one group used the balance bike and the other used the training wheel bike. The authors did not mention the intention of this approach, nor did they analyse or discuss the data based on the difference between groups or instruments. However, after being contacted to provide additional information, the authors reported that the participants in the balance bike group learnt quicker and more of them acquired independent cycling than the participants in the training wheel group. This information corroborates the idea that the BB could promote an earlier and smooth transition to the TB (Ballantine, 1992; Becker & Jenny, 2017; Shim & Norman, 2015).

The iCan Bike studies (Cain et al., 2012; Hauck et al., 2017; Hawks et al., 2020; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011) and Burt et al. (2007) opted for the roller bicycle. The basic idea is to afford children a more stable perception lessening the balance challenge in the initial stages of learning. During the learning process, as the confidence and technique improve, the rollers are changed to more tapering ones on the end, which pose a greater balance challenge, until the child can finally transit to the TB. Despite having theoretical support and having been designed with technical rigor (Klein et al., 2005), the roller bicycle may not be an effective training tool for all novice riders, and for some, it might be too stable, similar to using training wheels (Cain et al., 2012).

The tandem bicycle (or twin, is a form of bicycle designed to be ridden by more than one person), was also used in most of the studies as an intervention complement, allowing children to experience the correct turn, brake and pedal fast (Cain et al., 2012; Hauck et al., 2017; Hawks et al., 2020; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011). Considering that the fear of falling is one of the barriers in the process of learning how to cycle (Temple et al., 2016), the tandem bicycle seems to be an interesting way to introduce cycling to novice riders, allowing them to overcome their fear and enjoy the pleasure of pedalling.

Due to the different sample characteristics and protocols of studies included in this review, it is not possible to determine precisely which training bicycle is the most effective. The comparison between different types of learning bicycles should be investigated in the future.

2.6.4. Intervention progression

All studies included in this review used a progressive sequence of training bicycles and/or exercises and games in the learning process, starting with simpler bicycles (e.g., the roller or balance bicycle), or simpler exercises (e.g., mount and dismount the bicycle, learn how to brake, first ride in a straight line and then turn), which seems to be an effective strategy. Being able to progressively increase the complexity of the task along the learning process, seems to be one of the key points to successfully teach someone how to cycle. In fact, when no progressive learning strategies are used, the age to learn how to cycle independently increases. A recent study by Mercê et al. (2022) indicates that children who exclusively use the conventional bicycle learn to cycle significantly later than children who used other learning paths (e.g. using the balance bike or training wheels). When children learn how to cycle by simply using the conventional bicycle, with pedals and no support, they must learn how to manage the breaks, the handlebar, the pedals and acquire balance all at once, which seems to be too complex, resulting in a later learning age.

2.6.5. Independent riding assessment

In seven out of the nine studies included in this review, the pre-intervention assessments of independent riding were based on parents' reports. Whereas Dunford et al. (2017) based their assessment on the child's report, and just Kavanagh, Moran, et al. (2020) assessed the children's ability to ride a TB directly. The definition of independent riding was not consensual, even for the iCan Bike articles that followed the same programme. For future studies, a clear and unanimous definition should be adopted. Defining independent riding by simply being able to ride a minimum distance and considering the possibility of having someone's help to start seems to be slightly slim and ineffective. As Reynolds et al. (2016) point out, children that participated in bike camps and who did not acquire the self-start and brake, would most likely not be able to continue riding when they return home. It is suggested that to be considered an independent cyclist the child should not only perform a predefined distance (30 feet, about 10 m, c.f., Ulrich et al., 2011), but should also be able to self-start and brake.

2.6.6. Individual and family constraints

Studies identified different characteristics or constraints of the children and families that influenced the learning progress and, consequently, should be considered in future interventions. Ulrich et al. (2011) reported that children with lower levels of motivation frequently use leg fatigue as an excuse to dismount the bicycle, practicing less, which delays learning. Temple et al. (2016) also considered the child's motivation to be a facilitating factor for learning. Although it is accepted that children's motivation plays an important role in the learning process, only one of the reviewed studies (MacDonald et al., 2012) assessed the child's desire to learn to ride a bicycle. In future studies, the motivation assessment should be considered, and special attention needs to be given to less motivated children to increase their active practice time. One motivation strategy suggested by Kavanagh, Moran, et al. (2020) is to allow the more willing children to go first. This might help less motivated children to gain trust and see that cycling could be fun.

The fear of falling was considered by different authors a major constraint for learning how to cycle (Temple et al., 2016; Ulrich et al., 2011). In this sense, cycling programmes should consider the fear constraint and include strategies to overcome it, for example using special bicycles for learning such as the tandem bicycle (iCan Bike programme), or having the instructor running beside the child in the first trials, so that he/she feels safer (Dunford et al., 2017).

Functional constraints also influence the learning process. Although leg fatigue was sometimes an excuse for interrupting practice, Ulrich et al. (2011) also recognized that it may have been present. MacDonald et al. (2012) concluded that children who acquired cycling during camp had greater leg strength than children who did not acquire it. The problem of leg weakness is also more evident in children with disabilities, as were the majority of the children that participated in the programmes included in this review, e.g., hypotonia is one of the typical characteristics of children with Down syndrome. After identifying this constraint, the authors made some suggestions for parents who consider enrolling their children in learning to cycle programmes. MacDonald et al. (2012) encouraged working on leg strength with the help of physical education teachers before enrolling, and Ulrich et al. (2011) recommended that therapists should provide the knowledge and methods for parents to increase their child’s leg strength. The parents were also identified as another constraint by different studies. Temple et al. (2016) refers that having parents that are involved and value cycling were facilitating factors for the learning process. Ulrich et al. (2011) also suggested that future interventions should include parents to maximize the cycling frequency. And lastly, Kavanagh, Moran, et al. (2020) highlighted that parental support is pivotal to pre-schoolers, in order to provide encouragement, opportunities and support for physical activity and cycling learning. Interventions should consider strategies to guarantee family support, such as providing families with information and tips on learning how to cycle, or on maintaining and increasing bike use once children acquire the ability to cycle.

2.6.7. Health outcomes

Studies that followed up on children after they learned how to cycle, showed that, when compared to the control group, the bike camp’s children had a decrease in sedentary time, an increase in moderate to vigorous physical activity, an improvement in leg strength, and a better body composition (Hauck et al., 2017; Ulrich et al., 2011).Hauck et al. (2017) even suggested that learning how to ride a bicycle could disrupt the cycle of consistent unhealthy weight gain over time, in children with disabilities. This suggestion is in accordance with the Stodden et al. (2008) model, which claims that motor competence has a fundamental role in the promotion of healthy trajectories of life regarding physical activity and weight management. In fact, cycling has recently been considered a foundational movement skill as it provides a direct or indirect pathway to a lifetime of physical activity (Hulteen et al., 2018).

Considering that some authors reported that the bike camp helped children to be less fearful and more motivated to try other physical activities (Temple et al., 2016; Ulrich et al., 2011), we might also argue that learning how to cycle may have led children to do more physical activity with and without the bicycle, which culminated in the better muscle conditioning and body composition that were shown in the follow ups. The present review corroborates the positive cascade of social, emotional and health benefits that start with learning to cycle, and that might impact children with and without disabilities.

2.6.8. Tips for future interventions to teach how to cycle

We identified a set of tips for future bicycle programme interventions that aim to teach how to ride a bicycle. These tips were based on the studies included in this review, which were almost all, eight out of nine, conducted on children with disabilities. So, some tips are probably not adjusted to children without disabilities:

- Training should occur in a clear (or with few obstacles), safe and preferentially large space.
- In the initial stages, the saddle should be lowered so that children can touch the ground with both feet, and the handlebar should be elevated to promote a more upright posture.
- For children with disabilities, an individualized approach should be privileged. The ratio instructor/participant should be one-to-one accompanied by feedback during practice.
- An intensive approach with several consecutive days of practice can be used and it represents the common learning process.
- For some children, an intervention programme consisting of only four or five practice days might not be enough to acquire independent cycling.
- Each session’s duration should vary between 45 and 75 minutes.
- Fatigue can impair actual practice time, therefore, when working with younger or less fit children, increase session frequency rather than session duration.

- The use of training wheels should be avoided, as they are proven inefficient, and it is argued that their use is counterproductive.
- The intervention should be based on progressive learning:
  - Use simpler training bicycles (e.g., the balance bike) and simpler exercises (e.g., mount and dismount the bicycle) first.
  - Use learning stages (e.g., first ride in a straight line, then turn and later do slalom).
- Teach braking early in the programme for safety reasons. Teach children to use the handbrakes and to stop by placing both feet on the ground.
- Motivation is important. Assess children's motivation levels and improve them, since it will influence the actual practice time. To improve motivation:
  - Use fun games during the intervention.
  - If children are not all practicing at the same time, let the more willing children to go first, the other children might become more motivated and gain trust as they see their colleagues having fun.
- Fear of falling is a major barrier. Find strategies to overcome it (e.g., include tandem bicycle rides or have the instructor running beside the child in the first trials).
- The criteria to define the acquisition of independent cycling skills should include self-start and brake without help.

2.6.9. Limitations

In this study, a broadly and complete search was conducted by performing a comprehensive review in the main electronic databases on the subject under analysis, including a grey literature search, and also a hand search in the reference lists of the reviewed papers, and in systematic reviews approaching bicycle intervention programmes (Sersli et al., 2019; Spinks et al., 2005; Yang et al., 2010; Zeuwts et al., 2020). Although no language restrictions were applied, only keywords in English were used. This methodological option might have led to the exclusion of articles that did not have a title or abstract in English.

The review's limitations were mainly related to the outcomes. The D&B quality checklist (Downs & Black, 1998) was used to assess the quality and the risk of bias, and most studies were rated as having poor quality, with only one RCT (Ulrich et al., 2011) and other non RCT (Kavanagh, Moran, et al., 2020) studies presenting fair quality. Regarding the external validity, a score of zero points was attributed in all reviewed papers, proving that the studies' results and conclusions cannot be generalized with confidence to the entire population. Internal validity scored higher, in a possible score of seven, six studies scored five points (Burt et al., 2007; Cain et al., 2012; Hauck et al., 2017; MacDonald et al., 2012; Ulrich et al., 2011), two studies scored four points (Kavanagh, Moran, et al., 2020; Temple et al., 2016) and the last two points (Dunford et al., 2017) . However, these low scores should be interpreted with caution, as in this type of studies it is simply not possible to ensure that participants are blind to the purpose of the study and that the staff/technicians are also blind to the main outcomes of the intervention. Besides these points, future studies should try to clearly identify the statistical treatment, the data distribution and the outcome measures, in order to ensure a better internal validity.

2.7. Conclusions

This systematic review aimed, primarily, to clarify the strengths or weakness of the existing literature regarding cycling programmes that aimed to teach how to cycle independently. Despite the growing interest in cycling in the last decades, we could only find nine studies with programmes that aimed to teach children how to ride a bicycle independently. One of the major weaknesses identified in this review was the paucity of intervention studies that aim to teach children without disabilities how to cycle, only one study was identified. Maybe because cycling is a cultural and valued activity (MacDonald et al., 2012; Ulrich et al., 2011), which in some countries is quite popular, typical developing children learn how to cycle in their normal course of development, without the need to enrol in a specific programme. However, probably due to the importance of cycling to increase children's autonomy and physical activity lifespan, in some countries (e.g., Portugal) there has been a recent debate on the inclusion of cycling lessons in the physical education curriculum. This highlights the need to also develop and implement learning to cycle programmes for children without disabilities.

Another important conclusion to be considered in future studies is that there should be a common criterion for independent cycling, preferably including the ability to start, ride a certain distance and brake. Among the nine studies included in this review, this criterion was not consensual, even among studies using the same protocol. For this reason, it was not possible to compare the efficacy of the different methodologies. However, we could identify several methodological aspects that acted either as facilitators or as barriers in the learning process, allowing us to suggest tips for future bicycle interventions with children. Since the suggested tips were mainly based on studies with children with disabilities, researchers should consider the need to adapt them to children without disabilities. Interventions that aim to teach children without disabilities are needed, to confirm which of these tips are fully applicable to all children.

The best strategy to teach children how to cycle is probably a progressive strategy that starts with learning bicycle that enables the child to explore balance challenges from the beginning, without being too complex. Once the balance is achieved, a smooth transition to the conventional bicycle can be ensured. Along the process, there should be a focus on an individualized intervention, feedback and motivation, taking into account each child's specific characteristics. This usually implies adjusting the bicycle to the participant's anatomy and trying to create a good learning environment by involving the parents and families in the learning process. Barriers should also be considered. For example, using the tandem bicycle (Cain et al., 2012; Hauck et al., 2017; Hawks et al., 2020; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011), or running beside the child in the first trials (Dunford et al., 2017) can help to overcome the fear of falling. Probably, the effect of other constraints can be studied (e.g., simple touch may enhance external proprioceptive feedback, allowing greater balance self-control) (Clapp & Wing, 1999; Krishnamoorthy et al., 2002).

The present review corroborates the health benefits of learning to cycle, in this case specifically in children with disabilities. Studies reported a decrease in sedentary time, an increase in physical activity, greater leg strength and a positive influence on body composition (Hauck et al., 2017; Ulrich et al., 2011) in children who learned how to cycle. In addition, children also became less fearful and more motivated to try other physical activities (Temple et al., 2016; Ulrich et al., 2011), leading us to believe that learning how to ride a bicycle can be a possible solution to disrupt the cycle of consistent weight gain over time in children with disabilities (Hauck et al., 2017), thus, avoiding future health problems and contributing towards a more fulfilling life.

All articles included in this review targeted children aged four and above. However, it is important to promote an early practice that adjusted each child's characteristics, since the sooner children learn to ride, the sooner they will enjoy its benefits. Future studies with stronger methodologies and younger and children without disabilities are needed to identify the best methodologies for teaching how to cycle.

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Chapter **3**

3. Learning to Cycle: From Training Wheels to Balance Bike

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3.1. Abstract

Background: Learning to cycle is an important milestone in a child's life, so it is important to allow them to explore cycling as soon as possible. The use of a bicycle with training wheels (BTW) for learning to cycling is an old approach practiced worldwide. Most recently, a new approach using the balance bike (BB) has received increased attention, and several entities believe that this could be most efficient. Drawing on the work of Bronfenbrenner (1995) and Newell (1986), this study aimed to analyse the effect of BB's use on the learning process of cycling independently. Methods: Data were collected in Portugal from an online structured survey between November 2019 and June 2020. Results: A total of 2005 responses were obtained for adults and children (parental response). Results revealed that when the BB's approach was used, learning age (LA) occurred earlier (M=4.16±1.34 years) than with the BTW's approach (M=5.97±2.16 years) (p<0.001); or than when there was only the single use of the traditional bicycle (M=7.27±3.74 years) (p<0.001). Conclusions: Children who used the BB as the first bike had a significantly lower LA than children who did not use it (p<0.001). To maximize its effects, the BB should be used in the beginning of the learning process.

Keywords: balance bike; bicycle with training wheels; learning to ride a bicycle; constraints; learning paths; cycling; Portugal.

3.2. Introduction

Humans have different natural modes of locomotion, such as walking and running. With the cultural evolution of our species, the bicycle was invented as a transport vehicle, being more efficient, economic and less tiresome than our natural modes of locomotion (Herlihy, 2004). Nowadays, this invention won a very important role in human life; it is used everywhere for transportation, exercise, sports competition, or simply for recreation (Astrom et al., 2005; Oosterhuis, 2016). Cycling also proved to be an activity that improves health. It has a positive relationship with cardiorespiratory fitness in youths, cardiovascular fitness in adults, and a strong inverse relationship with all-cause mortality, cancer mortality and morbidity in middle-aged and elderly people (Oja et al., 2011). In children, cycling also has several health benefits, like better cardiorespiratory fitness, less body fat, and less incidence of metabolic syndrome (Ramírez-Vélez et al., 2017). There are also social benefits, such as the development of relational and emotional skills, promoting fun play moments where children can interact with other people, and make new friendships (Karabaic, 2016; Orsini & O'Brien, 2006). In addition, cycling allows for a greater exploration of the environment mobility, enabling children to become more independent and active (Smith et al., 2017). Cycle trains are a good example of this, children travel to school by bicycle and stop at their colleagues' houses increasing the "train" until school (Smith et al., 2020). Most recently, the active transport in children, including cycling, has also revealed an positive as-sociation with academic achievement and cognition (Phansikar et al., 2019). For all these reasons, learning to ride a bicycle is an important milestone in children's lives (Zeuwts et al., 2015), so it is important to allow children to explore cycling as soon as possible.

The present study draws on the theoretical juxtaposition of the Bioecological Theory of Bronfenbrenner (Bronfenbrenner, 1995) and Newell's model of constraints (Newell, 1986) applied to the learning pathways of bicycles sequences that children go through until they are able to cycle independently and without training wheels.

According to Bronfenbrenner, the child's development occurs within interactions and relationships between the child and his/her environment (Bronfenbrenner, 1979, 1995). The different layers of environment affect the child's development, including motor development and the learning of new skills, such as learning how to cycle. The initial model proposed by Bronfenbrenner (1979), considered the following layers: micro-, meso-, exo-, and macrosystem. At a later stage (Bronfenbrenner, 1995), time was included into the model and the chronosystem dimension was added. The different microsystems consist in a set of environments where the child can engage in face-to-face interactions with other people; for example, family, friends, or community institutions like the school are examples of microsystems. If the microsystems the child interacts with value cycling, and if the child has access to a bicycle since an early age, it is more likely that he or she will learn to ride a bicycle earlier than if cycling and having a bicycle are not valued or prioritized. Pa-rental encouragement is a key factor not only to cycle learning (Temple et al., 2016), but also for increasing cycle practice (Emond & Handy, 2012). The mesosystem comprises the interactions between the different microsystems, for example, the relationship between the child's family and the school. If the school launches a "bike to school" campaign and the family has a good relationship and an active participation in the school, it is more likely that they will join that campaign (Emond & Handy, 2012). The exosystem includes contexts where the child is not directly involved but that can have an indirect effect on him/her, such as the availability of community programs for cycling in the child's neighbourhood, or the media promotion of active transport and cycling. The existence of a community program to promote cycling in a family can enhance bicycle use and learning from an early age (Chandler et al., 2015). The macrosystem consists of societal, cultural and global influence, which can include the cultural value given to cycling, the role attributed to gender, or simply the laws and governmental policies. If the government promotes safe conditions for cycling, for example through bike paths' construction or protective laws for cyclists, an increase in cycling is expected (Florindo et al., 2018). Finally, the chronosystem adds the dimension of time; for example, the era in which the child lives also influences the value given to cycling, the age at which the child's parents will give him/her a bike, and the type of bike the child will be given (if any).

In our perspective, when looking at the milestone of learning to ride a bike, Bronfenbrenner's theory shares a common ground with Newell's model of constraints (Newell, 1986), namely in terms of what Bronfenbrenner and Morris (Bronfenbrenner & Morris, 1998) describe as four fundamental properties (person, context, time and process), which dynamically interact with each other in order for developmental acquisitions to occur. The process is the central intermediate element of the model as it represents particular forms of interaction that occur over time between the person and the environment. These reciprocal interactions, designated of proximal processes, progressively become more complex and are considered the key agents of human development (Bronfenbrenner & Morris, 1998). However, the degree of influence these proximal processes have on development varies according to the interrelationship given by the evolving person's characteristics, the immediate and more distal environmental contexts, and the time periods of these interactions (Bronfenbrenner & Morris, 2006). Similarly, in a more microscopic scale, according to Newell, movement arises from the dynamic interaction between individual, task and environmental constraints (Bronfenbrenner, 1979, 1995; Newell, 1986). Individual constraints consist of the features of the system itself, like age or motor competence. Probably, children with a better motor competence and a greater motor repertoire will learn to ride a bicycle more easily (Rodrigues et al., 2021). Task constraints consist of features related to the task itself that can be modified, such as the instrument used, its duration and its frequency. For example, several institutions believe that the balance bike can be more efficient for learning than the bicycle with training wheels (PCF, 2020a, 2020b). Finally, environmental constraints are features related to the physical environment like the weather, or to the sociocultural factors like the family context. In this sense, the dynamic proximal processes between the child and the environment advocated by Bronfenbrenner's theory are also present in Newell's model. According to this model, these proximal interactions between the different constraints are fundamental, and if any constraint changes, the resultant movement changes. Sometimes constraints change mildly (e.g., when the individual constraint of the height of the child changes it might be necessary to adjust the height of the bike), but sometimes constraints change more abruptly (e.g., changing a task constraint such as taking the training wheels out will interact with the child's ability to keep balance).

To learn how to ride a bicycle, the combination of constraints and possible pathways are endless. For example, the child can learn alone, with parents, friends; can practice in the street, cycle path or dirt; use a balance bike, bicycle with training wheels, or simply the traditional bike.

The learning process is always individual and complex. Each system, each human being, is unique and is influenced by the sociocultural environment and by different constraints (Bronfenbrenner, 1979, 1995; Newell, 1986). The variability of possible pathways to learn how to cycle is probably one of the reasons why the better or the most efficient methodology and type of bike used for learning is still not consensual.

The use of the bicycle with lateral training wheels (BTW) is a worldwide practice, however not everyone agrees with this approach (Becker & Jenny, 2017; Shim & Norman, 2015). Recently, the use of the balance bike is increasing; in Portugal, one of the biggest sporting goods retailers started selling this bike in 2012-2013, and some of the biggest supermarkets also started in this decade, which may also have contributed to making BB more accessible and popular. A balance bike (BB) consists of a bicycle without training wheels or pedals, so children should use their feet against the ground to propel themselves. Several institutions, including the Portuguese Cycling Federation (PCF) and the Biciculture House in Portugal, believe that using a BB instead of the traditional BTW improves the learning process. For this reason, some initiatives of the PCF, such as the "Cycling for Everyone" and the "Cycling Goes to School", provide balance bikes for children who do not know how to ride (PCF, 2020a, 2020b).

While the traditional and old approach with BTW allows children to explore the pedalling being balanced by the training wheels, the new approach with BB works the other way around, allowing children to first explore the balance in the bicycle, and then introducing the pedalling (Figure 2). Despite the empirical experience of bicycle instructors that prefer to use BB and the positioning of recognized entities like PCF, the scientific literature that supports balance bike's use is very scarce. In this sense, the present article aimed to study the influence of balance bike's use on the process of learning to ride a bicycle independently, adopting a bioecological approach to such a relevant acquisition in terms of children's motor development. More specifically, we aimed to: (i) verify if the BB's use is related to a possible decrease in the learning age of independently cycling (LA) over decades; (ii) identify the most common learning pathways of a bicycles sequence (learning paths); (iii) verify if the learning paths are related with the LA; and (iv) analyse and compare the LA between children who used and did not use BB.

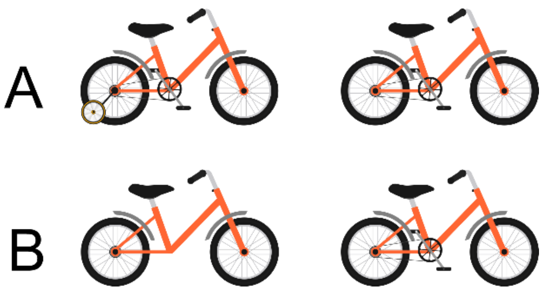

Figure 2. Old and new approaches for learning to cycle independently: (A) using training wheels; (B) using the balance bike (BB).

3.3. Materials and Methods

3.3.1. Survey

The data collection was carried out within the scope of the Learning to Cycle project (L2Cycle), which developed a retrospective online survey to access the cycle LA (Mercê, Branco, Catela, Lopes, et al., 2021). This retrospective method has been used before to collect the LA of several other milestones, e.g., roll over, sit up, stand alone, walk, first words, smiling or crawling (Chojnacki et al., 2019; Highman et al., 2008). To create the L2Cycle survey, several phases have been completed; during the pilot phase, an initial version of the survey was developed by a group of four experts in child development and was tested online on 485 participants. A sub-sample of 30 participants was additionally inquired about the comprehension of the survey. After that, some adjustments were made. For example, one group related to the dates of acquisition of different motor milestones was deleted, and some questions were reformulated to improve clarity according to the respondent's suggestions. At a second stage, the survey was discussed with a group of five international experts who provided further suggestions (e.g., adding questions regarding mother tongue and different seasons of the year). Finally, the survey was translated for different languages and is now available in 10 languages (Portuguese - from Portugal and Brazil, English, German, Croatian, Finish, French, Dutch, Italian, Japanese and Spanish). For the current article, only the Portuguese data were analysed. The final Portuguese version was launched online on 22 November 2019 and data for the current study were collected between that date and 8 June 2020. The survey was publicized in the national conference on Child Development and disseminated through social media (Facebook, Instagram, WhatsApp), and by email. In addition, partnerships with the PCF and children's and parent's magazines were established for dissemination on their websites and paper magazines.

The survey takes approximately five to fifteen minutes to complete (depending on the number of children), it is anonymous, and is comprised of three sections:

1. “About you” - Questions about the participant’s own experience and biographical data (e.g., place of residence, age, gender, physical activity habits, if they know to ride a bike, if not - why not, if yes - when did they learn, what types of bikes were used and in what sequence, where did they learn, who taught them, how often do they ride a bike, what do they use it for).

2. “About your older child” (to be completed only if the participant has children) - These questions are the same as the questions in the first group but regarding the participant’s older child.

3. “About your younger child” (to be completed only if the participant has more than one child) - These questions are the same as the questions in the first group but regarding the participant’s younger child.

This survey was approved by the Ethics Committee of the Faculty of Human Kinetics (approval number: 22/2019).

3.3.2. Sample

The survey was completed with information regarding 2386 participants. For the present study, only participants born during or after the decade of 1960-69 and who could ride a bicycle independently were considered (n=2005). Participant’s age ranged from 2.39 to 60.18 years (M=27.97±14.7 years). In order to analyse differences in learning to ride a bike across generations, the birth decades of the participants were considered. Regarding geographical location, we collected data from participants in all 20 Portuguese districts and the two autonomous regions, Madeira and Azores. Descriptive data of the sample is presented in Table 2.

Table 2. Descriptive data (mean, standard deviation, minimum and maximum) regarding age and sex of the participants by decade and total.

Decades	Decimal Age (years)			Gender (n)			
	M ± SD	**Mini**	**Max**	**Male**	**Female**	**Don´t Want to Say**	**Total**
1960–69	55.05 ± 2.70	50.05	60.18	31	129	0	160
1970–1979	44.53 ± 2.75	39.91	50.29	119	238	2	359
1980–1989	35.65 ± 2.92	29.98	40.23	92	227	0	319
1990–1999	23.79 ± 2.88	19.92	30.23	209	236	1	446
2000–09	15.92 ± 3.20	10.13	20.21	251	214	3	468
2010–19	7.34 ± 1.81	2.39	10.35	142	109	2	253
Total	27.97 ± 14.7	2.39	60.18	844	1153	8	2005

3.3.3. *Statistical Analysis*

Data extracted from LimeSurvey was organized and codified by a Matlab routine specifically developed for this purpose. The data were later processed in the software Statistical Package for the Social Sciences (SPSS, version 25).

Analyses of frequency and chi-square tests were used to investigate the differences in the percentage of BB's use between consecutive decades. One-way ANOVAs were performed to assess differences in the LA across decades and between different learning paths (i.e., considering the order of use of the BB). In cases of non-homogeneity, the Welch correction was applied. To investigate significant differences between groups, the Bonferroni or the Games Howell post-hocs were used, depending on the existence or not of homogeneity of variances (Field, 2013). The level of significance was set at 0.05.

3.3.4. *Sample Calculation*

Sample calculation was performed a posteriori with the software G*Power (version 3.1.9.7.). For this calculation, it considered the effect size of the main variable, age learned, from the data of test's version, which revealed an effect size of 0.1. A one-way ANOVA was performed on the calculation, which considered the question with the lowest sample, 1341, and the higher number of groups, 8, with a significance level of 0.05. This sample calculation estimated an observed power of 0.76.

3.4. Results

3.4.1. *Learning Age over Decades*

Learning age changed significantly over the decades ($F(7, 786)=41.79$, $p<0.001$, $\eta p^2=0.07$). Considering consecutive decades, only a non-significant increase between 1960-69 and 1970-79 (Figure 3) was found. After that, the LA always decreased, with significant differences between 1970-79 and 1980-89 ($p=0.01$), and between 2000-09 and 2010-2019 ($p<0.001$).

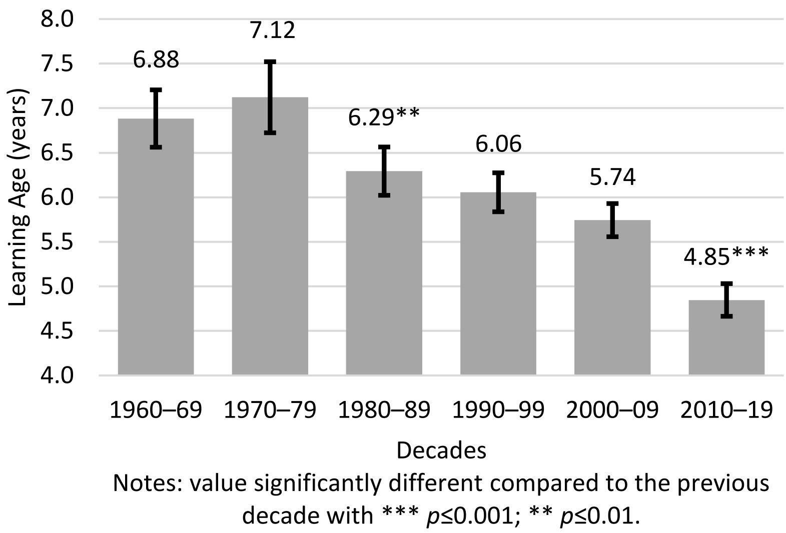

Figure 3. Evolution of learning age according to decades; mean and 95% confidence interval.

3.4.2. Use of BB and BTW over Decades

Results regarding the types of bicycles used to learn indicate that the percentage of people using the BB has increased over time from 9.6% (for people born in the 1960's) to 49.2% (for people born between 2010 and 2019). The percentage of people using the BB increased rapidly in this millennium, since when analysing consecutive decades, we found significant differences between the decades of 1990-99 and 2000-09 (χ^2(1)=6.32, *p*=0.012); and between 2000-09 and 2010-2019 (χ^2(1)=55.02, *p*<0.001) (see Figure 4).

The percentage of people using the bicycle with two training wheels (BTW) has significantly increased over several decades, more specifically between 1960-69 and 1970-79 (χ^2(1)=17.62, *p*<0.001), between 1970–79 and 1980–89 (*χ2*(1)=11.34, *p*<0.001), and between 1980-89 and 1990-99 (*χ2*(1)=19.90, *p*<0.001). This use stabilised around the percentage of 85% between 1990-99 and 2000-09, and having significantly decreased for the first time between 2000-09 and 2009–2019 (χ^2(1)=10.78, *p*=0.001), reached the value of 75.2%.

Lastly, the percentage of people using the bicycle with one training wheel (B1TW) remained relatively stable between the decades of 1960–69 and 1980–89. It only in-creased once between the 1980-89 and 1990-99 (χ^2(1)=10.31, *p*=0.001), and then dropped twice consecutively between 1999–00 and 2000–2009 (χ^2(1)=4.80, *p*=0.028), and 2000–2009 and 2010–2019 (χ^2 (1)=30.04, *p*<0.001).

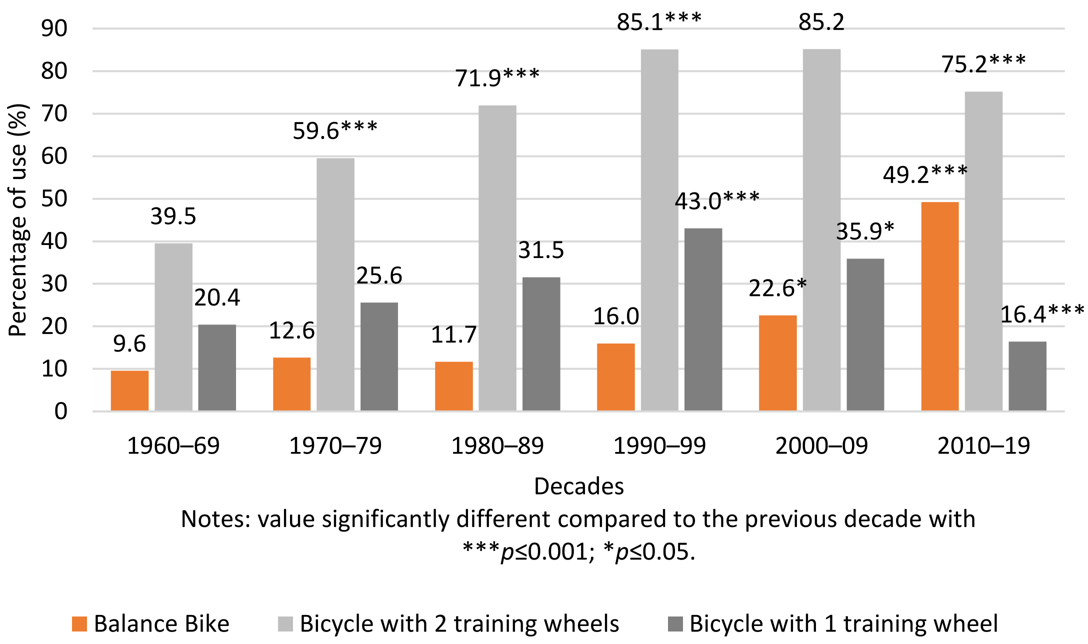

Figure 4. Percentage of use of BB, BTW and B1TW according to decades.

3.4.3. Learning Paths

The type of bikes and order in which those bikes were used during the learning process defines the different learning paths that were used. We considered the possible use of four types of bikes during the learning process: the balance bike (BB), a bike with two training wheels (BTW), a bike with just one training wheel (B1TW), and the traditional bike with no training wheels (TB). The learning paths emerge from any combination between the order of use of these bikes that ends with the TB. In the present article, the learning paths are represented by a sequence of four numbers, the position of the number represents the type of bike used and its value represents the order. More specifically, the first digit represents the BB, the second represents the BTW, the third represents B1TW, and the fourth represents the TB. So, if the child presented a learning path of 1002 it means that the BB was used in first place, the BTW or B1TW were not used, and the TB was used in second place. If one digit is repeated (e.g., 1102), it means that the child used those bikes simultaneously.

Of all the possible combinations, we found 29 different learning paths in our sample, but only the learning paths that were used by at least 30 participants were considered for analysis (Figure 5).

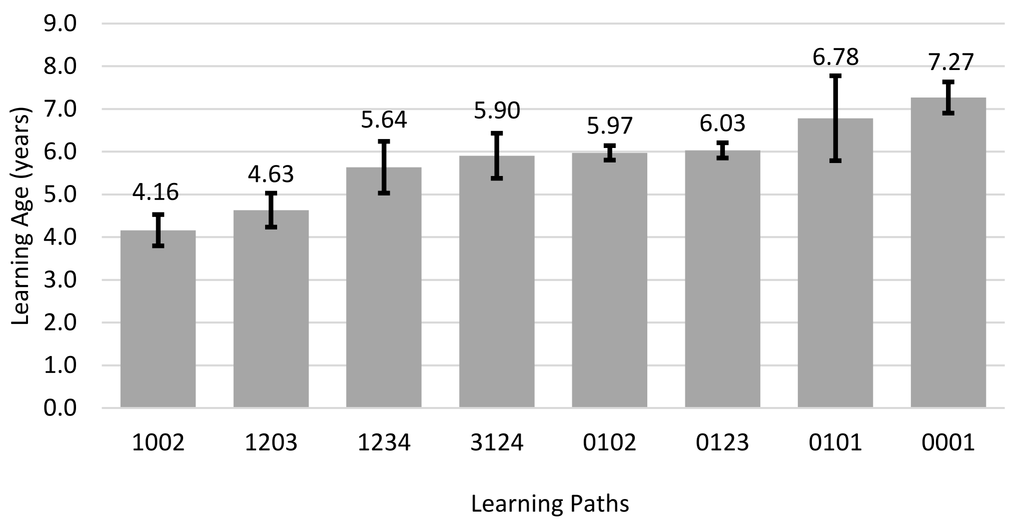

Figure 5. Learning age according to learnings paths; mean and 95% confidence interval.

Results indicated that the LA is significantly different depending on the learning paths used ($F(7, 194)=26.83$, $p<0.001$, $\eta p^2=0.08$). Descriptive statistics of the LA according to the different learning path and results of the post-hoc analyses are present-ed in Table 3.

Table 3. Descriptive statistics (mean, standard deviation and confidence interval) of learning age according learning paths.

Learning Path	Participants	M ± SD	95% CI Lower	95% CI Upper	Games Howell Significant Differences
1002	54	4.16 ± 1.34	3.80	4.53	All *** except 1203
1203	53	4.63 ± 1.44	4.23	5.03	All *** except 1002
1234	44	5.64 ± 1.99	5.03	6.24	0001 ***, 0123 ***, 1002 ***, 1203 ***
3124	42	5.90 ± 1.69	5.38	6.43	0001 ***, 1002 ***, 1203 ***
0102	630	5.97 ± 2.16	5.80	6.14	0001 ***, 1002 ***, 1203 ***
0123	364	6.03 ± 1.73	5.85	6.21	0001 ***, 1002 ***, 1203 ***, 1234 ***
0101	37	6.78 ± 2.98	5.79	7.78	0001 ***, 1002 ***, 1203 ***
0001	404	7.27 ± 3.74	6.90	7.63	All ***

Notes: first digit in learning path—balance bike; second digit—bicycle with two training wheels; third digit—bicycle with one training wheel; fourth digit—traditional bicycle; *** $p\leq0.001$.

The learning path with the lowest LA (M=4.16±1.34 years) was the one where the BB was used first, and then TB (1002). Considering these values and using the mean minus the standard deviation as a reference, we believe that by two and a half years of age, children seem to be ready to start using the balance bike. People who used the BB first and then TB had a significantly lower LA ($p<0.001$) than people who used any of the others learning paths, except using the BB first, two training wheels second, and then TB (1203). The traditional learning approach, which starts by using the two training wheels and then TB (0102) had a mean LA of 5.97±2.16 years. The learning path with the highest LA was the single use of the TB (0001), with a mean age of 7.27 ± 3.74 years, a value significantly higher than all the other learning paths ($p<0.001$).

The percentage of use of each learning path over the decades is shown in Figure 6, and it is possible to verify that the percentage of the learning paths with lower LA, as 1002 and 1203, increases; while the one with higher LA, 0001, decreases.

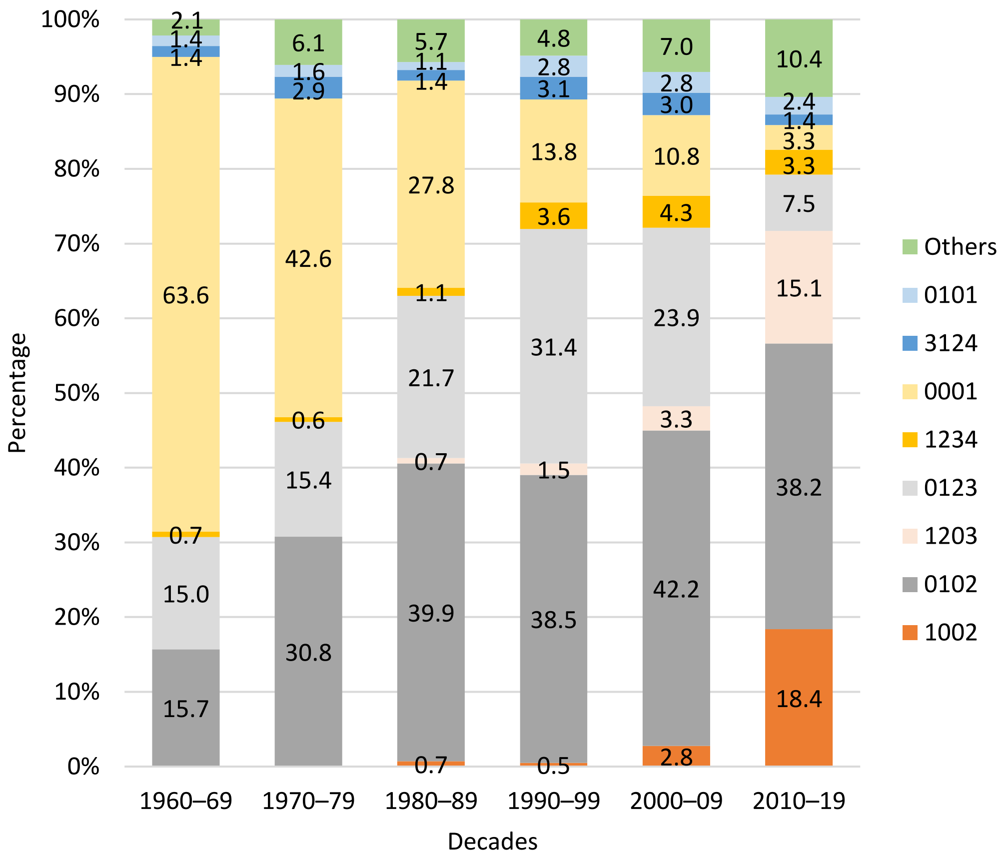

Figure 6. Percentage of learning paths by decade.

3.4.4. Order of Use of the Balance Bike

Considering not the learning path, but the order of use of the balance bike in the learning process, there were significant differences in LA depending on the moment the BB was used ($F(1, 4)=9.88$, $p\leq0.001$, $\eta p^2=0.02$). The lowest LA occurs when the BB is used first (M=5.13±2.89 years), while the highest LA occurs when the BB is not used (M=6.32±2.13 years) (see Figure 7).

The group who used the BB first learned at a significantly earlier age than the groups that never used it (*p*<0.001) or that used it in 4th place (*p*<0.001).

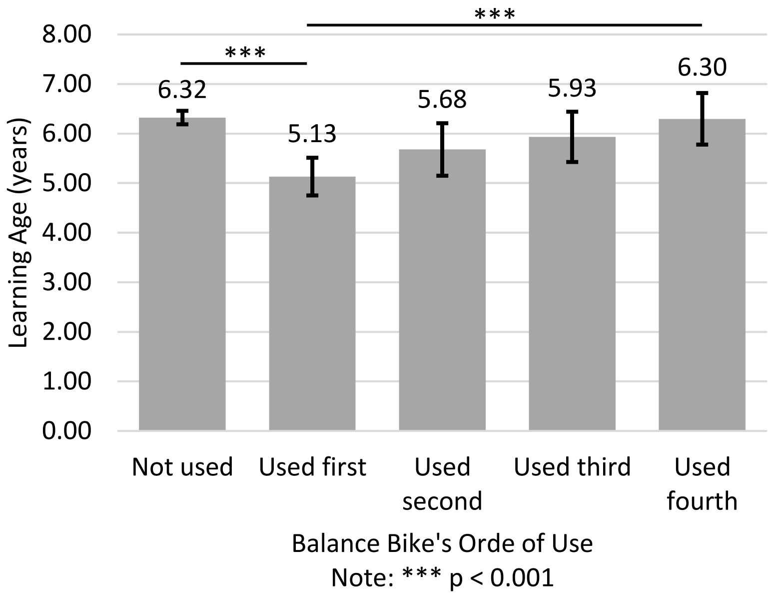

Figure 7. Learning age according to the order of use of balance bike; mean and 95% confidence interval.

3.5. Discussion

3.5.1. Relation between BB's Percentage of Use and the LA over Time

Although the BB's boom in Portugal was recent, our results indicated that at least since the 1960s some people mentioned using it in the process of learning to cycle in-dependently. Looking from a historical perspective, the BB is very similar to the first bicycle model. The bicycle was created in 1817 by Karl Drais, and it consisted of a wooden prototype just with two wheels, without chain, brakes or pedals. Therefore, riders should propel the bike by pushing the floor with their feet (Andrews, 2017; Herlihy, 2004). Maybe this bicycle model persisted in some way over time. It is also possible that even after the general commercialization of the training wheels, some people still chose to remove the pedalboard and let children play with the bicycle in-stead of using the training wheels. We could identify the biggest boom in the use of the BB between 2000-09 and 2010-2019, which coincides with the decreases in the use of B1TW in the decade of 2000-09, and of BTW and B1TW in the decade of 2009-2019. One of biggest sport articles retailers in Portugal started to sell BBs in 2012-2013, and some of the biggest supermarkets also started to commercialize it around the same time. In this decade, the media also started to include images of balance bikes in commercials. The bigger dissemination of the BB also lead entities like PCF to include it in their cycling programs (PCF, 2020a, 2020b). Some municipalities have even started to make BBs available in preschools to promote earlier cycling. All of these interactions between the macrosystem (cultural views in biking and healthy lifestyles), exosystem (cycling programs in the municipality and BB incorporated in media), mesosystem and microsystem (opportunity to explore the BB in school and with friends), added to the fact that the BB became more accessible to consumer, contributed to the significant in-crease of the BB's use.

Children born during the last decade (i.e., 2010-2019) had the lowest LA com-pared to the other groups. However, the results of this decade should be considered with caution. Due to the historical proximity of this period, some of the participants born in the last years of this decade still have not learned how to ride a bicycle. Thus, early learners might be slightly over-represented in the last decade. Nevertheless, the tendency for a significant decrease in LA across decades was clear. Considering that the BB's use increased significantly in the last two decades, it is possible that one of the factors associated with the decrease in LA is the increase in the use of BB.

3.5.2. Learning Paths

We found a great variability of learning paths in our study, which underlines the fact that the same motor developmental state can be achieved over different pathways (Waddington, 1957).

The most frequent learning path was the traditional approach (n=630), using first the bicycle with two training wheels and then the traditional bike (learning path 0102). This data reinforces the idea that training wheels are a practice ingrained in the culture of learning to ride a bicycle. The second most frequent learning path is the one with the higher LA, the single use of TB (n=404, learning path 0001). Although it does not seem to be a path that facilitates learning, this high frequency might result from a lack of availability of other type of bike. If the child has no opportunity to explore the BB or the training wheels, he/she probably will learn by just using the TB. It is interesting to note that the use of this pattern decreases over the decades (Figure 6), possibly due to the greater accessibility of training bikes such as the BB or the BTW. The first use of two training wheels followed by one training wheel and then the TB (learning path 0123), follows as the third most frequent path (n=364), highlighting once more the training wheels culture. After this, using first the BB and then the TB is the next most frequent learning path (n=54, learning path 1002). The BB's use has significantly increased ($p<0.001$) in the last decade (Figure 4), so it is expected that the frequency of the learning paths involving the BB, and particularly this new approach for learning, will increase in future.

The child's learning path occurs in specific socioecological contexts, from proximal to distal (Bronfenbrenner, 1995), and is shaped at every moment by the interaction between the existent constraints (Newell, 1986). The parents support during cycling learning is related to the microsystem layer; the community culture and cycling pro-grams, to the mesosystem layer; the media promotion of training wheels or balance bike, to the exosystem layer; and a culture that values and promotes cycling, to the macrosystem layer. All these environments have the potential to shape the child's learning path. In addition, the child's individual constraints will also influence the learning process. For example, a poor body composition (BC) is associated with a lower balance ability (Deforche et al., 2009; Kakebeeke et al., 2017; McGraw et al., 2000; Pau et al., 2012). Considering that balance is fundamental for cycling, and particularly challenging in the initial stages of learning, children with a poor BC will probably have more difficulty in learning how to cycle independently. The lack of balance can also interact with other individual constraints, such as the child's motivation to learn. If a child constantly struggles to keep balance and falls frequently during the first stages of learning, he/she will be more likely to develop a fear of falling and to start avoiding cycling to prevent injuries. Conversely, if the child has a good motor competence, it is expected that he/she experiences more success during learning, feels more motivated, and learns to ride a bicycle earlier (Robinson, 2011; Stodden et al., 2008). Finally, the task constraints also play an important role in the learning process. The fact that different learning paths, using different types of bikes, significantly correlated with LA in our study highlights the importance of the task constraints in the dynamic process of learning how to ride a bike.

The most successful path for learning (i.e., the path with the lowest LA, around four years of age) seems to be to use the BB first and then the TB (1002). On the other hand, using the two training wheels first and then TB (0102) seems to postpone learning to a later age (around six years of age in our study). According to our data, and not considering other potential confounding variables, by directly comparing these two approaches (Figure 2), it seems that the newest approach with the balance bike promotes a faster learning than the older, with training wheels. In average, in the present study, children who transitioned directly from the BB to the TB learned to ride 1.81 years earlier than children who transitioned from the BTW to the TB. However, considering the weaknesses inherent to the methodology of a retrospective survey, and the fact that the sample is not distributed equally by genres and decades, these conclusions must be analysed with caution.

By analysing the learning paths sorted increasingly by LA (Figure 5), it is possible to verify that in the first three paths, with the lowest LA, the BB was used the first. In the fourth path, the BB was used third, and in the last four paths, with the highest LA, it was not used. This ordering of patterns seems to confirm, only for the data presented, the association between the use of BB in the learning process and the lowest LA. Some authors consider that balance is the most difficult challenge in the process of learning how to cycle (Becker & Jenny, 2017; Shim & Norman, 2015). The balance bike improves balance from an early stage, not focusing on the pedalling coordination, and maybe this is the key for its success.

The BB allows children to explore several movement patterns while using it; they can walk, run, propel the bike with both feet or just one, and can also explore the flight phase when they experience balance for increasing amounts of time without any contact of the feet with the ground. While doing this, children are exploring and learning to control their centre of gravity and the bicycle's centre of gravity, as they learn to keep balance on the bicycle.

With the BTW, children develop first the ability to pedal, and balance is not a challenge because it is guaranteed by the training wheels. Therefore, when children transition from the BTW to the TB removing the training wheels, they have to learn how to balance and there is a greater instability associated with the pedalling. This approach seems to pose a greater challenge than mastering balance first and feet coordination afterwards. It should be noted that all the paths fulfil the purpose, all allow children to learn to ride a bicycle, but some of them are faster than others.

The learning path with the highest LA consisted of the single use of TB, with a mean of 7.27 ± 3.74 years. In this approach, the initial challenges are great since there are no training wheels to guarantee the balance and the pedals are already there to be used. The child should simultaneously learn how to balance, pedal, break and turn. This seems to be a too much complex task, leading to a longer duration of the learning process.

3.5.3. Order of Use of Balance Bike

The importance of using the BB at the beginning of the learning process is clear if we look at the LA according to the order of use of the balance bike learning path (Figure 7). Using the BB first afforded a significantly lower LA than not using it ($p<0.001$). The task constraint of using the BB influences the learning process (Newell, 1986), but that influence should occur earlier in the learning process, since as BB ceases to be prioritized, its effect decreases. Possibly, this happens not because of the BB itself, but because of the introduction of other types of bikes that require different types of adaptations from the child and cause more noise in the learning process. When the BB was not the first bike used, it generally means that children started to explore the pedalling before testing their balance, and exploring balance at a later stage does not seems to be the best option since it costs time. When BB is used in the last place, the effect is almost lost and the LA differs significantly from when it is used in the first place (p=0.022).

3.5.4. Strengths and Weaknesses

The major strength of this study was to address the existent gap in the literature concerning the influence of using the BB on this learning process. Although our results clearly support the general feeling that exists among bike instructors that the BB accelerates learning, due to the characteristics of this study (i.e., online survey), we could not analyse the learning process in a more individual basis. The results show that learning how to cycle independently is a process quite sensitive to the task constraints, specifically to the type of bicycle used, but the influence of specific individual constraints, such as body composition (Deforche et al., 2009; Kakebeeke et al., 2017; McGraw et al., 2000; Pau et al., 2012) or motor competence (Rodrigues et al., 2021) on this task should be addressed in studies with a different design (e.g., smaller sample of children followed longitudinally during the learning process). This type of study would also allow us to better understand the process of mastering to control the balance bike and to explore its flight phase during the initial learning stages. Finally, the comparison between the learning process among different cultures and genders can be explored in the future.

The main weakness of the study is inherent to its typology; as this study was a retrospective survey, the recall risk is possible, i.e., the participants could not remember accurately the details asked (Halverson, 1988; Sedgwick, 2012). Considering that the recall risk may be higher in older participants, as a strategy to control and minimize this possible bias, the responses of participants born before the decade of 1960–69 were not considered. In addition, the younger and the older participants could interpret the questions differently; as strategies to avoid this, the questions were developed and discussed in order to be simple, clear and objective. Prior to the survey's application, 30 participants aged between 18 and 60 were asked about the comprehension of the survey. Other questions, such as the age of first approach to cycling or the cycling frequency during learning were not included. We believe these are important questions, but according to the feedback of the interviews, they would be difficult to address in a retrospective survey study. Finally, another limitation is related with the sample; although it is not small (n=2005), the number of males and females by each decade, and the number of participants between decades, are not equivalent. The sample includes more females than males, especially in the older decades, which are possible limiting factors of the results.

3.6. Conclusions

To our knowledge, this is the first large scale study to investigate the influence of using a BB in the process of learning to ride a bicycle independently. Our results indicate that using a BB, particularly during the first stages of the learning process, leads to a significant decrease in the LA for this motor milestone. However, considering the study's design and its weakness, the extrapolation of these results should be considered with caution. The use of the BB has been increasing throughout the decades, accompanied by a decrease in the average age for learning, which in Portugal has been more marked since the beginning of the millennium. There are different benefits of learning how to cycle earlier. For example, children who begun to cycle at an early age are more likely to have a healthy weight in the subsequent school years (Pabayo et al., 2010), they can have fun moments cycling outdoors with peers or family, they develop motor components, and mature their social and emotional skills (Karabaic, 2016; Orsini & O'Brien, 2006). Although a great number of learning paths will always continue to exist, it seems that the sooner children master balance, the earlier they will be able to control the TB. For the present data, the difference in the LA for cycling independently varied by two to three years depending on the learning path and the type of bikes used. This temporal gap could have an impact in a child's life, so it is important to promote the best approach for learning how to cycle as soon as possible, which seems to be the one that uses the BB first. Based on the data, it is suggested to start learning to cycle at about two and half years of age by using the balance bike.

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Chapter **4**

4. Learning to Cycle: Are Physical Activity and Birth Order Related to the Age of Learning How to Ride a Bicycle?

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4.1. Abstract

Objective: the present article aimed to verify whether the age at which children learn to ride a bicycle is related to their physical activity or birth order. Methods: data were collected from an online structured survey between November 2019 and June 2020. A total of 8614 responses were obtained from 22 countries. Results: The results reveal significant differences in learning age depending on the frequency of physical activity ($F(5, 7235)=35.12$, $p<0.001$, $\eta p^2=0.24$). People who engaged in physical activity less than twice a month learned to cycle later (M=7.5±5.3 years) than people who engaged in physical activity on a daily basis (M=5.7±2.2 years) ($p<0.001$). There were also significant differences in learning age according to birth order ($F(2, 3008)=7.31$, $p=0.00$, $\eta p^2=0.005$). Only children had the highest learning age (M=5.5 2.4 years), whereas those who were born last had the lowest, (M=5.1±1.9 years) ($p=0.013$). Conclusions: creating opportunities for children to be engaged in play and physical activity and social modulation through their older siblings seem to be key conditions to encourage children to learn how to ride a bicycle from a young age and to foster their motor development.

Keywords: learning; bicycle; child; birth order; survey.

4.2. Introduction

The concept of physical activity (PA) refers to any bodily movement produced by a muscle's contraction that substantial increases the energy expenditure above baseline (ACSM, 2019), including riding a bicycle. All movement, including getting from one place to another or actively playing with friends during leisure time, or movement that requires significant energy expenditure in a person's work, is also considered physical activity. Several conceptual models have studied and explored the relationship between the practice of physical activity, motor competence and the health promotion. The World Health Organization (WHO, 2019) recognizes that young children should have opportunities to participate in a range of developmentally appropriate play-based physical activities, which will help them to develop motor competence (Wrotniak et al., 2006), social and emotional skills (Eime et al., 2013), and health (Poitras et al., 2016). In fact, the fundamental role of PA in children's development is widely recognized (Carson et al., 2017; Colella & Morano, 2011; WHO, 2019).

According to Stodden's model (2008), good levels of motor competence have a key role in promoting healthy trajectories of life concerning PA and weight management. Therefore, motor competence is considered to be a primary mechanism that promotes engagement in PA. Recently, Hulteen and collaborators (2018) presented a new conceptual model for PA across lifespan. This model proposes the use of the term "foundational movement skills" instead of "fundamental movement skills", arguing that foundational movement consists of movement patterns reflecting a broad range of movements that directly or indirectly have an impact on the individual's capability to be physically active. These movements can be developed to enhance participation in PA and to promote health throughout lifespan. The model argues that these skills should be viewed through a social, cultural and geographic filter. This assumption reinforces the idea that foundational skills are not entirely pre-determined and could vary between different contexts. Activities such as swimming, riding a bicycle or doing push-ups or squats are now considered to be foundational skills, in which children should develop motor competence in order to become more physically active during their lifespan. Ultimately, the model recognizes that the individual's specific attributes, such as physical characteristics, including weight status or cardiorespiratory fitness, and psychological constructs, such as self-efficacy or perceived competence, also affect the development of these skills and, consequently, the participation in PA across lifespan.

This new model (Hulteen et al., 2018) provides a broad view of motor development and its relationship with the promotion of PA and health, highlighting the importance of the new concept of foundational skills. Learning how to ride a bicycle is recognized as one of the foundational movement skills (Hulteen et al., 2018; Kavanagh, Issartel, et al., 2020), and it is also an important motor milestone for children (Zeuwts et al., 2015). Cycling is a lifelong skill used for several purposes—as a mode of transportation, in sports, or simply for recreation (Kavanagh, Issartel, et al., 2020). Riding a bicycle is a complex skill that allows for fun moments with peers and family (Orsini & O'Brien, 2006), promotes greater exploration of the environment and independent mobility in children (Smith et al., 2017), provides several benefits to physical health, including improvements in cardiorespiratory condition and body composition (Ramírez-Vélez et al., 2017), and to mental health, with the development of emotional and social skills (Handy & Lee, 2020; Karabaic, 2016; Orsini & O'Brien, 2006). These benefits continue throughout life as long as the child, the teenager or the adult continues to cycle; e.g., children who begin to cycle earlier are more likely to have a healthy weight in later school years (Pabayo et al., 2010).

The idea that cycle could be a factor that triggers and further promotes physical activity engagement throughout life (Hulteen et al., 2018), is corroborated by some intervention studies, namely with children with disabilities, which identified that learning to cycle made children less fearful and more motivated to try other physical and sports activities (Temple et al., 2016; Ulrich et al., 2011). Children who learned how to cycle spent less time participating in sedentary behaviours, and more time participating in moderate to vigorous physical activity time when compared to control group children (Hauck et al., 2017; Ulrich et al., 2011). In addition, they had better body composition with higher leg strength, and less body fat percentage than children who did not know how to cycle. These results led Hauck et al. (2017) to suggest that learning how to ride a bicycle could disrupt the cycle of consistent unhealthy weight gain over time in children with disabilities, which is in line with Hulteen's suggestion of considering cycling as a foundation movement that promotes PA (Hulteen et al., 2018). However, the relationship between cycling and PA might be bidirectional. Children who engage in more PA are probably also more likely to try cycling, and to learn how to ride a bicycle at an earlier age, than more sedentary children.

Having siblings is another factor that can influence children's participation in PA and their motor development. However, there is no consensus regarding the effect of having an older sibling in the literature. Some authors claim that older brothers or sisters negatively influence younger siblings' development, arguing that having siblings implies dividing parental attention, affecting communication opportunities and contributing to a delay in language development (Wellen, 1985). On the other hand, it has been argued that older brothers or sisters positively influence younger siblings' motor development. Due to social learning, young children tend to observe and imitate older children who are meaningful to them, such as friends or siblings (Barr & Hayne, 2003). The social modelling involved in learning a motor skill is also an important aspect of this process. In this sense, learning how to cycle may become a social activity through which siblings create opportunities (i.e., affordances) to play. Having the chance to play with siblings improves cognitive, social and emotional development (Rebelo et al., 2020). In this way, the motor development associated with learning how to ride a bicycle also entails a significant gain for the child in terms of fostering other developmental areas. Although it is relatively consensual that older siblings influence the motor development of the younger ones, the specific characteristics of the family probably also determine the type and magnitude of this influence (Berger & Nuzzo, 2008; Leonard & Hill, 2016).

Considering that riding a bicycle is a foundational skill and an important motor milestone for children, and taking also into account that motor development is influenced by several individual (Hulteen et al., 2018) and environmental factors (Venetsanou & Kambas, 2010), the present study aimed to verify whether the age of learning to ride a bicycle is related with the child's frequency of physical activity and/or birth order. It has been hypothesized that more physically active children learn to cycle earlier; that younger siblings learn earlier than older ones; and that older ones, in turn, learn earlier than only children.

4.3. Materials and Methods

The present study is part of the international project L2Cycle (Learning to Cycle), which aims to assess different aspects related to the process of learning how to cycle in different countries (e.g., learning age, socio and demographic aspects, type of bicycles used, or who taught the person to cycle). For this purpose, a survey was created on LimeSurvey, hosted by the Faculty of Human Kinetics (University of Lisbon, Lisbon, Portugal), and approved by its ethics committee.

An initial version of the survey was developed by four motor development experts and was tested online on 485 participants, with a sub-sample of 30 participants additionally asked about their comprehension of the survey. Some adjustments were made (e.g., clarifying that the age of learning how to ride should address independent cycling without the help of training wheels or parents). At a second stage, the survey was examined and discussed with five other international experts who provided further suggestions (e.g., adding questions regarding different seasons of the year). Finally, the survey was translated into different languages, now available in 10 languages (Portuguese—from Portugal and Brazil, English, German, Croatian, Finnish, French, Dutch, Italian, Japanese, and Spanish).

The survey has 3 sections: (1) "About you", questions about the participant's (adult) personal experience of learning to cycle and demographic data; (2) "About your oldest child" (only if the participant is a mother or father), the same questions as in the previous section, but regarding the participant's oldest child; (3) "About your youngest child" (only if participant has more than one son/daughter), the same questions as in the previous section, but regarding the participant's youngest child.

The questions of the survey regarding physical activity were as follows: "When you (your child) learned to ride a bicycle, how often did you (he/she) practice sports, outdoor play, or physical activity?" For this study, six frequencies of PA practice were considered: (1) less than twice a month, (2) twice a month, (3) once a week, (4) two or three times a week, (5) four to six times a week, (6) daily.

The variable birth order had three categories: older, younger or only child. The birth order of the adults was not questioned, and for this reason it was not considered for this study.

The survey was publicized through the social media (Facebook, Instagram and Twitter), and by email. In addition, partnerships with cycling federations, kids and parent's magazines and non-profit cycling organizations were established in different countries for dissemination on their websites and paper magazines. Data for this study were collected between 22 November 2019 and 8 June 2020.

Descriptive data analysis was performed to characterize the sample. One-way ANOVAs were used to determine the effects of the frequency of physical activity and birth order on learning age for cycling. Post hoc Scheffé tests were conducted when needed. The level of significance was set at p=0.05.

4.4. Results

There were 8614 responses to this survey. Those responses referred to 4637 adults (self-response) and 3977 children (parental responses). Participants' mean age was 29.11 years (SD=17.7), 4975 were male, 3595 were female and 44 preferred not to disclose the sex. Data came from 22 countries: Portugal (2386), Brazil (1556), Italy (1484), Finland (991), United Kingdom (769), Mexico (463), Belgium (438), Croatia (364), Germany (63), Spain (39), USA (21), France (11), Canada (9), Norway (5), Austria (4), Japan (3), United Arab Emirates (2), Bosnia (2), New Zealand (1), Cape Verde (1), Cayman Islands (1), and Taiwan (1).

There was a significant difference in the learning age for cycling depending on children's frequency of physical activity practice ($F(5, 7235) = 35.12$, $p<0.001$, $\eta p^2=0.24$) (Figure 8).

Children who practiced physical activity less than twice a month (2×/month) learned significantly later than those who practiced two to three times a week (2–3×/wk), four to six times a week (4–6×/wk) and daily (all $p<0.001$). Those who practiced 2×/month also learn later than those who practiced 4–6×/wk (p=0.009), and daily (p=0.001). Children who practiced once a week learn later than those who practiced 2–3×/wk (p=0.003), 4–6×/wk ($p<0.001$) and daily ($p<0.001$). There was no difference in learning age between children who practiced 4–6×/wk and daily.

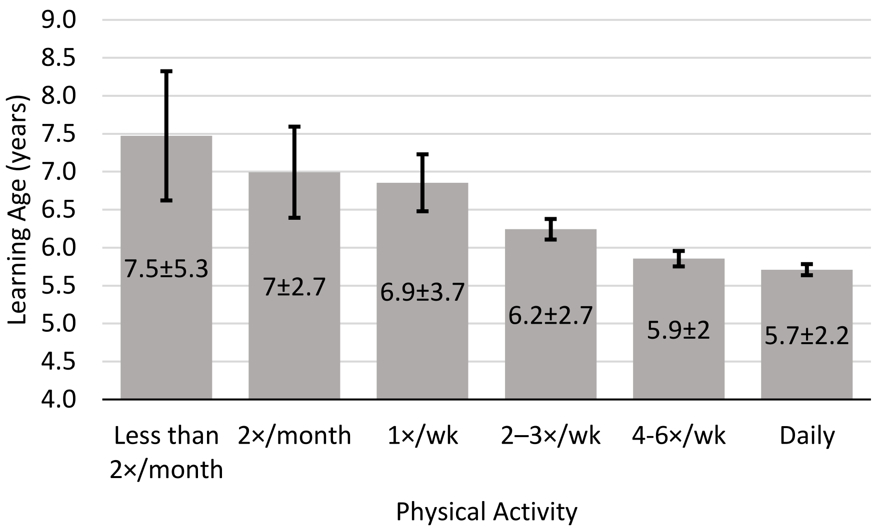

Figure 8. Mean age and standard deviation to learn how to cycle by the frequency of physical activity practice (error bars represent 95% CI).

A significant difference in learning age was found according to birth order ($F(2, 3008)= 7.31$; $p=0.001$, $\eta p^2=0.005$), (Figure 9). Younger children learned earlier than older children ($p=0.004$) and only children ($p=0.013$). No significant differences were found between the learning age of older children and only children ($p=0.821$).

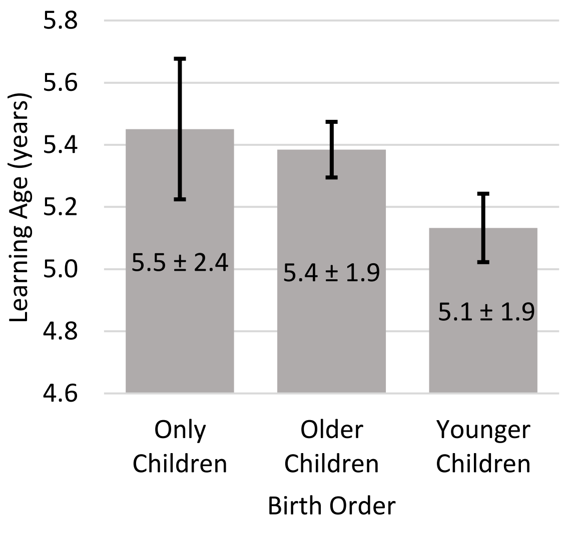

Figure 9. Mean age and standard deviation to learn how to cycle according to the birth order (error bars represent 95% CI).

4.5. Discussion

Hulteen's model (2018) highlights the important role of foundational movement skills, such as cycling, to promote and maintain healthy PA trajectories throughout lifespan. In the present study, the causality effect between cycling and PA practice was not possible to address, but a relation between PA and the foundational skill of riding a bicycle was confirmed in the early stages of development. The greater the frequency of PA, the lower the age for learning how to cycle. Children who practiced physical activity more than three times a week learned earlier than all the others, proving the first hypothesis that more physically active children learn to cycle earlier. These results have the same pattern when analysing the data according to geographical variables (Southern Europe, Northern and Western Europe, and Latin America, all $p<0.001$). It seems that the relationship between learning to cycle and PA could be bidirectional. In this way, learning to cycle would promote future PA (Temple et al., 2016; Ulrich et al., 2011), and practicing PA would lead to an earlier learning onset age regarding cycling, as we have seen in this study. During childhood, practicing PA, usually through active play, is important for the child to explore and increase his/her motor repertoire, and to develop balance and co-ordination (Carson et al., 2017). When learning how to ride a bicycle, the child should manage and coordinate his/her body with the bicycle, while simultaneously pedalling and balancing. Therefore, coordination and balance are fundamental aspects for cycling. Some authors even claim that balance acquisition is the biggest challenge for cycling (Ballantine, 1992; Shim & Norman, 2015). Most likely, children who practice PA more frequently have a better chance of developing the necessary skills to learn to cycle, which ultimately leads them to learning at a younger age than children who are more sedentary.

Practicing PA also improves the child's cardiorespiratory condition and muscular fitness (Poitras et al., 2016). Some previous studies with children with disabilities pointed to leg strength as a conditioning factor for learning how to cycle (MacDonald et al., 2012; Ulrich et al., 2011). Children with lower leg strength developed muscular fatigue more quickly and tended to stop pedalling and training more easily, compromising and/or delaying their cycling acquisition. In typical developing children, leg strength may not be such a conditioning factor in the learning process; however, given that cycling is an activity that requires some cardio and muscular fitness, fitter children would probably learn to cycle more easily. In addition, doing PA also improves phycological attributes, such as perceived competence (Christiansen et al., 2018), which in turn tend to increase the engagement in physical activities (De Meester et al., 2016). Hence, the positive relationship between children's frequency of practicing physical activity and the age that they learn to cycle is probably influenced by different physical and psychological attributes, as mentioned in Hulteen's model (2018), such as the levels of balance and coordination (Carson et al., 2017), the cardiorespiratory and muscular fitness (Poitras et al., 2016), and the perceived competence (Christiansen et al., 2018). Another possible cause that might explain the positive relationship between children's PA and their learning age for independent cycling is that children who practice more PA might have earlier opportunities to practice, because their parents value PA and might give them a bicycle earlier.

The influence of the family, especially of the parents, in the process of learning to cycle has already been approached. Studies indicated that having parents who value cycling and promote its practice leads children to learn how to cycle earlier (Temple et al., 2016; Ulrich et al., 2011). However, as far as we know, this is the first study to explore the sibling's influence in the process of learning how to cycle. The results confirm the second hypothesis raised, that younger children learn how to ride a bicycle earlier than older and only children. When considering geographical variables, there were differences between the three regions. In Southern Europe, the younger children learned significantly earlier than the older children (F(2, 1887)=3.50, p=0.030, ηp^2=0.004), whereas, in Northern Europe (F(2, 678)=4.40, p=0.013, ηp^2=0.13), younger children learned significantly earlier than only children. There were no significant differences in Latin America (F(2, 431)=2.67, p=0.71, ηp^2=0.012). Perhaps younger siblings benefit from watching the older ones and even from their help in some cases (Barr & Hayne, 2003; Venetsanou & Kambas, 2010). Other studies, not specifically focused on learning how to cycle, showed that having siblings influences sports participation, and siblings have been suggested to play a key role in sports expertise development (Hopwood et al., 2015). Riding a bicycle is usually an active pleasurable activity to do with younger siblings, increasing their cycling skills and, consequently, accelerating their independent cycle acquisition and expertise. Additionally, siblings' interactions through play also promote children's motor and physical development (Rebelo et al., 2020), which ultimately might contribute to an earlier acquisition of cycling. In fact, children from 6 to 15 years of age with siblings presented significantly better physical fitness than only children, independent of sex or somatic status (Rodrigues et al., 2020), while at the preschool age, only children showed lower motor competence than children living with other siblings (Clearfield et al., 2008). Finally, another possible reason for younger siblings to learn how to cycle earlier might be the simple fact that they are more likely to benefit from having an available bicycle to explore and play earlier (i.e., their sibling's bicycle). Similarly, the fact that the child has someone to copy or imitate was pointed out as a determining factor for the acquisition of the task, which needs to be learned (Clearfield et al., 2008; Dickerson et al., 2013). Clearfield et al. (2008), in a socialization study focusing on the transition between crawling and walking, found that as infants evolve to a new form of locomotion, they progress from passive to active participants in their social environment, moving from observers to agents of social interaction. Although this was not the focus of our study, and considering our results, this phenomenon may have been the catalyst for the need to learn to ride a bicycle earlier, especially when their social peers (in this case the family) are already doing so. From the perspective of the observing child, cycling can be interpreted as a form of social exploration, as a way to keep up with parents, siblings and/or other children, or as a form of independent exploration of the environment, similar to children who move from crawling to walking, whose visual horizon is broadened.

The third hypothesis, predicting that older siblings would learn to cycle earlier than only children, was not confirmed. Some studies indicate that there are reciprocal effects of sibling relationships on motor development (Leonard & Hill, 2016). The idea is that by playing together, both siblings improve motor development, increasing their participation in sports (Hopwood et al., 2015). Cycling with a brother or sister is, probably, more fun than cycling alone. So, having a sibling to cycle with can lead to greater practice and enjoyment, which can promote both children's learning. The sibling's interactions could be an influencing and catalysing factor for learning how to cycle. However, the data from the current study do not support the idea that siblings' interactions promote both siblings' motor achievements when it comes to cycling. The analysis of our data suggests that only children are a quite heterogeneous group regarding their cycling learning age; some only children might have benefited from the greater availability of their parents to teach them how to cycle, which might have compensated for the fact that there were no siblings to play with. The interaction between these factors and the relationship between learning age and the number of siblings should be investigated in future studies.

The present research findings reinforce the sociocultural nature of motor development, more specifically of the age from which a child learns how to cycle independently. Such a process is affected by factors, resources, properties, dispositions and constraints made available by the socioecological niche of children's and families' lives. Future studies should therefore consider the theoretical perspectives of motor development and task performance as a biosocial process as suggested by authors such as Bronfenbrenner and Morris Bronfenbrenner and Morris (2006) and Newell (1986).

4.6. Conclusion

The amount of physical activity that children do is related with their learning age for cycling. Children whose parents report partaking in daily physical activity learn, on average, 1.8

years earlier than those whose parents report exercising less than twice a month. It is possible that physical activity affords better balance, coordination, muscular fitness, and perceived competence, accelerating the learning age for independent cycling.

Younger siblings learn earlier than older siblings and only children. The younger siblings might benefit from having an available bicycle earlier, and probably also learn by imitation and interaction with their older siblings.

The fact that the amount of physical activity and birth order are related to the learning age for cycling emphasizes the importance of context constraints in motor development during early childhood.

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Chapter **5**

5. Learning to cycle: a Constraint led intervention programme on different cycling task constraints

Short version submitted as:

Mercê, C., Keith, D., Catela, D., Branco, M., Vanda, C., & Cordovil, R. (2022). Learning to cycle: a Constraint Led Intervention Programme. Physical Education and Sport Pedagogy

5.1. Abstract

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, however, some evidence suggests that this approach is counterproductive. Purpose: Underpinned by an ecological perspective and Constraints-led approach, the aim of this paper is to investigate whether learning how to ride a bicycle in childhood can be shaped by the specific task constraints related to the kind of bicycle used (i.e., balance bike and 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 (mean age: 6.08±1.19 years) who could not previously cycle and 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 traditional bicycle (TB). The acquisition of independent cycling was assessed based on established cycle learning milestone achievements, without help: (i) self-launch, (ii) ride for at least 10 (consecutive) metres, and (iii), braking. To be considered an independent rider participants needed to achieve all these milestones, without any help. During the TB sessions, the number of days that each child needed to acquire each learning milestone and independent cycling was recorded. Results: The programme had a success rate of 88% for the achievement of independent cycling, with 100% success in the BBs group and 75% in the BTWs group. The BB participants learned to significantly more quickly self-launch, ride, brake, and cycle independently, than the BTW participants. Number of days needed to ride were associated with body mass index. No correlation was found between motor competence and the learning to cycle milestones. 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. Body composition influenced the time needed to acquire riding skills, although it did not significantly influence the time needed to achieve cycling independence.

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

5.2. Introduction

Since its invention the bicycle has gained an important role in everyday life of humans. Nowadays, this sustainable mode of transport (Pucher & Buehler, 2017) is used everywhere for exercise, sports competition, travelling or simply for recreation (Oosterhuis, 2016). Recently, cycling was proposed as a foundational movement skill, because it promotes engagement in physical activity, leading to positive health trajectories throughout the life course (Hulteen et al., 2018). Indeed, the benefits of cycling are well documented in scientific literature, applicable across the whole life course. In childhood, cycling promotes 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 short, the perceptual-motor competence of cycling can support numerous mental, physical and social health benefits. For these reasons, learning to cycle is an important achievement milestone in children's personal and motor development (Zeuwts et al., 2020; Zeuwts et al., 2015).

The present study is framed by an ecological dynamics perspective, arguing for a non-linear trajectory in learning (Chow et al., 2022; Chow et al., 2007). In a non-linear pedagogical approach, learning involves the coupling between perception and action when interacting with the environment, based on the constant development, exploration and acquisition of a reciprocal relationship between the environment, the individual and the task to be performed (Renshaw et al., 2010). The ecological concept of an affordance emphasizes the continual interaction between an individual and the environment, defined as *opportunities for action* that can be perceived and utilised within the environment during performance (Gibson, 1979).

Learning how to ride a bike, underpinned by key concepts in ecological dynamics, is not a linear process, emerging as each child adapts and self-organises to key task constraints framed by the relations of each learner and the learning environment. 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 the variability of the proposed tasks and adequate manipulation of constraints (Button et al., 2020).

In the present study, the aim is to consider the contribution of a Constraint-led approach to learning how to cycle. The Constraints-led approach (CLA) (Davids et al., 2008; Renshaw et al., 2010) provides theoretical insights to didactically structure the process of learning to cycle.

As previously noted, this approach advocates that learners should be challenged and guided to use information to self-regulate actions and adaptively to changing task and environmental constraint. As this study seeks to investigate, a key challenge 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., task variability) in the learning environment, creating instabilities and perturbations which promoting the 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 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 triggers new emerging goal-directed movement solutions (Chow et al., 2007).Those constraints are predicated on dimensions of Newell’s model (1986), proposing that movement emerges from the interaction of the personal characteristics of the actor (e.g., a child’s anthropometry, motor competence, motivation to learn, previous experience on the bicycle), the task (e.g., the type of bicycle used to learn), and the environment (e.g., gravity or cycling surface to be navigated). 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 learners in cycling, and design learning contexts accordingly. Furthermore “decisions on manipulation must be also based on prior analysis by practitioners” (Correia et al., 2018). This means that, planning an intervention according to pedagogical methods 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., 2018).

Recently, a systematic review was carried out to synthetize, compare and evaluate different interventions and strategies implemented to teach children to cycle (Mercê, Pereira, et al., 2021). 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 concerns 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).

5.2.1. *Cycling Task Constraints*

In the process of learning to cycle, different training bicycles can be used. The most common is the BTW, which allows children to first learn how to pedal without needing to regulate their posture and balance on the bike, negating the fear of falling. With this bicycle, children are only allowed to explore the synchrony of balancing 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 so, in contrast to the BTW, the child needs to couple their postural regulation actions with the bicycle movements to maintain balance from the first moment. Thus, 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.

According to the studies reviewed by Mercê et al. (2021), the BTW may not invite children to explore balance in forming a system between their body and bicycle from the beginning (Cain et al., 2012; Hauck et al., 2017; Hawks et al., 2020; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011). Burt et al. (2007) sought to clarify this issue by explaining that, when the lateral training wheels are removed, the children experience instability, activating ineffective defence responses, freezing their movements and making their upper torso and arms rigid and inflexible. This freezing of motor system degrees of freedom has been predicted for early motor learning by Bernstein (1967).

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 only learning to cycle intervention targeted at typically developing children that we are aware of (Kavanagh, Moran, et al., 2020), also used two groups, one with the BB and another with the BTW. But the aim of that study was to develop and validate a cycling proficiency scale. For that reason, differences in learning that emerged between groups, due to the use of different task constraints, were not studied. According to our knowledge, no study has been carried out to compare different training bicycles and to investigate their effects on the learning process.

The present study sought to investigate and compare the process of learning to cycle using the most common, traditional approach, the BTW, versus the most recent one, the BB, in a two-week intervention. More specifically we aim to compare the efficacy and efficiency of the two approaches for learning to cycle. Additionally, the role of some intrinsic constraints, namely body composition (e.g., Kakebeeke et al., 2017) and motor competence (e.g., Rodrigues et al., 2021), will also be analysed.

5.3. Methods

5.3.1. Study Design

This study was approved by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon (approval number: 22/2019). The study design (see Figure 10) 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 traditional 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.

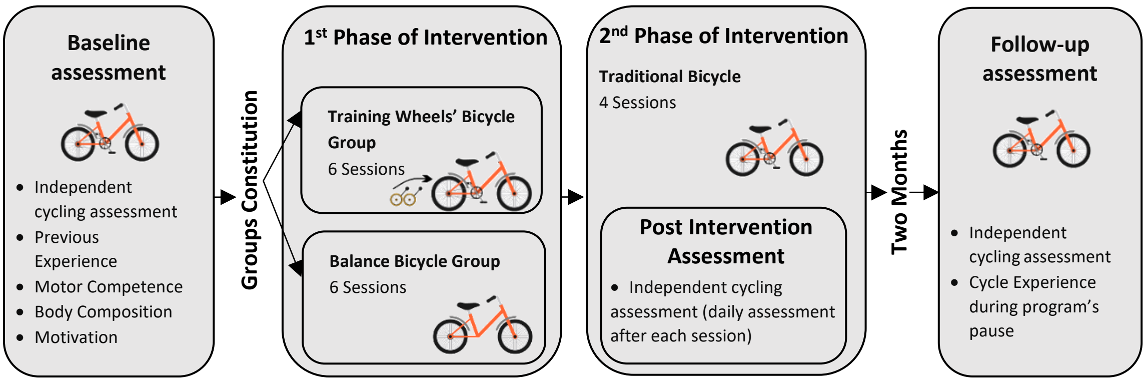


Figure 10. Study's design.

5.3.2. Baseline Assessment

The following assessments were undertaken as part of the research protocol: independent cycling assessment, parental survey, measures to determine participant body mass index (i.e., height and weight), motor competence and motivation.

5.3.3. *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, Moran, 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 10 consecutive metres, 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, Pereira, et al., 2021). For all these assessments, children were invited to cycle on a traditional bicycle, and researchers observed and registered each cycle milestone.

5.3.4. *Previous cycling experience*

A parental survey was carried out to collect relevant information, such as previous experience of each participant on different types of bicycles (i.e., balance bike, bicycle with two training wheels, bicycle with one training wheel and a traditional bicycle). Information on the frequency of physical activity in each participant was recorded.

5.3.5. *Body composition*

Height and weight of each participant were recorded, according to the International Society for the Advancement of Kinanthropometry (ISAK) protocols (Norton & Eston, 2019) and used to calculate body mass index (BMI). After calculation, participants' BMI values were classified according to WHO criteria (WHO, 2006a). Height was measured to the nearest 0.1 cm using a stadiometer, and weight was measured to the nearest 0.1 kg using a digital scale: Tefal Sencio.

5.3.6. Motor Competence

Participants' motor competence was assessed using the Motor Competence Assessment Battery (MCA) (Luz et al., 2016) and scores were classified according to the percentile values for Portuguese children (Rodrigues et al., 2019). The general motor competence score was computed as the average of the standardized values (i.e., percentiles for age and sex) of each child in the six component tests of the MCA.

5.3.7. Motivation

Children's motivation to learn to cycle was also evaluated (MacDonald et al., 2012) and assessed through a pictorial 5-point Likert scale (1. saddest face: no motivation to learn; to, 5. happiest face: great motivation to learn). Before starting the intervention, children were asked to choose the face which corresponded best to their current desire to learn to cycle.

5.3.8. Participants and Group Constitution

Initially, 101 children were enrolled in the intervention study. However, prior to the pre-test, and because of the conditions of the Covid-19 pandemic, one of the schools (36 children) went into lockdown and were required to exit the project. Of the 65 children in the remaining school, seven never attended the activities. The baseline assessment sample then numbered 58 children. However, 14 children already knew how to ride a bicycle, so, they were not included in the learning intervention, and 16 children dropped out of the programme before starting. The intervention started with 28 children, but three quit in the beginning, leaving a final sample of 25 children. All 25 children participated in the pre-testing, intervention, post assessment and follow-up. Figure 2 shows the flow of participants. The final sample had an age range of 3- to 7-years (M=6.08 years; SD= 1.19), consisting of both sexes (11 girls and 14 boys), from two public elementary schools in Alfragide, Portugal. None of the sample participants were able to cycle independently at the beginning of the intervention (Figure 11).

After collecting 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).

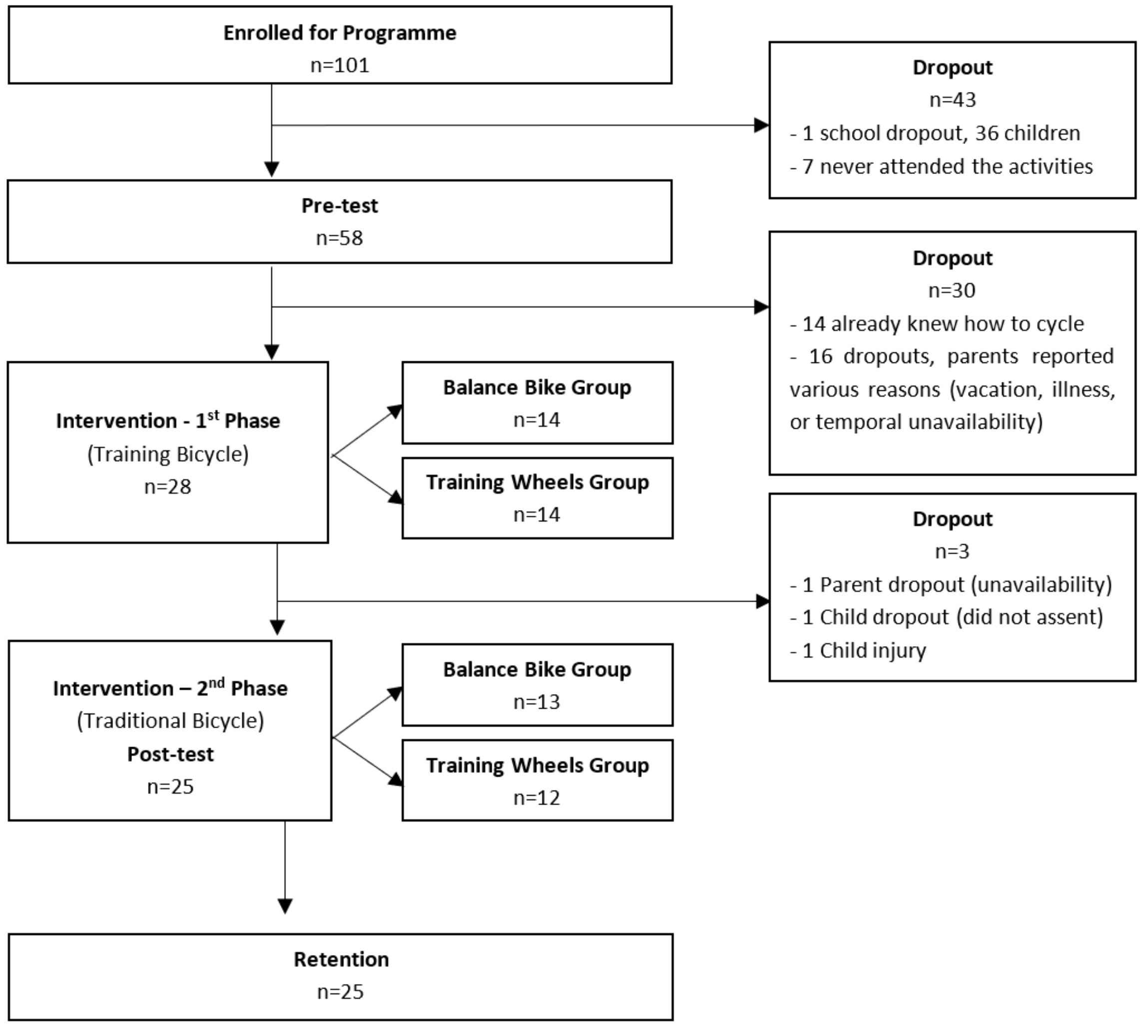


Figure 11. Flow of participants thought the study.

5.3.9. Intervention

The Learning to Cycle (L2Cycle) Intervention Programme consisted of a two-week programme developed to teach children without disabilities to cycle independently using a traditional bicycle. Specifically, the L2Cycle Intervention Programme was designed 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.

This programme was based on implementing key ideas of the Constraints-led approach (Chow et al., 2007; Davids et al., 2008). Through considering individual constraints (e.g., frequency of physical activity, motor competence, motivation to learn), the CLA focuses essentially on the manipulation of bicycle constraints, in order to afford children to explore how to use perceptual information to guide cycling actions. Guidelines from a recent systematic review on cycling programmes (Mercê, Pereira, et al., 2021) were also considered, 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).

For intervention delivery, this study counted on professional support of physical education teachers, with a ratio of teacher-learners of one-to-two or, at maximum, one-to-three. The intervention programme was set up in the school's playground. The daily sessions lasted approximately 40 minutes each, with 10 minutes for preparation (e.g., each child learning to adjust helmet and bicycle to their anthropometric characteristics), 30 minutes 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, allowing full time for effective 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 traditional bicycle (second phase) (Figure 1).

5.3.10. Post assessment

The independent cycling assessment was taken daily by each participant at the end of each session of the second phase of intervention (i.e., 4 sessions with the traditional bicycle) (Figure 1). 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 traditional bicycle to learn.

5.3.11. 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).

5.3.12. 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 days 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. Kruskal-Wallis tests were used to analyse differences between reported motivation levels and frequency of physical activity, along with the days needed to achieve the learning milestones and independent cycling, with estimation of effect size η^2. Spearman correlation coefficients were used to determine the possible associations between the variables of MC, BMI and decimal age and days needed to achieve the cycle milestones and independent cycling. For all tests, a statistical significance level of p=0.05 was adopted.

5.4. Results

5.4.1. 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 days needed to achieve independent cycling. Regarding cycling milestones, only a moderate positive correlation was found between the number of days 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 4.

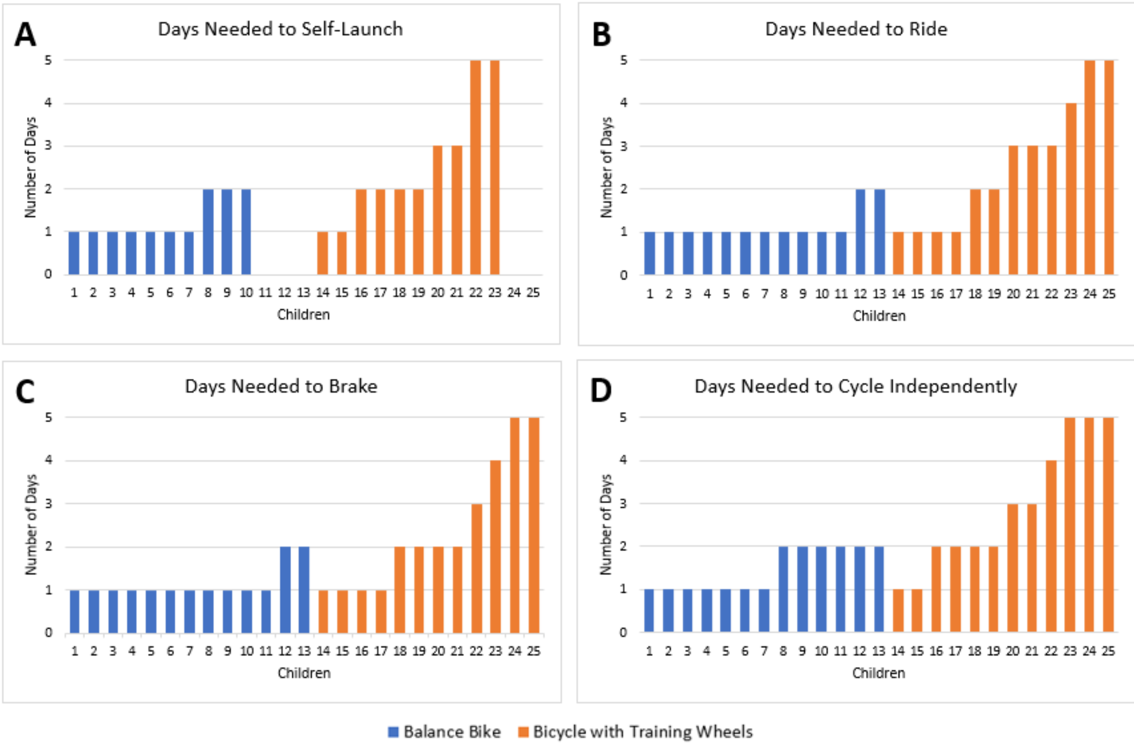
Table 4. Descriptive statistics (M, SD and Mdn) for age, body composition and MC scores, per group and for the total sample.

	BB Group		BTW Group		Total	
	M±SD	**Mdn**	**M±SD**	**Mdn**	**M±SD**	**Mdn**
Age (years)	6.12±1.22	6.64	6.04±1.2	5.65	6.08±1.19	6.50
Height (m)	1.18±0.10	1.20	1.13±0.07	1.08	1.16±0.09	1.18
Weight (kg)	23.43±8.37	22.30	21.27±4.10	19.35	22.39±6.63	19.40
BMI (kg/m²)	16.34±3.4	15.24	16.43±1.97	15.67	16.38±2.75	15.52
MC's score (mean percentile)	45.01±22.1	39.28	43.35±16.89	39.53	44.21±19.38	39.40
	Percentage		**Percentage**		**Percentage**	
Low weight	15.38 %		0 %		8 %	
Normal weight	53.86 %		75 %		64 %	
Overweight	15.38 %		0 %		8 %	
Obesity	15.38 %		25 %		20 %	

5.4.2. 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 traditional bicycle). All participants in the BB group successfully acquired independent cycling within two sessions when transferring to the traditional bicycle. In the BTW group, three participants did not achieve independent cycling after the four sessions with the traditional bicycle. Figure 12 presents the necessary days needed to achieve each milestone and independent cycling for each child by treatment group.

Figure 12. Days needed, per child and group, to learn to self-launch (A), balance (B), brake (C) and cycle independently (D) during the second phase of intervention (with traditional bicycle).



Note. The five missing values in the days needed to self-launch refers to the children who could not reach the ground due to insufficient leg length.

The number of participants who learned how to cycle independently was not significantly different between groups. However, children in the BB group learned significantly faster than the BTW group. They needed significantly fewer sessions with the traditional 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 5.

Table 5. Descriptive statistics (M, SD and Mdn) of days needed to acquire the cycle milestones during the traditional bicycle sessions, and programme success rate.

Days to acquire	**BB Group**		**BTW Group**		**Total**	
	M±SD	**Mdn**	**M±SD**	**Mdn**	**M±SD**	**Mdn**
Self-launch	1.30±0.48	1.00	2.00±0.76	2.00	1.61±0.7	1.50
Ride	1.15±0.38	1.00	2.58±1.51	2.50	1.84±1.28	1.00
Brake	1.15±0.38	1.00	2.42±1.51	2.00	1.76±1.23	1.00
Independent cycling	1.46±0.52	1.00	2.92±1.51	2.50	2.16±1.31	2.00
Success Rate	**Percentage**		**Percentage**		**Percentage**	
	100%		75%		88%	

5.4.3. 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 TB, 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.

5.5. 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 an intervention) of two weeks can be enough to help children from 3 years of age, without disabilities, to learn to ride a traditional 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. After teaching children to cycle independently, other aspects such as traffic safety behaviours could be introduced later.

5.5.1. 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 should 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, 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 traditional bicycle. But there are also advantages in promoting a greater stability, for example, when using the bicycle with training wheels (BTW). These are mainly in alleviating children's fear of falling with the stabilisers (Temple et al., 2016). Also, children can start practising pedalling from the beginning. However, these benefits might not be enough to compensate 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, leading to a reduction in use of motor system degrees of freedom (Bernstein, 1967). This response is dysfunctional in the long term since by freezing their movements and making their upper torso and arms rigid and inflexible, learners impair their postural 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 TB, 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 on the bicycle; but they need to be able to 'unfreeze' the degrees of freedom 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 pedagogical solution to reduce the degrees of freedom problem in the process of learning to cycle (Newell & Mcdonald, 1994, pp. 531-532). 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 days to self-launch, ride, brake, and cycle independently, see Table 5. By observing these children, our findings are in line with comments of Burt et al. (2007), who claimed that children who used training wheels become inflexible and tense when transferring to the TB. From an ecological dynamics' rationale, the participants' adaptations to the BTW task constraint is not a "counterproductive motor plan", but rather could be considered "a restrained exploration strategy". This is because, according to our results, not being able to explore balance and postural regulation on the BTW bike, delays the ability to adapt to a traditional 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 or training wheels, 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, Branco, Catela, & Cordovil, 2021). 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 to balance and ride when they are required to transit to the TB. Our results showed that, among the 13 children of the BB group, 11 of them (84.6%), were able to ride on the TB in the first session. These children ended up being able to ride on the TB 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 TB, and after the second session only 6 children (50%) did so (see Figure 12, panel B).

During the sessions with the TB, self-launch was also acquired earlier by children transferring from the BB group. Self-launch is a dynamic balance task. When using the TB, 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 TB (see Figure 12, panel A).

Learning to brake in the TB 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 day. In the BB group, 11 children (84.6%), safely braked in the first session with TB, whereas only four children (33.3%) of the BTW group did so (see Figure 12, 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 the suggestions of other authors (Ballantine, 1992; Becker & Jenny, 2017; Mercê, Pereira, et al., 2021; Shim & Norman, 2015). These 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.

Also, a recent survey study (Mercê, Branco, Catela, Lopes, et al., 2021), which looked at the different cycling learning paths, considering the different types of bicycles used for the learning process. The data from that study indicate that children who used the BB followed by the TB learned to cycle significantly earlier (4.16±1.34 years) than those who used the BTW followed by TB (5.97±2.16 years). The study also found that the single use of TB led to a later learning age (7.27±3.74 years). It was suggested that excessive complexity of the motor task of cycling with a TB may lead 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 motor 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 day, 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).

5.5.2. Learning how to cycle and personal constraints of participants

Some studies had previously identified an inverse relationship between being overweight and motor performance in stability and locomotion tasks (Steinberg et al., 2018; Teasdale et al., 2013). This detrimental effect of being overweight on postural stability and movement organisation also affects children (D'Hondt et al., 2008; Teasdale et al., 2013). In a sample of pre-schoolers, Kakebeeke et al. (2017) studied the relation between body composition and motor performance and concluded that children with higher values of fat mass were less proficient in some gross locomotor tasks, such as jumping sideways and running.

Based on the data from these studies, it is reasonable to assume that children with a higher BMI would probably struggle more than normal-weight children to learn to cycle. Indeed, a positive correlation has been reported between children's BMI and the number of days needed to achieve the ride ability. This result is in accordance with studies that found that overweight and obese children have lower levels of balancing stability (D'Hondt et al., 2008; Kakebeeke et al., 2017; Teasdale et al., 2013). In our study, the extra difficulty in balancing, due to body composition, did not significantly affect the total number of days needed to achieve independent cycling, a basic measure of learning with our sample.

Regarding motor competence (MC), no correlation was found between motor competence and the number of days needed to achieve any of the cycle learning milestones. These results underpin the key idea that learning is task specific, contradicting some expectations that greater levels of MC will facilitate learning of new motor tasks throughout the lifespan (Rodrigues et al., 2021). It seems that the effect of manipulating the type of bicycle used (task constraint) had a greater influence on participant learning, than the effects of their MC (individual constraint). Due to the limited sample size, the interactive relationship between MC and the task constraints of learning to cycle should be further investigated in future studies.

Regarding children's physical activity (PA), a recent study indicates that the amount of previous physical activity (PA) can also influence the age at which a child learns to cycle (Mercê, Branco, Catela, Lopes, et al., 2021). Evidence, based on self-reported data and parental information, has indicated that people who undertake PA daily learn to cycle significantly earlier than people who are less active. In our sample all children reported that they were physically active daily, so the homogeneity of the sample was also a problem for this variable. In future studies direct measures (e.g., using accelerometery) and not self-reported data on PA are needed to further explore the relationship between participant PA levels and learning to cycle.

5.5.3. 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.

5.5.4. 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). 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, Branco, Catela, Lopes, et al., 2021).

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, intervention should include ramps, since ramps seemed to promote the greatest exploration of the glide pattern in the BB group participants. Possibly, the increased speed gained while descending the ramps, act as an inviting affordance (Withagen et al., 2012) for children to lift their feet of the ground and simply glide, exploring how to maintain balance on the bicycle. This affordance may also mean that velocity is a key parameter for learning to glide, inviting 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 traditional 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 TB earlier.

5.6. Conclusion

The L2Cycle programme had a success rate of 88% for the whole group, with 100% success in the BB group. These data were later corroborated by the follow-up which revealed total learning retention of the ability of cycling independently, highlighting that a two-week bicycle camp can be effective for children from 3 years old, without disabilities, to acquire independent cycling. The results of our study provide support for the decision of including cycling learning in children's curriculum, starting in the kindergarten. We concluded that learning to cycle using the BB, in some ways, is faster and more effective than learning using the BTW.

5.7. References

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Chapter **6**

6. Learning to Cycle: Is Velocity a Control Parameter for Children's Cycle Patterns on the Balance Bike?

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6.1. Abstract

The balance bike (BB) has been pointed as the most efficient learning bicycle, due to its inherent stimulation of balance. However, the process of acquiring balance control in the BB has not been explored. This study aimed to: i) categorize the cycle patterns of children on the BB, ii) compare the cycle patterns in different stages of learning (before and after six sessions of a BB practice program); and, iii) verify if velocity is a control parameter that leads to transitions between different cycle on BB. Data were collected during the Learning to Cycle program, in 12 children with 6.06±1.25 years. Velocity was measured by an inertial sensor measurement (IMU) in the BB. Seven different movement patterns were captured and categorized through video analysis. After practice, there was an increase in the mean number of different patterns, and in the global mean and maximum velocity, which were interpreted as an improvement of motor competence in the use of the BB. Results obtained support the hypothesis that velocity is a control parameter, which leads to the emergence of diverse patterns of behaviour. As speed increases, feet contact with the ground becomes less frequent and locomotor modes that imply longer flight phases start to emerge.

Keywords: balance bike, children, cycle patterns, control parameter, L2Cycle Program

6.2. Introduction

Riding a bicycle is a foundational movement skill (Hulteen et al., 2018) and an important motor milestone for children's life due to its several health and social benefits (Oja et al., 2011; Ramírez-Vélez et al., 2017). Therefore, it is important to promote cycling acquisition early in development, being essential to investigate this learning process.

The Dynamical System Theory (Kelso, 1995; Kelso, 2009), provides an appropriate framework to study learning and development, since it addresses the process of change, trying to capture and understand the transitions that occur in complex systems (Corbetta & Vereijken, 1999). The learner is considered a complex biological self-organized system, and movement patterns emerge out of the interactions between the different subsystems in the body, the task, and the environment (Newell, 1986). According to this theory, during motor behaviour or learning, the movement patterns that arise are the order parameters or collective variables of the system, which are constrained by the control parameters that can produce change from one movement pattern to another (Kelso, 1995). Due to the non-linear behaviour of complex systems, in certain conditions, a small change in the control parameter can lead to abrupt changes in the overall system, resulting in a phase transition between states of the system when one state becomes a greater attractor than the previous one. For example, an increase in the treadmill velocity might not cause someone to change from walking to running, but if that increase occurs around 2 m/s it probably will (Kung et al., 2018), since it is not mechanically efficient to walk at that speed. Velocity was also identified as a control parameter for the locomotor patterns in horses. Horses have three stable patterns- walk, trot and galop, and as the velocity increases the horse's locomotor system is compelled to transit from walk to trot and then, from trot to gallop (Hoyt & Taylor, 1981).

Velocity can also be a control parameter for learning how to cycle. Recently, the way children learn how to cycle has been changing. Instead of using training wheels, many children are starting to use the balance bike (BB), a bicycle without pedals nor training wheels (Mercê et al., 2022). Studies indicate that the BB is a more effective learning tool than the traditional bicycle with lateral wheels (Mercê et al., 2022; Mercê, Pereira, et al., 2021). Not having pedals, is a task constraint that affords children to explore several modes of locomotion, like walking, running or gliding on the bike. These different cycle patterns are organisational stable states that correspond to different order parameters in the dynamic system theory. During the glide pattern, children do not have any direct contact with ground since their feet are up; so, they need to explore and acquire the dynamic balance with the bicycle, in order to cycle. Considering that balance acquisition is a key element for cycling (Ballantine, 1992; Mercê, Pereira, et al., 2021; Shim & Norman, 2015) promoting the glide in the BB could enhance children's dynamic balance control accelerating the transition to the traditional bicycle, the one with pedals. To better understand the learning process in the balance bike, it is important to categorize the different cycle patterns that might emerge while children explore it, and also try to identify the control parameter that promotes the transitions between them. However, to our knowledge, no study has done that.

Considering the importance of velocity in determining the transition between modes of locomotion in humans and animals (e.g., Hoyt & Taylor, 1981; Kung et al., 2018), we hypothesize that it might also be a control parameter in the emergency of the BB's locomotor patterns. Thus, at higher velocities the child could be compelled to transit to the glide pattern. So, in the present study we aimed to: i) analyse and categorize the cycle patterns of children on the BB, ii) compare the patterns that emerge in different stages of learning (before and after six sessions of a BB practice program); and, iii) verify if velocity of propulsion is a control parameter that leads to transitions between the different cycle patterns exhibited on the bike.

6.3. Material and Methods

6.3.1. Study Design

Data for this study was collected during the Learning to Cycle program (L2Cycle). This intervention program aimed to teach young children to cycle, and included daily cycle sessions of 30 minutes each, divided in two phases: a first phase of six sessions with BB; and a second phase of four more sessions in a traditional bicycle, i.e., with pedals. For the present study, only data referring to the first phase of the program, with BB, were considered. A first observation (observation 1) was conducted before the BB's sessions, and a second observation (observation 2) was made after these sessions.

The programme and the data collection were approved by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon (approval number: 22/2019).

6.3.2. Participants

Participants in the study were twelve children (four girls), between three and seven years of age (M=6.06; SD=1.25 years), who could not cycle independently using a traditional bike. To be considered an independent cyclist, the child should have the ability to self-launch; ride for at least 10 consecutive meters and brake safely.

6.3.3. Data Collection and Protocols

In each data collection moment (observation 1 and 2), each child was invited to ride a BB during five minutes, in a 10 m x 10 m camp, with no further instructions.

Children's trials with BB were filmed with a smartphone (Samsung A71, South Korea) at 30 Hz, positioned in one of the field's vertices to cover it entirely.

The bicycle's velocity was collected through an inertial measurement unit (IMU) (SparkFun 9DoF Razor, Niwot, Colorado, USA) secured in the spokes of the front wheel (Cain et al., 2012). According to previous pilot testing, the IMU was sampled at 100 Hz, the accelerometer at 4 G and the gyroscope at 2000 deg/s.

To synchronize the IMU and the video data, before the task, the researcher lifted and dropped the front wheel of the BB on the ground tree times. The data were later synchronized by identifying the video frame of the first impact of the front wheel on the ground, which corresponded to the first acceleration peak in the IMU.

6.3.4. Data and Statistical Treatment

The categorization of the cycle patterns started by a first video analysis to identify the potential patterns. Subsequently, the categorization criteria was discussed and elaborated by a panel of three experts, two in child motor development and one in biomechanics and movement analysis. After unanimous consensus (Table 6), the instrument inter reliability was assessed through the overall Fleiss's kappa statistics, and the intra reliability through the overall Cohen's kappa (Hallgren, 2012). Four independent observers independently categorized 35 video clips (five clips for each defined pattern), revealing an overall inter reliability of k=0.854, and an intra reliability of k=0.921. After ensuring a strong instrument reliability, all videos were visualized categorized, by the same observer, using Kinovea software to identify the first and last frames of each pattern. The number of different patterns explored was collected per child and moment of observation.

The variables related to the velocity were calculated with a custom matlab routine which converted the angular velocity of the front wheel to linear velocity. By synchronizing IMU and video data, it was possible to calculate the global velocity of each child by observation, as well as the velocity of each pattern.

The frequency of children that explored each pattern, and descriptive statistics regarding global and pattern's velocities per child, were determined by moment of observation (Table 7).

The Shapiro Wilk test was used to estimate the samples' normality of data distribution. Accordingly, the number of different patterns explored by each child between the two moments of observation was compared with the Wilcoxon test; and the global velocities (i.e., minimum, mean and maximum) between the two moments of observations were compared using paired sample t-tests; the r effect size was also calculated.

Based on the data collected in observation 2, probability curves, which show the probability of each cycle pattern to occur at a given speed, were calculated (see Figure 13). A moving filter average with a span of 0.2, was applied by the method of local regression, using lower weight to outliers in linear least squares and a second-degree polynomial model (rloess).

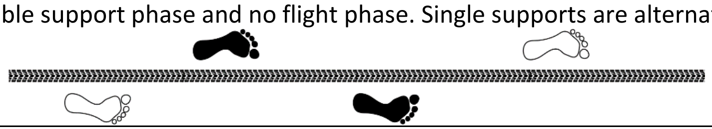
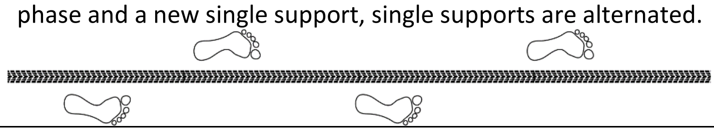
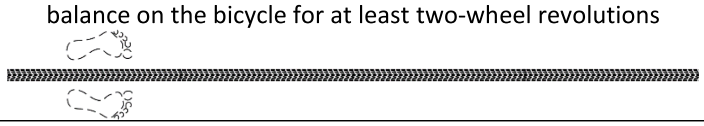
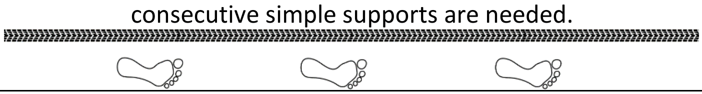
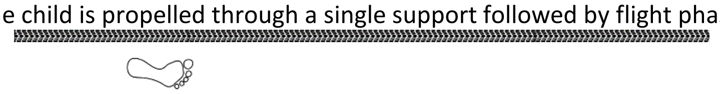
Thresholds were estimated between each consecutive pair of curves. Those thresholds represent the moment when the previous pattern become less probable to occur than the previous one, indicating a phase transition in the system.

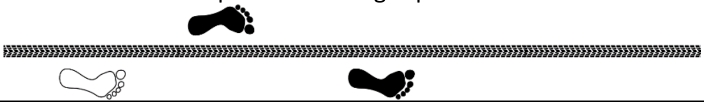
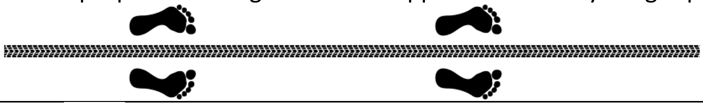
6.4. Results

6.4.1. Categorization of Locomotor Patterns

Seven mutually exclusive cycle patterns were categorized: walking, running, gliding, trotting, hopping, single hopping and jumping. The type of contact in the ground along movement (i.e., single support, double support, flight phase) was used as criterion to distinguish between patterns (Table 6). For all patterns, excluding the glide, the start was considered at the first frame of the first support, ending at the last frame of the last support. In the glide pattern, the start was considered from the initial and single moment of impulse (followed by the flight phase) until the moment immediately before the subsequent contact of the feet or foot on the ground. To be considered as gliding, the child must balance on the BB, without immediately search a new support, for at least two-wheel revolutions.

Table 6. Categorization of cycle patterns on BB, based on ground contact phases description.

Patterns	Description and Ground Contact Phases
Walk	Based on walking pattern. Composed of a single support phase, followed by a double support phase and no flight phase. Single supports are alternated. 
Run	Based on run pattern. Composed of single support phase, followed by flight phase and a new single support, single supports are alternated. 
Glide	The child propels himself (through a single or double support) and maintains balance on the bicycle for at least two-wheel revolutions 
Hop	The child is propelled through a single support followed by flight and a new single support on the same side. To be considered a hop, at least two consecutive simple supports are needed. 
Single Hop	The child is propelled through a single support followed by flight phase. 

Trot	The child is propelled through a single support followed by a double support phase and a flight phase. 
Jump	The child is propelled through a double support followed by a flight phase 

Notes: single support; double support; single or double support; bicycle trace.

6.4.2. *Cycle patterns pre and post intervention*

Considering all sample, in observation 1 four different patterns were identified: walk, run, glide and hop; whereas in observation 2 seven patterns were identified. Between observations 1 and observation 2 a significant increase occurred in the number of different patterns performed by children (z=-3.10, p=0.002, r=-0.26), global mean velocity ($t(11)$=-8.50, p<0.001, r=0.93), global maximum velocity ($t(11)$=-12.89, p<0.001, r=0.97); see Table 7.

Table 7. Global and cycle patterns' velocities (minimum, mean and maximum), and frequency of children who experienced each pattern by moment of observation 1 and 2.

Velocities (m/s)	Observation 1				Observation 2			
	Min Velocity	Mean Velocity	Max Velocity	N	Min Velocity	Mean Velocity	Max Velocity	N
	M±SD	M±SD	M±SD		M±SD	M±SD	M±SD	
Global	0.01±0.01	0.67±0.26	1.31±0.41		0.13±0.30	1.60±0.47	2.52±0.49	
Walk	0.01±0.01	0.68±0.25	1.28±0.39	12	0.17±0.41	1.12±0.24	1.95±0.19	11
Run	0.99±0.41	1.36±0.25	1.72±0.03	2	0.58±0.57	1.75±0.44	2.48±0.52	12
Glide	1.78[a]	1.86[a]	1.90[a]	1	0.85±0.57	1.75±0.42	2.31±0.60	12
Trot				0	0.93±0.71	1.68±0.43	2.17±0.43	12
Hop	0.89±0.03	1.11±0.25	1.35±0.49	2	0.93±0.63	1.68±0.44	2.30±0.40	12
Single Hop				0	1.04±0.56	1.70±0.45	2.20±0.57	12
Jump				0	1.23±0.89	1.61±0.70	1.91±0.60	8

Note. [a] SD not presented since only one episode occurred.

6.4.3. *Velocity as a control parameter*

Considering all patterns, three of them stand out as the most frequents in different velocity bands. In lower velocities the walking pattern prevails achieving almost the total frequency. As the velocity increases the walk frequency decreases, and in the velocity value of 1.32 m/s (t_1) the walking and the running frequencies cross over, with the run becoming the most frequent pattern. As the velocity continues to increase the glide frequency also increases and crosses the run with the value of 2.15 m/s (t_2), becoming now the most frequent, see Figure 13.

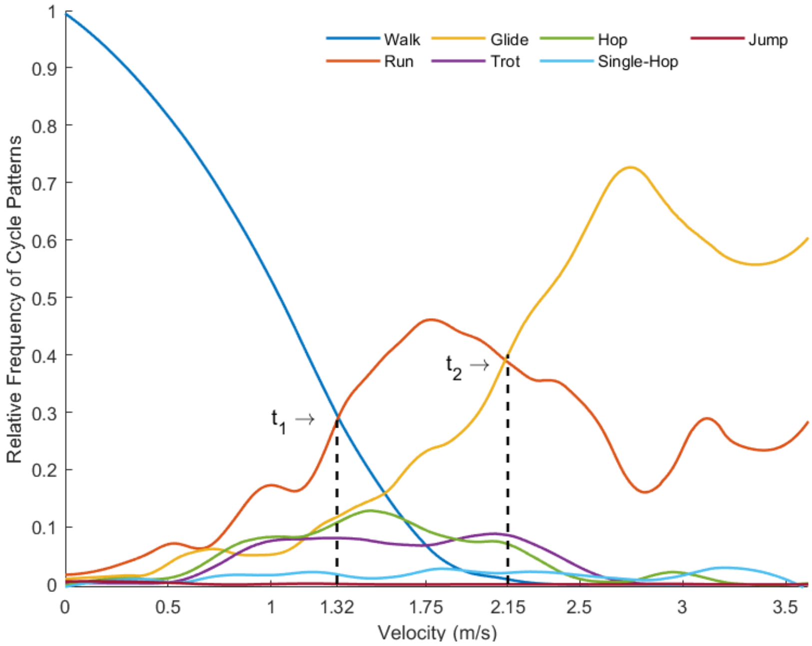


Figure 13. Probability curves for the seven cycle patterns to occur at different velocities, and threshold points (t1 and t2) that indicate a shift in the prevalent cycle pattern.

6.5. Discussion and Implications

6.5.1. Categorization of Locomotor Patterns

The first objective of this study was to analyse and categorize the cycle patterns used by children when riding a BB. Results revealed at least seven distinct patterns, meaning that the BB can afford a diversity of motor behaviours to children. This possibility of achieving the same end state (i.e., riding the BB) by different paths (i.e., using distinct patterns) reflects the equifinality of the child-bicycle system (Waddington, 1957).

So far, and despite the BB's increasing popularity, research specifically targeting this bicycle is still scarce. We could find two articles with suggestions for BB exercise or sessions (Becker & Jenny, 2017; Shim & Norman, 2015), and just one article that studied the effect of BB sessions with preschool and/or elementary school children (Shim et al., 2021). However, in none of them the different patterns of locomotion are analysed, defined, or categorized. Thus, the present study addressed this gap in the literature, presenting a categorization of the cycle movement patterns that emerged while children freely used the BB in diverse surfaces, slopes and at different velocities (L2Cycle Programme). The current categorization can now be used for different purposes, such as comparing different learning paths in the use of BB, assessing preferences according to the child's characteristics, or monitoring each child's cycling evolution.

6.5.2. Evolution of Locomotor Patterns from Pre to Post Intervention

Regarding the second objective, the comparison of the evolution of locomotor patterns from pre (observation 1) to post intervention (observation 2), there are some points that should be noted. During observation 1, children had an initial contact with the BB for five minutes, and even within such a short time frame, children displayed four different patterns (walk, run, glide and hop). These abilities emerged without any instruction, resulting solely from the child's exploration of the constraints inherent to the system child-BB, thus they seem to be foundational patterns for BB motor learning. After the six sessions of 30 minutes, which correspond to three hours of potential practice, the children significantly explored a greater number of locomotor patterns. Seven children tried all seven patterns, and the other five tried six of them. The L2Cycle program was conceived based on ecological and dynamic perspective propositions, i.e., there was a structuring of the practice environment (slopes, friction gradient, obstacles) and a regulation of a possible control parameter ("try faster"), thus prescribing practice conditions, but without specific instructions as how to propel the ground (patterns). In the absence of specific instructions, the system child-BB worked as a dynamic system, capable of self-organization, in which several cycle patterns emerged as a result of exploration of the existent constraint.

From observation 1 to 2, children also significantly increased their global mean and maximum velocity, meaning that they not only were able to perform more patterns, but they also improved their motor efficiency on the BB. This improvement in a short period of time is in accordance with the study of Shim et al. (2021); a BB's intervention with pre-school children with significant improvements in their balance after just three hours of practice (15 to 20 minutes sessions, during three weeks). The fact that in our study and in Shim et al.'s (2021) study, practice occurred along different days, seems to be an advantage, because it allowed the learners to benefit from the both motor learning modes, the on-line mode, which occurs when the learner is practicing, and also the off-line mode, in which the learner continues to acquire or stabilize the skill during sleeping or napping (Cai et al., 2014; Debarnot et al., 2011).

6.5.3. Velocity as a Control Parameter

The present data confirmed that velocity can be considered a control parameter for the emergence of different locomotor patterns on the BB. Traditionally, testing velocity as a control parameter is done in controlled laboratory settings, using a treadmill that allows a constant increase in velocity, followed by a decrease at the same rate (e.g., Prilutsky & Gregor, 2001; Tseh et al., 2002). However, learning to cycle in a treadmill with changing speeds would not be a good option in terms of safety for the children and the task would have lower ecological validity. Assessing learning in a real world context using the IMUs, small portable biomechanical devices, allowed us to capture the velocity in a reliable way (Cain et al., 2012), while children freely explored the constraints that acted upon the child-BB system (Newell, 1986).

The significant increases in velocity and in number of explored patterns between the observation 1 and 2, is the first indicator that velocity is a potential control parameter. According to our data, as new velocity limits started to be explored, new cycle patterns started to emerge, which is in accordance with de definition of a control parameter that moves the system through its collective states (Kelso, 1995).

This hypothesis is confirmed in Figure 13, which shows that there were three main preferred cycle patterns, or order parameters, on the BB: walking, running and gliding. As velocity changes, the system moves though these patterns. For velocities below 1.32m/s walking seems to be the more stable action mode, being the one that children display with greater frequency. However, above 1.32m/s (t1) running seems to become more comfortable, and that is the preferred action mode until the velocity reaches 2.15m/s (t2), where gliding becomes the prevalent action mode. So, velocity can be considered a control parameter of the system that leads to phase transitions as the stability of the different attractors becomes threatened. Besides the three main cycle patterns other action modes were explored by children, but with lower frequency. This multiplicity of patterns for the same velocity could represent a catastrophic multimodality flag (Gilmore, 1981); a characteristic phenomenon of dynamical systems (Kelso, 1995). Those less frequent patterns reflect children's exploration of new solutions, which occur mainly between 0.7 m/s and 2.5 m/s, since at lower speeds walking is clearly the strongest attractor and at higher speeds gliding seems to be preferred.

Interestingly, the walk and run velocities with and out of the BB are similar. The mean velocity of the walk pattern on the BB was (1.12m/s) very close to walk out of the bicycle of typically developing children aged 10 years old (1.21m/s) (Diamond et al., 2014), and the maximum velocity of run pattern on (2.48m/s) the BB to jogging mean velocity in those children (2.61m/s) (Diamond et al., 2014). Similar results were also found for 3-4 year old children for walking, between 0.5m/s and 1.5m/s; and, for 7-8 years old mean velocity between 0.5 to 2.0m/s (Dejaeger et al., 2001).

The present findings provide new information about the exploration of the dynamics of cycling through the practice with the BB. For intermediate speeds, children tend to explore various organizational states (cycle patterns on the bike) that afford shorter or longer flight phases, with no contact of the feet with the ground. At higher speeds, gliding becomes prevalent, leading children to experience balance for longer periods as it is necessary to ride a traditional bicycle. Previous literature found support to the hypothesis that BB is a better tool to learn to cycle independently, compared to the bicycle with lateral training wheels (BTW), because it seems to enable balance acquisition since the early stages of learning (Ballantine, 1992; Mercê et al., 2022; Mercê, Pereira, et al., 2021; Shim & Norman, 2015). However, until now, it was not known which cycle patterns were more frequently explored by children on BB, nor what were the preferred velocities for the transition between them. Considering the importance of acquiring the gliding pattern to control balance before trying to ride a traditional bike, children should have the opportunity to explore different velocities during learning with the BB. This can be facilitated for example by choosing a learning environment that has small uneven ramps, or by promoting races with the bicycle. After being able to control velocity and balance, children can move to the traditional bike and start to practice pedalling to learn to cycle independently.

6.6. Conclusion

This study identified seven distinct locomotor patterns used by children while learning to cycle with the BB. The number of locomotor patterns explored increased as children became more skilled in the BB (i.e., in the second observation). Walking, running and gliding on the BB were prevalent over the other locomotor patterns, and each one was prevalent at critical values of velocity. Thus, velocity was identified as the control parameter that moves the system through its different collective states. At higher velocities (above 2.15m/s) gliding becomes the preferred action mode. To glide children need to maintain balance on the bike, which is important to facilitate the learning and acquisition of cycling in the traditional bicycle. For this reason, parents and teachers should be able to create practice conditions that potentiate the exploration of different velocities during learning.

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Chapter 7

7. Learning to Cycle: why is the balance bike more efficient than the bicycle with training wheels? The Lyapunov's answer

To be submitted.

7.1. Abstract

To ride a bicycle is a foundational movement skill that can be acquired in early ages. The most common training bicycle is the bicycle with lateral training wheels (BTW); however, the balance bike (BB) is pointed as the most efficient, due to its immediate balance requirements. This study aims to investigate why the BB was proved to be more efficient than the BTW for learning to cycle, by comparing the variability of the child-bicycle system throughout the learning process with these two types of bicycles. Data were collected during the Learning to Cycle Program, in which 23 children (6.00±1.2 years old) were included. Participants were divided in two training groups, BB (N=12) and BTW (N=11). Angular velocity of the children and bicycle were collected by four inertial sensors measurement (IMU) located in child vertex and T2, bicycle frame and handlebar, in three moments: i) before training, ii) immediately after training, and iii) two months after training. The largest Lyapunov exponents were calculated to assess movement variability. Results obtained support the hypothesis that the BB affords a greater postural variability during cycle training compared to the BTW. It is proposed that the greater variability allows a more adaptative response in the transition to the traditional bicycle, being one of the reasons for the BB's greater learning advantage.

Keywords: bicycle, variability, nonlinear, postural control, learning paths.

7.2. Introduction

Riding a bicycle is a foundational movement skill (Hulteen et al., 2018) with multiple lifetime benefits (Ramírez-Vélez et al., 2017). Therefore, learning how to cycle should be promoted as early as possible (Mercê, Pereira, et al., 2021). According to the literature, even though the bicycle with lateral training wheels (BTW) is the most common approach to learn to cycle worldwide (Mercê et al., 2022), the balance bike (BB), a bicycle without pedals nor training wheels, is the most efficient learning bicycle (Ballantine, 1992; Burt et al., 2007; Cain et al., 2012; Mercê et al., 2022; Mercê, Pereira, et al., 2021) (Chapter 5). Some authors even argue that the use of BTW is a mistake (Ballantine, 1992) and that can be counterproductive (Burt et al., 2007; Newell & Mcdonald, 1994). By adding the side wheels, as an artificial way to increase the stability and minimize the oscillations of the bicycle, the child learns how to pedal without experiencing the bicycle's imbalances. When the training wheels are removed, the child is confronted for the first time with the instability of the bicycle and ends up activating defensive responses by freezing his/her upper limbs and trunk, which consequently leads to the loss of balance on the bicycle (Burt et al., 2007) (Chapter 5). On the other hand, a child that uses the BB from the start, needs to deal with instability since the first moment, and only has to deal with pedalling after achieving the balance. Knowing that the balance acquisition is considered a key aspect for learning to cycle (Ballantine, 1992; Mercê, Pereira, et al., 2021; Shim & Norman, 2015), this could be the reason for the BB's greater efficiency compared to the BTW. However, although several authors argued that the BB is the most efficient training bicycle (Ballantine, 1992; Mercê et al., 2022; Mercê, Pereira, et al., 2021; Shim & Norman, 2015), only one study aimed to compare these two bicycles (Chapter 5). The study presented in Chapter 5 applied an intervention program (L2Cycle), comparing two groups of kindergarten and elementary school children, where one group practiced with the BTW and another with the BB. The authors found that the BB group learned significantly faster to self-start, cycle, brake and cycle independently (all of these cycling milestones performed sequentially) than the children in the BTW group, which corroborates previous literature, but leaves unsolved the "why" question. To the best of our knowledge, no study until now has investigated the cause of this higher efficiency of the BB.

Our hypothesis lies in motor variability affordance. The classical approaches to movement variability consider it as a noise phenomenon or a result of errors (Stergiou et al., 2006; van Emmerik & van Wegen, 2002). Nevertheless, the more recent dynamical system and chaos theories highlight the functionality and importance of variability. The same coordination task, like cycling with a training bicycle, could be performed by multiple elements or degrees of freedom (e.g., motor units, muscles, joints, limbs, movement axis and planes), and by a wide variety of combinations between them (Latash et al., 2002). The ability to produce several solutions for the same coordination task affords adaptability, which allows the system to deal and overcome with unexpected and challenging situations as, for instance, to be able to use a traditional bicycle (Davids et al., 2008; van Emmerik & van Wegen, 2002).

Variability can be measured by several methods, linear tools like the standard deviation quantify the amount of the variability independently of their order in the data series (Stergiou et al., 2006) while nonlinear methods afford an analysis based on the process, looking for both structure and quality of variability (da Costa et al., 2013). To analyse variability in biological systems, as in the case of a child riding a bicycle, the nonlinear tools can provide a deeper insight in the neuromotor control of the movement (da Costa et al., 2013). The largest Lyapunov exponent (LyE) is one of the most used nonlinear methods to assess stability and variability (da Costa et al., 2013; Kędziorek & Błażkiewicz, 2020). This method reconstructs the data in a state phase and measures the rate of how the nearly orbits converge or diverge. In periodic signals the LyE value is 0, as the orbits did not converge or diverge. A positive LyE indicates chaos in the system and means that the orbits are diverging, while a negative value indicates that the orbits are converging (Harbourne & Stergiou, 2003). The LyE has already proven to be a valid measure to analyse the human gait (Kędziorek & Błażkiewicz, 2020; Mehdizadeh, 2018), being that lower values of LyE values indicate rigidity in the system and its inability to adapt; while higher ones indicate greater variability and adaptability with the system being able to faster response to destabilization and to better control the balance (Kędziorek & Błażkiewicz, 2020; Smith et al., 2010).

Considering the gap in the literature regarding the justifications for the greater efficiency of the BB's compared to BTW, and the potential of using nonlinear methods to study variability, the present study aims to investigate the process of learning to cycle with the BB and with the BTW addressing these issues. More specifically, we intend to compare the variability (by using the LyE) within the same training bicycle group (BB or BTWs), between bicycle groups (BB vs. BTW) at different stages of learning, and between children who did and did not learn to cycle independently. We hypothesize that the BB affords greater movement variability compared to the BTW during the moment of first contact and after training, that there is no difference in variability after children learn to independent cycle on the traditional bicycle, and that children who did not learn to cycle independently during the program have lower variability than the children who did. If these hypotheses are confirmed, the greater BB's variability could be the reason for its greater efficiency in the acquisition of cycling milestones in a traditional bicycle.

7.3. Methods

7.3.1. Study Design

This study was conducted during the Learning to Cycle Program (L2Cycle), a two-weeks bicycle camp that helped children to learn how to cycle, which was simultaneously used to collect data regarding the learning process by using two different training bicycles. The program included six lessons with a BB group and a BTW group, followed by four sessions with both groups using the traditional bicycle (TB) (i.e., with pedals and without training wheels). The training location had different surfaces, slopes and vertical obstacles, which allowed children to self-explore basic milestones of cycling, namely, self-start, moving around, and braking. The sessions were performed daily with a duration of 30 minutes and were conducted by physical exercise technicians with safety equipment (for more details, see Chapter 5).

To analyse the cycle learning process three evaluation moments were defined, a first moment before the training program with the training bicycle (O1), a second moment after the six training lessons still with the training bicycle (O2) and, finally, a third moment (O3), two months after the training program, with the TB, see figure 14.

The programme and the data collection were approved by the Ethics Committee of the Faculty of Human Kinetics (approval number: 22/2019).

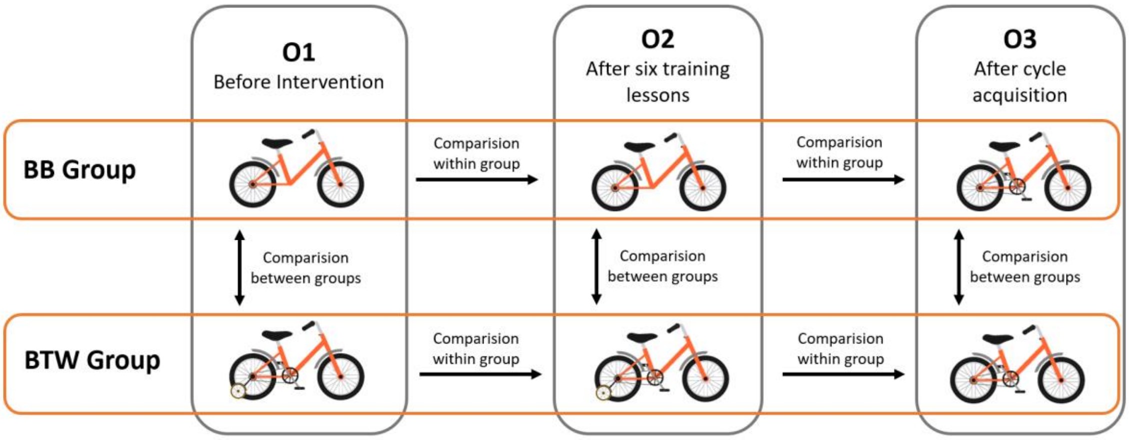

Figure 14. Presentation of the study design (2 groups x 3 moments), with identification of the comparisons.

7.3.2. Participants

Twenty-three children participated in the study (nine girls), with ages between three and seven years (M= 6.00; SD=1.20 years). Twelve children were allocated to the BB group and eleven to the BTW group. The groups did not differ in age, motor competence or body composition (Chapter 5).

Before the intervention, we confirmed that none of the participants was able to cycle independently, meaning that they did not know how to ride a traditional bicycle. To be considered as independent riders the children needed to fulfil the following criteria: to be able to perform the self-launch (to start cycling, the researcher could only stabilize the bicycle if the child's feet could not reach the ground, due to small stature), cycle for at least 10 meters, and brake safely.

All children performed the O1 and O2. However, in O3, four BB's children did not participate, one due to health issues and three because they were not able to perform the self-launch, due to their low stature; other four BTW's children did not participate in O3, one because his low stature, and three because they did not acquire the independent cycle with the TB.

7.3.3. Bicycle Equipment

The bicycles used were the LittleBig Balance Bike (LittleBig, Ireland). This model was chosen because it can be adapted, through the rotation of its saddle, to children from 2 to 7 years old, and because it allows the insertion of the pedal crank in it. BTW group used the same LittleBig model, but with the pedal crank and two lateral training wheels applied. The use of the same bicycle model in the two groups also allows to eliminate possible variables masked by different bicycle models, e.g., ergonomic issues or friction.

7.3.4. Data Collection and Protocols

In all evaluation moments (O1, O2 and O3), children were invited to ride a bicycle for five minutes, in a 10m x 10m camp, and with no further instructions (for more details, see Chapter 6).

To capture children's and the bicycle's movement variability four inertial measurement units (IMU) (SparkFun 9DoF Razor, Niwot, Colorado, USA) were used. In the child, one IMU was placed in the vertex point through an adjusted headband (Mercê et al., 2018; Shurtleff & Engsberg, 2010; Wolter et al., 2020), allowing the analysis of the head in children's postural control; and, another IMU was placed at the second vertebra of the thoracic column (T2) (Li et al., 2021), through a customized vest, allowing the analyses of the trunk segment. In the bicycle, one IMU was placed in the spokes of the front wheel, providing data from the handlebar; and, another one was placed in the seat tube of the bicycle frame, providing data relating to the whole bicycle (Cain et al., 2012). All IMUs collected data at a sampling rate of 100 Hz and were defined the full scale of 4G for accelerometer, and of 2000 deg/s for the gyroscope (Chapter 6).

Each collection was also video recorded to identify the moments when the child was cycling or performing other activities (e.g., stopping to rest or fall). The video was recorded with a smartphone (Samsung A71, South Korea) at 30 Hz. To synchronize the IMUs and the video, before each collection, the researcher lifted and dropped the bicycle's front wheel on the ground, for three consecutive times, with intervals of approximately five seconds between them. Before data analysis, a visual inspection was made to identify the three peaks corresponding to the three drops, and the several IMUs were synchronized by identifying the first acceleration peak in each one. The video was also synchronized to the IMU data by identifying the first video frame corresponding to the first impact of the front wheel on the ground, this synchronization allowed to identify in the IMU data the moments of cycling and other activities, previously verified in the videos. (Chapter 6).

7.3.5. Data and Statistical Treatment

Initially, all videos were analysed to identify the beginning and end of each data collection episode, as well as the moments when the child was not cycling (e.g., fell or left outside the video), these were later disregarded.

The data treatment was performed with a custom matlab routine. Considering that the time series' length affects the LyE's calculation, and following the recommendation that a time-normalization to a fixed point or duration is necessary (Mehdizadeh, 2018), all timeseries were cut according to the one with the lowest duration, which was fixed at three minutes. This value is within the literature recommendations (Mehdizadeh, 2018). After the normalization, the data were filtered using a low-pass second-order Butterworth filter with a cutoff frequency of 10 Hz (e.g., Donker et al., 2008; Stins et al., 2009). Therefore, the LyE values for angular velocity were calculated for each IMU, child and evaluation moment. The angular velocity variable was chosen because it allows the study of postural control (e.g., Allum & Carpenter, 2005; Budini et al., 2018), and because the movements under analysis are manly rotations.

For statistical analysis of the IMUs allocated in child' head and trunk, the three movement planes were considered, because movement occurs in all three. For the handlebar IMU, only the frontal and transverse planes were considered, since the handlebars do not move in the sagittal plane, and for the IMU of the bicycle frame, only the frontal plane was considered since it does not move in sagittal and transversal planes.

The statistical analysis was performed with the Statistical Package for Social Sciences (IBM Corp, version 26), and the significance level was defined at <0.05. Descriptive statistics were used for samples' characterization and for LyE values of each IMU by movement plane, evaluation moment and group. The Shapiro-Wilk test was used to estimate the samples' normality of data distribution. Accordingly, paired *t*-test were used to compare, within the same group, the values of each IMU, by movement plane, between the different evaluation moments. Independent *t*-test were performed to compare the same IMU by movement and evaluation moment, between the two training groups, BB and BTW, and between the BTW children who became independent riders and those who did not.

7.4. Results

The descriptive data (average ± standard deviation) of each IMU by movement plane, moment of evaluation (O1, O2 and O3) and group are presented in Table 8. All Lyapunov mean values are highly positive far from zero, meaning divergent orbits, or that body and bicycle oscillations are not regular in space; and are always higher in BB group, except for frontal plane at the O1 and O2 moments. Per group and between movement planes, Lyapunov standard deviations of the child and of the bicycle are small and similar, particularly very much smaller than Lyapunov means, that is statistically important, considering samples size. Interestingly, when the standard deviation is analysed, the BTW presents higher values than the BB for both O1 and O2, except only at the point O2-sagittal plane. However, in O3 this tendency is inverted, and the BB reveals higher standard deviations, with the only exception of vertex-frontal plane.

Table 8. Lyapunov descriptive statistics (M±SD), in BB and BTW groups, for each IMU, movement plane and evaluation moment (O1, O2, O3).

Group	IMU	Movement Plane	O1 M±SD	O2 M±SD	O3 M±SD
BB	Vertex	Sagittal	58.82±1.45	59.27±1.03	58.50±1.43
		Frontal	57.85±1.14	57.72±0.87	56.64±1.26
		Transverse	56.51±1.25	56.87±1.04	55.63±1.71
	T2	Sagittal	59.16±1.51	58.48±1.21	57.30±0.99
		Frontal	56.61±1.25	56.33±0.77	55.39±1.31
		Transverse	57.36±0.80	57.16±0.65	56.18±1.63
	Bicycle frame	Frontal	54.32±1.29	55.22±0.72	55.86±0.94
	Handlebar	Frontal	55.97±1.08	57.33±1.14	57.60±1.48
		Transverse	55.84±1.13	57.20±1.14	57.72±1.65
BTW	Vertex	Sagittal	56.60±2.13	55.39±1.35	58.41±1.36
		Frontal	55.18±1.76	57.51±1.13	56.22±1.98
		Transverse	53.91±1.87	54.94±1.35	54.37±1.45
	T2	Sagittal	56.01±1.82	56.28±0.98	57.58±0.78
		Frontal	52.58±2.16	53.43±1.21	54.55±1.23
		Transverse	55.02±1.87	55.97±1.70	55.79±0.98
	Bicycle frame	Frontal	57.52±1.82	58.28±1.49	55.01±0.47
	Handlebar	Frontal	53.39±2.12	55.35±2.02	57.56±1.10
		Transverse	53.54±2.22	55.51±1.66	57.68±0.67

7.4.1. Comparisons between evaluation moments

Considering the BB group, between pre-intervention (O1) and after six training lessons (O2), there were significant increases in the velocity's variability in: the bicycle frame for lateral oscillations in frontal plane ($t(11)=-2.41$, $p=0.035$, $r=0.588$); and in the handlebar for lateral oscillations in frontal plane ($t(11)=-3.74$, $p=0.003$, $r=0.748$), and left-right rotations in the transverse plane ($t(11)=-2.334$, $p=0.04$, $r=0.576$). No significant changes were observed for the vertex and T2 IMUs. Comparing the results after training with the BB (O2) with the results after cycle acquisition on the TB (O3), significant decreases occurred in T2's variability for all planes: children reduced their velocities for flexion and extension in sagittal plan ($t(7)=2.634$, $p=0.034$, $r=0.706$), lateral flexions in frontal plane ($t(7)=4.201$, $p=0.004$, $r=0.775$), and left-right rotations in transverse plane ($t(7)=2.467$, $p=0.043$, $r=0.682$); no significant changes were verified for the other IMUs. An illustrative schematic of all comparisons is presented in Figure 15.

Considering the BTW group, after the six training lessons there were significant increases in the velocity's variability in: the vertex for left-right rotations ($t(10)=-2.636$, $p=0.025$, $r=0.640$); and in the handlebar for lateral oscillations ($t(10)=-3.218$, $p=0.009$, $r=0.713$) and left-right rotations ($t(10)=-3.077$, $p=0.012$, $r=0.697$). There were no significant changes for T2 and bicycle frame IMUs. Comparing the results after training with the BB (O2) with the results after cycle acquisition on the TB (O3), significant increases in children's variability on T2 were verified in the velocity of flexion and extension ($t(6)=-3.152$, $p=0.020$, $r=0.790$), and in the bicycle frame's velocity of lateral oscillations ($t(6)=4.219$, $p=0.006$, $r=0.865$); no differences were found in the vertex nor handlebar (see Figure 15).

7.4.2. Comparisons between groups

The comparison between the BB and BTW groups, revealed a significantly greater variability in the velocities of the BB group, in O1 and O2, in: the vertex for flexion and extension ($t(21)=2.946$, $p=0.008$, $r=0.541$; $t(21)=3.915$, $p=0.001$, $r=0.650$), lateral flexions ($t(21)=4.352$, $p<0.001$, $r=0.689$; $t(21)=0.792$, $p<0.001$, $r=0.792$), and left-right rotations ($t(21)=3.951$, $p=0.001$, $r=0.653$; $t(21)=$, $p=0.008$, $r=542.$); in the T2 for flexion and extension ($t(21)=5.551$, $p<0.001$, $r=0.771$; $t(21)=4.749$, $p<0.001$, $r=0.720$), lateral flexions ($t(21)=5.541$, $p<0.001$, $r=0.771$; $t(21)=6.911$, $p<0.001$, $r=0.833$), and left-right rotations ($t(21)=3.961$, $p<0.001$, $r=0.654$; $t(21)=2.267$, $p=0.034$, $r=0.443$); and in the handlebar for lateral oscillations ($t(21)=3.724$, $p=0.001$, $r=0.630$; $t(21)=2.2926$, $p=0.008$, $r=0.538$), and left-right rotation ($t(21)=3.172$, $p=0.005$, $r=0.570$; $t(21)=2.865$, $p=0.009$, $r=0.530$). On the other hand, in both O1 and O2, there was a greater variability in BTW in the bicycle frame for lateral oscillations ($t(21)=-4.901$, $p<0.001$, $r=0.730$; $t(21)=-6.414$, $p<0.001$, $r=0.814$), confirming the Lyapunov mean values.

In O3, after cycle acquisition, the children of both groups just differed in the velocity of the bicycle frame lateral oscillations ($t(13)=2.188$, $p=0.048$, $r=0.519$), with BB's children revealing a higher variability.

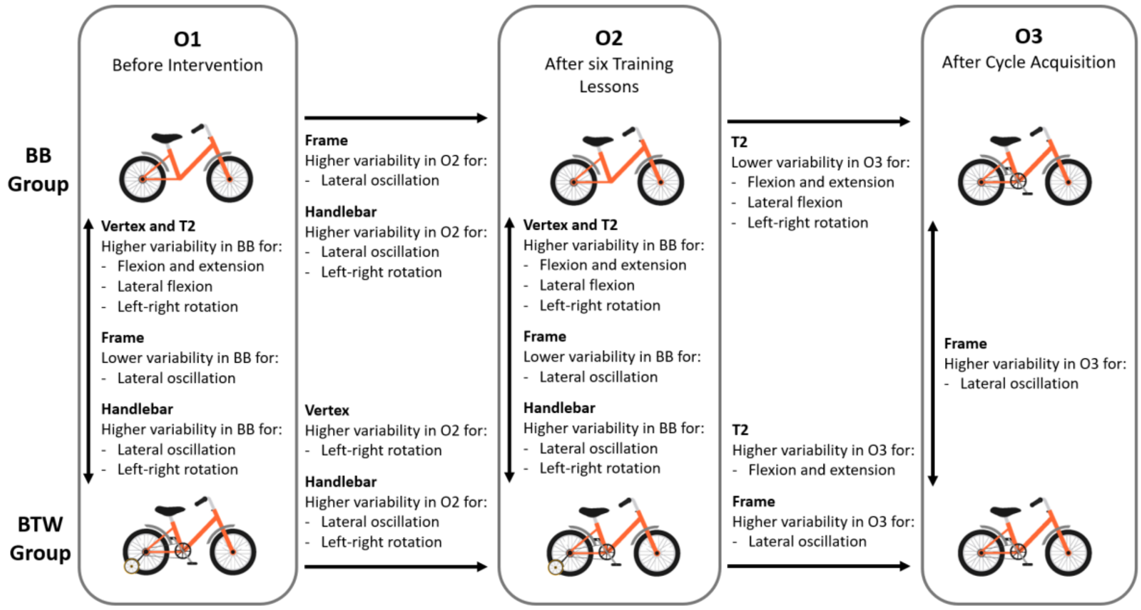

Figure 15. Abstract graph of comparisons results between moments of evaluation (O1, O2, O3) and between groups (BB, BTW).

7.4.3. Comparisons with children that did not acquire the independent cycle

At the end of the L2Cycle program, all children in the BB group successfully acquired independent cycling, however three children in the BTW group failed to do it. In this sense, to explore whether variability could be one of the reasons for this failure, a comparison between the children in the BTW who became independent riders and those who did not was performed, both in the first moment of evaluation, O1, and after six training lessons, O2. In O1, there was no significant difference in the variability on any IMU; meaning that at the beginning of training moment (O1), the BTW children who ended up not acquiring independent cycling behaved similarly to those who did. However, in O2, the independent riders (i.e., children who acquired independent cycling) revealed a higher variability in the velocities of the handlebar for lateral oscillations ($t(9)=4.411$, $p=0.002$, $r=827$) and left-right rotation ($t(9)=4.191$, $p=0.002$, $r=0.813$); no other significant differences were found in O2. It should be noted that children who did not acquire independent cycling showed lower mean values than the independent riders in all other IMUs and planes of movement, see Table 9.

Table 9. Lyapunov descriptive statistics of independent and non-independent riders, for each IMU, by movement planes and first (O1) and second (O2) evaluation moments.

BTW Group	IMU	Movement Plane	O1 M±SD	O2 M±SD
Independent Riders of BTW's group	Vertex	Sagittal	56.72±2.41	57.83±1.18
		Frontal	55.08±1.96	55.25±1.30
		Transverse	54.07±1.92	55.51±1.43
	T2	Sagittal	56.14±1.27	56.38±1.07
		Frontal	52.48±2.4	53.57±1.37
		Transverse	55.04±2.12	56.21±1.65
	Bicycle frame	Frontal	57.43±1.90	58.40±1.66
	Handlebar	Frontal	53.96±2.00	56.32±1.12
		Transverse	54.18±2.04	56.30±0.98
No Independent Riders of BTW's group	Vertex	Sagittal	56.28±1.43	56.65±0.26
		Frontal	55.43±1.39	54.09±1.31
		Transverse	53.49±2.05	55.08±1.29
	T2	Sagittal	55.65±1.00	56.02±0.80
		Frontal	52.84±1.70	53.05±0.69
		Transverse	54.98±1.37	55.30±1.99
	Bicycle frame	Frontal	57.78±1.92	57.97±1.03
	Handlebar	Frontal	51.86±1.93	52.74±1.45
		Transverse	51.83±2.04	53.41±1.16

7.5. Discussion

In the present study we aimed to analyse the variability in process of learning to cycle, along different evaluation moments, with the BB or the BTW. Variability did reveal to be a sensitive parameter, increasing after six training sessions in both groups, BB and BTW, in several body and bicycle points and movement plans. Since the LyE is calculated through the angular velocity, its greater variability implies greater and faster variations in oscillations, meaning that after training, the children were exploring more and faster their postural control, which was reflected in the increase of the velocity of head left-right rotations in the BTW; and in the bicycle's control, reflected in the increases of the velocities of the handlebar lateral oscillations and left-right rotation in both groups, and in the velocity of the bicycle frame lateral oscillation in the BB. In this sense, the variability increments could reflect the children's capability to deal with a more freely movable instrument for locomotion, the bicycle. Also, it is interesting to note that not only the patterns of increased variability were common to both groups, but also their differences. While between O1 and O2, the BB children increased their exploration of the bicycle frame's control, the BTW children did not, and increased the variability of head segment rotations. The use of BTW during cycle learning presents similarities with the use of baby walkers in the process of learning to walk, infants/children sit on the walker/bicycle and just need to walk/pedal without having to worry about balance control or lateral flexions or oscillations. Although the use of baby walkers is still not consensual (Badihian et al., 2017), some studies argue that they delay the child's development, namely the motor milestone of walking (Garrett et al., 2002; Siegel & Burton, 1999), while other studies do not confirm a developmental delay but identify kinematic changes in the gait pattern (Chagas et al., 2020). Even though training wheels are not baby walkers, the artificial support that both of these aids provide during the acquisition of a motor milestone, like walking or cycling, may not provide the necessary conditions for the child to self-organize and discover the new task or locomotion pattern.

When analysing a different stage of the learning process, comparing the end of the training period (O2) to the end of the period of practice with the TB (O3), we can see that the pattern of postural sway variability differed among the two groups; while BB's children reduced their variability in the trunk velocity (represented by the T2's IMU) for all movement planes, the BTW's children increased their variability in the velocity of trunk flexion and extension, and in the velocity of the bicycle lateral oscillations (represented by the bicycle frame's IMU). In this last observation, O3, the BTW children left the training wheels (as infants leave the baby walker), so their center of gravity was no longer stable and, consequently, they were forced to explore their trunk's postural control, as well as the bicycle's control.

As hypothesized, when comparing the postural control's variability between the two training bikes, the BB provided greater postural variability to the system child-bicycle since the first contact, in O1, as well as after practice, in O2. The BB resulted in greater variability in all movement planes at the head (represented by the vertex's IMU) and at the trunk, as well as in all planes at the steering wheel. By not having any artificial support (i.e., the absence of the training wheels) it is more difficult to keep the BB balanced even when feet are in contact with the ground, than the to keep the BTW balanced, because even when there is no feet contact with the ground, the BTW bicycle does not fall and has low lateral oscillations. Besides this task constraint difference, to ride the BB children must self-propel with their feet on the ground, and they can lead them to explore several cycle patterns, e.g., walking, running, hopping and others (see Chapter 6 for more details). Not long after the first contact with the BB, the child can simply push and maintain the balance with the BB by gliding (Chapter 6). The BB propitiates the exploration of a greater variety of cycle patterns, leading children to try a greater spatiotemporal variability in several segments and movement planes, which was reflected by the higher LyE values. The only exception was in the velocity of the bicycle frame lateral oscillations, in which the BTW children presented greater variability. This is a result that would not be expected since the lateral wheels limit the amplitude of the bicycle's lateral oscillations. However, even with lateral wheels, in tight curves or at higher speeds, the experimenters observed that the centrifugal force pushed the children's trunk to move laterally lifting one of the training wheels of the ground, resulting into a fall or to an abrupt return of the wheel to the ground. This rapid oscillation produced by mechanical factors may have led to a higher LyE value, thus justifying this unexpected difference.

When comparing the postural control's variability in the TB between both groups, only one significant difference was found, with the BB's children having higher variability in the velocity of the bicycle frame lateral oscillations. In general, these results shows that the same motor developmental stage, in this case the ability to cycle, can be achieved over different pathways, by using different training bicycles like BB or BTW (Mercê et al., 2022), in fact this is in line with what Waddington defined as the equifinality principle (Waddington, 1957). Interesting, when analysing the postural variability between the two groups in all observations, both in O1 and O2, the BB children had significantly higher LyE values with lower standard deviations for all points and planes, except in T2-O2-sagital plan. But this tendency was inverted in O3, the BB children continued to have higher LyE mean values (with just a significant difference in bicycle frames' rotation), but also revealed higher standard deviations in all points and movements, except in the vertex frontal plane. Despite having reduced the variability of their oscillations' velocity when they transfer to TB, between O2 and O3, BB children continue to have higher mean values of variability and, in O3, they even have higher standard deviation values. Considering that the LyE's standard deviation turns out to be a variability measure of the variability itself, and that the BB children showed greater success in learning to cycle than the BTW, the variability seems to have been used as a solution and not as a problem.

Recalling the theory of Bernstein (1967), coordinative tasks, like ride a bicycle, are acquired by mastering and unfreezing degrees of freedom (DOF), i.e., motor units, muscles, joints, limbs, movement axis and planes. More recently, Berthouze and Lungarella (2004) updated this theory and verified that the acquisition of coordinative tasks results from dynamic alternations between freezing and freeing DOFs, arguing also that the system needs to be perturbed to trigger these freezing and freeing mechanism. Our hypothesis is that the functional properties of the BB may have the necessary structural level of perturbation to trigger the system child-BB for the emergence of diverse self-organized cycle patterns. However, this might require a complexification of the child postural variability, as it was observed in the head and trunk IMUs values, in order to be attuned with the emergence of a greater BB functional variability, as expressed in bicycle frame and handlebar IMUs values.

Previous studies with LyE, have shown that the higher the value, the higher the system's variability and flexibility to faster response to perturbations and to better control the balance (Kędziorek & Błażkiewicz, 2020; Smith et al., 2010). Indeed, children from the BB group adapted more easily to the TB, acquiring all cycle milestones of self-launch, ride for 10 meters and brake significantly quicker than the BTW's children (Chapter 5); in the other hand, the BTW's children needed more time to adapt and, inclusively, three of them were not able to acquire independent cycling. As referred in Burt et al. (2007), when these children transited to TB they revealed defensive responses with a stiffness increase in trunk and arms, which impaired their balance on the bicycle and, consequently, their cycle acquisition. The less variability provided by training with the BTW did not propitiate them to achieve a greater postural flexibility and they end up freezing their DOF, as it is expected to happen with inexperienced practitioners, according to Bernstein (1967).

Another data that corroborates the hypothesis that the BB affords a greater variability, is related with the children who did not acquire the independent cycle in our study. If variability is a key aspect for learning how to cycle, then children who have failed to learn should show less variability, since they should still be freezing their DOFs. This hypothesis was confirmed by a non-riders' significantly lower variability, for all plans analysed in the handlebar. It would be expected that these differences would be also significant in other segments, possibly this was not the case due to sample size of only three children. Nevertheless, non-riders show lower mean values than independent riders for all analysed segments (IMUs) and in all motion planes, see Table 9.

7.5.1. Strengths, limitations and considerations for future studies

The present study is original and contributes to fill an existing gap in the literature, pointing out the higher variability as one of the reasons for the greater efficiency of learning to cycle with BB. Indeed, this finding also provides clues about the most efficient motor learning strategies, which should be based on exploring variability. Another innovative aspect is the application of the Lyapunov in the learning to cycle analyses. This nonlinear measure has already proved to be a reliable tool for study the human gait (Kędziorek & Błażkiewicz, 2020;

Mehdizadeh, 2018), however, to our knowledge, it had not yet been used in cycling. This study reinforces the LyE's utility and versatility.

The study's major limitation is related to the sample's size. Mainly, the size of the subgroup of children who did not acquire the independent cycle, which conditioned the comparisons and limits the generalization of this results. This analysis should be repeated in the future studies with a larger sample.

Although the analysis of variability using the LyE in this cycle learning context has revealed to be very interesting and relevant, it is important not to forget that this is just a variable. Currently, there are several other non-linear methodologies that afford an insight into motor skills control and allow the study of its process, like the recurrence quantification analysis (RQA) (Altenburg et al., 2021; Mercê et al., 2018) or the refined composite multiscale dispersion entropy (RCMDE) (Brigída et al., 2021). To gain a deeper understanding of the process of learning to cycle more investigation, using other nonlinear techniques, should be performed.

7.6. Conclusions

The present study contributes to a deeper understanding of the process of learning to cycle. Results revealed that the BB allows for a greater postural variability of the system child-bicycle, compared to the BTW; enabling children who use the BB to be more adaptable and to transit better and faster to the TB. The variability that in more traditional theories was seen as error or noise, must be re-evaluated as a part of the system's developmental dynamics, namely through non-linear techniques, like LyE that allows to quantify the system's ability or inability to adapt to the environment and learn more efficiently. The variability captured by the LyE technique may reflect the freezing and freeing DOFs processes, which afford the emergence of synergies between child and bicycle, during the acquisition of the foundational motor skill of riding a bicycle.

This study also provides scientific support for the proper choice of the balance bike as an adequate instrument for the acquisition of autonomous cycling. Policy makers, cycling federations, coaches, educators and parents should choose the BB over the BTW for children to learn to cycle.

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Chapter **8**

8. General Discussion and Conclusions

8.1. General Discussion and Conclusions

The present thesis investigated the process of learning to cycle throughout different timescales (Newell et al., 2001). After presenting the state of the art regarding the existent programs to teach children to ride a bicycle, the thesis adopted a larger timescale of motor development, using a retrospective approach to analyse different constraints that may influence the process of learning to cycle. Then, it transited to a shorter timescale, related with motor learning, where a descriptive analyses of the effect of a proposed program (L2Cycle) was presented. Finally, an even shorter timescale was used, which was related with motor control, when the symbiosis between velocity and stability control was studied. According to each timescale and objective, several theories and models of motor development and learning were adopted, such as the Bioecological Theory (Bronfenbrenner, 1995), Newell's Model of Constraints (Newell, 1986), and the Dynamical Systems Theory (Kelso, 1995). This multi approach and holistic view of the learning to cycle process is one of the bases of this thesis, which was deemed necessary to better obtain, analyse and discuss different parameters, experiences and behaviours regarding cycling experience. In a certain way, for each timescale, specific theories, theoretical models, propositions, and concepts were more employed, preserving a congruent theoretical perspective.

In chapter 2, a systematic review was conducted to characterize the state of the art regarding the intervention programs that aim to teach children to ride a bicycle, in order to identify and compare specific methodologies and protocols (first specific objective). Of the 2663 initial records identified in the initial search, nine articles were included in the final review, eight of them with children with disabilities (e.g., cerebral palsy, DCD, autism). This fact highlights the scarcity of study interventions focused on learning to cycle studies for children without disabilities. The review identified and discussed several methodological issues, namely the type of training bicycle. According to these studies (Cain et al., 2012; Hauck et al., 2017; Hawks et al., 2020; MacDonald et al., 2012; Temple et al., 2016; Ulrich et al., 2011), children who use the BTW learn to how pedal without fear of falling, but do not experience the bicycle's instability. Therefore, when the training wheels are removed, they end up activating defensive responses, that are expressed by blocking and freezing the trunk and upper limbs, leading to a loss of stability on the bicycle. Overall, the review sustained the possible advantage of non-using training wheels; allowed the compilation of a list of pedagogical tips; and sustained the recommendation that simpler bicycles, without pedals; and, simpler functional experiences should be used first.

In **Chapter 3**, the larger timeframe of development was adopted. The L2Cycle survey was developed to analyse the several constraints that may influence the process of learning to cycle (second specific objective). We found significant influence of the birth decade in the learning age (LA) for cycling, with a decreasing tendency over the decades. Interestingly, when the LA was compared by pairs of decades, some fluctuations can be noticed. For instance, LA slightly increased from the 60's to the 70's, which might have been related with the 1974 military revolution that took place in Portugal, leading to a period of social, political and (particularly) economic instability, which may have affected opportunities for children to practice cycling. Changes in LA over decades are an example of the influence of the chronosystem, as it is defined by Bronfenbrenner (1995) a time dimension of the environment, influencing the child's development.

Chapter 3 also addressed the influence of different learning paths (i.e., sequence of different bicycles used for learning) on cycling LA. The balance bicycle (BB) path, i.e., the use of a BB followed by the use of a traditional bicycle (TB), overcame the old approach of using a bicycle with training wheels (BTW), i.e., the use of BTW followed by the use of TB. It was found that children who used the BB path learned to cycle at a mean age of 4.16±1.34 years, 1.8 years earlier than those who had used the BTW path, where autonomous cycling occurred at a mean age of 5.97±2.16 years. These findings, based in a large-scale retrospective web survey, highlight the influence of the task constraints (i.e., type(s) of bicycle used for learning) on the process of learning to cycle, confirming the advantage of the BB that had already been suggested by the results of the previous systematic review (Chapter 2). Although these data added new and relevant knowledge, some questions remained unsolved. Retrospective surveys are prone to response bias, and confounding variables are often difficult to control in this type of studies. So, it would be important to test the two different learning bicycles in an intervention study, with controlled practice conditions.

The retrospective survey also allowed us to explore other factors that could have influenced the process of learning to cycle. In **Chapter 4**, we saw that individual constraints Newell (1986), namely the level of physical activity and the birth order of the child, influenced the LA for cycling. Children who practiced physical activity more than three times a week learned earlier than others with less physical activity. During childhood, practicing physical activity (PA), namely through active play, is crucial for children to explore and increase their motor literacy, and to develop balance and coordination (Carson et al., 2017). Probably, children who practice

PA more frequently had a better chance of developing the necessary motor competences to learn cycling, namely the coordination and balance capacities, which ultimately may have helped them to acquire autonomous cycling at a younger age. This finding ends up complementing Hulteen's model (2018). The author claims that the acquisition of foundational motor skills, such as riding a bicycle, enhances the participation in PA. The present data shows that participating in PA can also enhance these skills' acquisition. In this sense, this influence seems to be bidirectional, as a mutual feeding among motor competence and PA, namely through active playing with a bicycle. Regarding the influence of the birth order in the LA for autonomous cycling, younger siblings were reported to learn significantly earlier than older siblings or only children. The younger siblings may benefit from the imitation and interaction with their older siblings, in order to learn how to cycle (Barr & Hayne, 2003). Considering that the influence of older siblings in the younger's motor development is still not clear in literature (Rebelo et al., 2020; Wellen, 1985), these data thus added new information in favour of the hypothesis of a positive influence of older siblings.

So, the research findings on Chapter 3 and 4 reinforced the sociocultural nature of motor development, a process affected by factors, resources, properties, dispositions, and constraints available by the socioecological niche of children's and families' lives.

The findings of the Chapters 2 and 3 reinforced the idea that the BB is better for learning to cycle than the BTW. However, to our knowledge, this idea advocated by some authors (Hilpern, 2016a; Natalie, 2017) and entities (PCF) had never been scientifically tested. In this sense, the L2Cycle program, presented in **Chapter 5**, was developed to study how to promote learning of autonomous cycling for young children and, simultaneously, to investigate which one of the two most popular commercially available learning bicycles, BB or BTW, is the best practice bicycle (third specific objective). The program was developed based on the nonlinear pedagogy (NLP) (Chow et al., 2022; Chow et al., 2007) and constraints led approach (CLA) (Davids et al., 2008; Renshaw et al., 2010). These approaches were chosen because their conceptual frameworks accommodate better the findings of the previous studies; for example, in Chapters 2 to 4, it was found that environmental (e.g., decade of birth in Chapter 2), individual (e.g., practice of physical activity, Chapter 4), and task (e.g., training bicycle in Chapters 2 and 3) constraints influence the cycling learning process. Both NLP and CLA advocate that motor learning is a nonlinear process that involves coupling between perception and action and a constant reciprocal interaction between several environment, individual and task constraints (Renshaw et al., 2010). Also, in Chapter 4, the systematic review revealed that the best approach for children and youth to learn to cycle is a progressive learning strategy approach, which consists in one of the NLP's principles (Correia et al., 2019). In this sense, the whole program was developed by manipulating task constraints, like using diverse structured spaces, as different surfaces, slopes and vertical obstacles, to allow children to self-explore basic milestones of cycling, namely, self-launch, riding, and braking. Considering the lowest value of autonomous cycling learning age, identified in Chapter 3 (i.e., the mean value minus its standard deviation), we have estimated that from two and half year to three years of age, children had entered the sensitive period for learning how to cycle. So, based on this diverse information, a learning to cycle program (L2Cycle program) was tested with preschool and elementary school children. The program included 25 children divided in two groups, 13 in BB's group, 12 in BTW's group, and results revealed an 88% overall success rate; 100% success rate in BB's group and 75% in BTW's group. These results proved that a two-week intervention, with a frequency of five sessions per week, of 30 minutes of duration each session, can be enough for 3 years old children, without disabilities, to learn how to ride a traditional bicycle autonomously. The results also showed that the BB's group acquired the basic milestones and autonomous cycling significantly faster than BTW group. BB group children needed significantly less sessions with the traditional bicycle to self-launch, ride, brake, and to acquire autonomous cycling, i.e., to perform all these cycling milestones without any external (instruction and feedbacks) or functional (training wheels) help. These data corroborated earlier studies (Chapter 2 and 3) and sustained the hypothesis that the BB tends to be a more effective (i.e., leads to greater success) and efficient (i.e., in less time) learning bicycle than the BTW. Considering that balance is addressed in the previous literature as a key element for acquiring independent cycling (Ballantine, 1992; Becker & Jenny, 2017; Shim & Norman, 2015), and that the BB allows for testing the postural control and bicycle oscillations together since the first moment, this earlier and inherent need of self-regulation could be the reason for the BB's advantages. On the other hand, the BTW affords the exploration and acquisition of the cyclical (and identitary) movement of pedalling, without the need of controlling balance, which is guaranteed by the external support of the training wheels. In fact, the BTW basically allows the training of pedalling. As reported by Burt et al. (2007), when the children who had been using the BTW transited to traditional bicycle (TB), they tended to freeze their trunk and arms as defence responses to the bicycle's instability, in accordance with Bernstein's (1967) degrees of freedom freezing hypothesis. In our study, the three children who did not acquired autonomous cycling belonged to the BTW group, and also maintained this reported rigidity, throughout all sessions with the TB.

In addition, in Chapter 5 we have also explored the influence of individual constraints on the acquisition of cycling milestones. A positive association was found between children's body mass index and the number of days needed to be able to brake in a controlled manner. This result is in accordance with studies that found that children with overweight and obesity have lower balance stability (D'Hondt et al., 2008; Kakebeeke et al., 2017; Teasdale et al., 2013). However, and fortunately, this extra difficulty did not significantly affect the total of days needed to acquire the independent cycling; meaning that the BB may have an inclusive potential, i.e., affords overweighted children to acquire the ability of cycling and, consequently, may be a good a way for them to practice PA.

To our knowledge, the L2Cycle intervention study was the first one that aimed to investigate and compare the BB and BTW during the acquisition of independent cycling, proving the BB's greater efficiency. These results provide academic support for a more suitable choice of the training bicycle, closing a gap in the current literature; but they also raise new questions that should be investigated taking a closer look at the learning process, in order to perceive if the BB really enhances postural stability, and if so, how?

Thus, in **Chapter 6** we took a closer look at the learning process. During the L2Cycle program we had noticed that the BB children explored a great diversity of motor patterns during the learning process. Naturally, the absence of pedals demanded children to explore alternative solutions to produce the wheels movement using their own feet. So, the first step was to analyse which cycling patterns were being used by the children, which were the most prevalent ones, and if there was a sequence for their appearance. We analysed the cycling patterns on the BB during the first moment of practice and after six practice sessions, and it was visually detectable that some patterns only emerged at low velocities and others only emerged at high velocities. This led us to suggest that velocity could be considered a control parameter, that leads to the transition between the different cycling patterns (fourth specific objective). Velocity has proved to be a control parameter for horse locomotion patterns (Hoyt & Taylor, 1981) and for human locomotion (Kung et al., 2018). In fact, one of the task constraints of the L2Cycle program was to encourage children to explore faster velocities (prescription), but never to tell them how to do it (no description), in accordance with propositions of nonlinear pedagogy and CLA (Correia et al., 2019). Patterns varied with moments of double support (booth feet touch the ground), single support (just one foot touches the ground) or flight phase (no foot touches the ground). Seven distinct BB's cycle patterns were identified and categorized: walk, run, glide, hop, single hop, trot and jump. This finding implies by itself that young children (from three years of age) can detect several action possibilities, i.e., affordances (Gibson, 1979), with the BB, allowing them to engage in different modes of locomotion, which imply different ground contact rhythms and patterns of legs' synchronization. These different patterns resulted in different flight time phases, from zero- in walk, because there is always some contact with the ground- till maximum time - in glide, because no contact in the ground occurs. Additionally, if a child has no feet on the ground, the body-bicycle movements must be in synchrony to keep travelling, on the contrary they both will fall. So, in the glide pattern children propel themselves and then just ride, trying to keep the body-bicycle synchrony, without immediately looking for new support on the ground. This turns out to be the pattern that is most similar to cycling in a traditional bicycle, and the one that allows for a greater exploration of balance while the child-BB system changes over time, as it occurs in any dynamic system (Kelso, 1995). Due to the relevance of the glide pattern, it was important to understand which factor promoted the exploration of the glide, or, according to the dynamical systems theory, which control parameter could promote the transition to the order parameter of glide (Kelso, 1995; Kelso, 2009). Results from Chapter 6, indicate that the velocity increment led children to explore more motor solutions, supporting the idea that velocity acts as a control parameter (although we could not experimentally control it), leading to the emergence of new patterns of the system's behaviour. This hypothesis was corroborated by the relative frequency graph of action modes used (Figure 13), which showed three main preferred cycling patterns: walk, run and glide. Like in human locomotion, in which a velocity increase at a certain speed (around 2 m/s) leads the system to change from walking to running (e.g., Kung et al., 2018), and like in horse locomotion, where increases in velocity lead the horse to transition from walking to trotting (around 1.7 m/s) and then to galloping (around 4.6 m/s) (e.g., Hoyt & Taylor, 1981); also, in locomotion with the BB, velocity acted as a probable control parameter that led the children to change from a cycling pattern to another at certain speeds. For velocities below 1.32m/s, the walk pattern was the most frequent and stable, above 1.32m/s children tended to change to a run pattern, and when the velocity reached 2.15m/s the glide pattern emerged.

To our knowledge, this study presented, for the first time in the literature, the categorization of the BB's cycling patterns, indicating velocity as the probable control parameter that led to their emergence. We consider that this information is relevant for teachers and technicians to take decisions about the equipment selection for learning to cycle, and to program the learning in order to challenged and guided the learners to self-regulate their actions according to the task and environmental constraint (Correia et al., 2018, 2019).

Nonetheless, there were still other questions to be answered. When a child is on a bicycle that has no training wheels, which artificially ensure the bicycle's stability, probably there will be a greater spatial variability of child's body and of the bicycle than when riding a BTW. So, offering children a BB to learn generates a paradox: cycling requires body and bicycle synchronized stability, but a bicycle without training wheels or other stabilizers (like an adult holding the bicycle or the child) results in a higher probability of spatial variability in the body-bicycle system. However, children in the BB group managed to achieve the cycling milestones and independent cycling more rapidly than those in the BTW group. The influence of the stability or lack of stability during the learning process needed to be further investigated.

Thus, in **Chapter 7** we adopted a narrower timescale to look at the motor control processes that occur during learning to cycle. We aimed to study the fast postural and bicycle spatial adjustments, comparing motor variability along the learning process with the BB and the BTW, in specific moments: i) initial contact; ii) after six practice sessions; and, iii) after cycling acquisition with the TB (fifth specific objective). We hypothesized that the BB provided a greater motor variability than the BTW, leading to a greater motor adaptability because children need to deal and overcome unexpected and challenging situations (Kedziorek & Blazkiewicz, 2020; van Emmerik & van Wegen, 2002), including in abrupt transitions, like the one that occurs when experiencing a traditional bicycle for the first time. When comparing the first moment and the moment after the six practice sessions, the results show significant increases in the variability of the system child-bicycle, in both groups, calculated by the Lyapunov exponent. These findings demonstrate that the variability is a sensitive parameter in learning to cycle, reflecting the children's capability to deal with the bicycle. When comparing both groups, BB and BTW, the results confirmed the first part of the hypothesis raised, the BB provided significantly greater postural variability in the system child-bicycle, both in the initial contact and after practice. The BB's riders had greater variability in all movement planes at the head and at the trunk, as well as in all planes at the steering wheel. The second part of the hypothesis, which argued that a greater motor variability led to a greater adaptability to the TB, was confirmed by comparing children who achieved autonomous cycling and those who did not. Although results should be interpreted with caution, due to the small number of children who did not acquire autonomous cycling, those children revealed significantly lower variability for all plans analysed in the handlebar, and lower mean values in all the other points and movement planes. So, instead of induced artificial stability (training wheels), the free spatial variability allowed by the BB, enhanced the child-bicycle system synchrony, affording more efficiency during the process of learning to cycle. Berthouze and Lungarella (2004) in an update to the degrees of freedom theory (DOF) (Bernstein, 1967), claimed that the acquisition of coordinative tasks results from dynamic alternations between freezing and freeing DOFs, arguing also that the system needs to be perturbed to trigger these freezing and freeing mechanism. The present data highlight the greater motor variability afforded by the BB, which triggered the system child-BB to release more degrees of freedom and to become more adaptative to the TB constraints, when children change to this type of bicycle. This more efficient adaptation to the TB occurred even though the BB children had never experienced the pedals before. This highlights the paramount importance of mastering the coordinative capacity of stability control in the early stages of learning, since balance control seems to be more important than the ability of pedalling and must be the main criteria when teaching a person to ride a bicycle. On the other hand, the BTW seems to be too stable, not allowing children to explore the freezing-freeing mechanisms during learning, and leading the child to freeze when facing the TB's instability for the first time. So, our results are in accordance with the degrees of freedom theory (DOF) (Bernstein, 1967) and subsequent theoretical developments (Berthouze & Lungarella, 2004).

8.2. Methodological Considerations

The studies reported in this thesis used different methodologies for data collection according to the specific problems that were being investigated. The decisions regarding the use of those methodologies are explained next.

To analyse the influence of different constraints in the process of learning to cycle, we opted to collect data using a web-based survey (Chapters 3 and 4). This method provided us with two major advantages, first it allowed us to collect a large sample in a relatively short time (information was collected for 2005 participants only in Portugal) (Fricker & Schonlau, 2002) and, secondly, it allowed the expansion of this study to other countries both in Europe (Italy, Finland, Spain, Belgium, United Kingdom, Croatia and Netherland) and in America Latin America (Brazil and Mexico). This collection method thus allowed to fulfil one of the specific objectives of the thesis (according to objectives) and the internationalization of the study with the creation of new objectives, such as the comparison of learning to cycle in different countries and cultural realities, which end up transcending this thesis and has already resulted in a publication (Cordovil et al., 2022). Nevertheless, this method also has some disadvantages inherent to its typology. As the questions are asked without the possibility of clarifying them while filling the survey, erroneous interpretations may occur (Alderman & Salem, 2010); in order to avoid this error a first pilot data collection was carried out and 30 participants were asked about their understanding of the research. As it is a retrospective method, there is also the possibility of the recall risk is possible, i.e., the participants could not remember accurately the details asked, especially in the older participants (Halverson, 1988; Sedgwick, 2012). Considering this disadvantage and to avoid this possible error, we opted not to include the responses of participants over the age of 70 (i.e., born in the 1960s–69 decade).

In the studies that were focused in analysing the process of independent cycling acquisition and in the analysis of motor variability with the two learning bikes for children (BB and BTW), we opted to use inertial measurement units (IMMUs) for data collection (Chapters 5-7). Considering that data collections were carried out in a kindergarten playground and not in the laboratory, the IMMUs seemed to be the best option to collect data. These sensors have been used in sports (Camomilla et al., 2018), and combine a gyroscope and an accelerometer, collecting respectively data on the angular velocity and acceleration simultaneously, in the three movement planes. Small size and extremely portable, IMUs were ideal to collect our data with children and in the bicycles. However, we could not find previous intervention studies that had used IMUs to analyse postural variability during cycling acquisition; consequently, it was necessary to define and test a protocol for data collection and treatment. In an initial protocol we have considered six IMUs located in following points: in the vertex, to provide data related to the head segment (Mercê et al., 2018; Shurtleff & Engsberg, 2010; Wolter et al., 2020), where vision and vestibular system are located, which are of great importance for postural control; in the 12th dorsal vertebral (D12), which corresponds approximately to the child's center of mass (Shumway-Cook & Woollacott, 2017), which provide data related to the trunk segment, where a great number of postural muscles are allocated; on both child's feet, in order to identify the moments when the feet touched the ground (moments in which the acceleration should be zero), which could provide important information to categorize the BB cycling pattern; on the bicycle's handlebar, to allow the analysis of its rotations, which is one of the degrees of freedom of the bicycle; lastly on the bicycle's frame, to allow the analysis of the bicycle's oscillations, which may represent the result of the interaction of the child with the bicycle, in order to reach stable spatial travel. To analyse the velocity variable of this child-bicycle system, a LED was placed on the bicycle's frame, for later analysis by videography. Considering the necessity to categorize the cycling patterns with the BB, the children's practice trials were also videorecorded.

The exploratory data collections with this apparatus highlighted several problems. The first problem identified was the time needed to set up the data collection. Data needed to be collected individually within the school schedule and with limited time to use the practice space, so it became important to define a protocol that was less time consuming. In the initial protocol, what took the most time was the placement of the six sensors, especially the two on the feet due to the way they need to be attached. Since the collections would also be video-recorded and the video allowed to identify the moments of feet contact with the ground, the IMUs from the feet were removed.

The second problem was the IMU location on D12, this point presented very low values in lateral flexions, which by watching the video did not seem to represent the rotations in the frontal plan of the child's trunk. Although we can consider the trunk as a segment, in biomechanical models it can be divided into several sections, in which the approximate location of the T12 point serves as an endpoint of lower and upper trunk. In this sense, this point works as an axis for the lateral flexions of the upper region of the trunk, which can explain why the sensor did not show the oscillations seen in the video. For this reason, we decided to change the IMU from the T12 to the second thoracic vertebral (T2), at the end of the upper trunk section (Li et al., 2021).

The third problem consisted in collecting the bicycle’s velocity using the videography, not only due to the time consumption of data processing, but mainly because when the child moved freely with the bicycle, they ended up covering the LED. Considering Cain et al. (2012) study, which calculated the bicycle's speed through the angular velocity of the wheel, we chose to change the IMU from the handlebar to the front wheel. This new positioning, see Figure allowed not only to calculate bicycle’s velocity, but also to collect the rotations and inclinations of the handlebar.

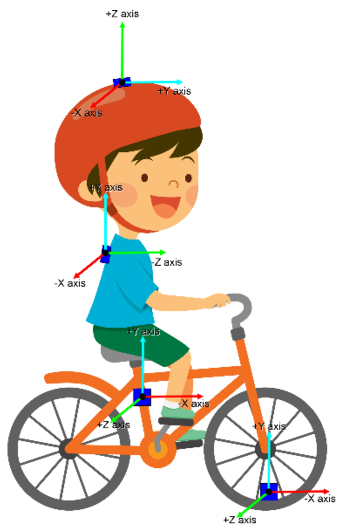

Figure 16. Illustrative figure of the IMUs’ placement on the bicycle and child.

The last problem was to synchronize all the IMUs. As there was no procedure or software to synchronize the IMUs, they were fixed to the bicycle and then the front wheel was lifted and dropped to the ground three times, with an interval of approximately five seconds. Thus, for synchronization purposes, during the data processing, the acceleration graph of each IMU was created and all IMUs were then manually synchronized by identifying the first acceleration peak that corresponded to the first impact of the front wheel on the ground.

Finally, it was necessary to program the IMUs to ensure adequate data collection. Knowing that some nonlinear techniques need a large amount of data to be processed (Deffeyes et al., 2009; Mehdizadeh, 2018), the sample frequency has set at 100 Hz. Considering that in exploratory collections the acceleration data did not reach the 2g, and in order to be able to observe phenomena such as falls, the accelerometer was set to 4g. Since the gyroscope would be used to calculate the velocity and, the maximum speed that children could reach with the bicycle was not known prior to data collection, it was set at the maximum value available of 2000 deg/s.

8.3. Recommendations for Practice

The works presented in this thesis have several practical implications regarding the process of learning to cycle. During the analysis of the cycling learning age (Chapter 3), it was found that children can learn how to cycle autonomously with BB from the age of two and a half or three years (chronological age). Considering that for cycling with a BB the child only needs to have acquired autonomous walking, i.e., the ability of the child to walk independently without support and without falling for about 10 meters (motor age) (Burnay et al., 2021), which occurs around 12 months of age (WHO, 2006b) probably soon after that, they can try to start walking with the BB. However, most balance bikes available in the market are probably big or heavy for children younger than 2 years of age, since the results of our survey indicate that the sensitive period to stimulate the acquisition of the foundational motor ability of autonomous cycling, with a BB probably starts around two and a half years of age. This finding gives parents, educators and/or teachers a practical recommendation regarding the moment from which they can (and should) introduce the BB, in order to facilitate an earlier acquisition of this motor ability, enhancing concomitant benefits, such as improving the child's motor literacy, having a fun motor practice and improving balance (Shim et al., 2021).

In Chapter 5, the L2Cycle program was presented, and pedagogical recommendations were made for preschool and elementary children, namely, prioritizing unstructured activity with exploratory and functional play with the bicycle, and creating or finding practice environments that allow the exploration of different surfaces and ground inclinations. Considering its easy application, without the need for a specialist technician, and its high success rate, the L2Cycle program can be used in future interventions by teachers (from kindergarten educators to elementary school teachers) in physical-motor activities, and by parents and family members.

The categorization instrument for the BB's cycling patterns (Chapter 6), can be used as a tool to analyse children's learning processes and paths with the BB, but it can also be used as a practical tool for parents, educators or teachers to adjust their intervention and manage the environment, in order to allow children to explore a greater diversity of cycling patterns, trying different velocities of displacement, e.g., playing games that involve racing or exploring descending ramps. The categorization instrument associated with the analysis of the velocity of displacement, revealed that the glide pattern is achieved at greater velocities (around 2.15m/s), highlighting the importance of creating situations that increase velocity, for children to be able to ride with no feet contacting the ground, achieving the glide pattern with the BB.

8.4. Recommendations for Future Research

In our studies, no association was found between the variables of motor competence (MC) or body composition (BC) with the days needed to reach the cycling milestones or the independent cycling in both the BB and the BTW groups (except for the body mass index with the braking) (Chapter 5). However, considering that the BB children acquired the cycling milestones and autonomous cycling earlier than the BTW children, and that all children in the BB group learned to cycle, regardless of their MC or BC, the balance bike seems to be not only better for learning (i.e., more efficient), but also more inclusive. In fact, in the BTW three children did not acquire cycling, of which two were children with obesity and one had low motor competence (below the 40th percentile for her age and sex). These findings should be confirmed by studies with larger samples, but the BB seems to help children to overcome some of their difficulties related to individual constraints, like low MC (Rodrigues et al., 2021) or unadjusted body composition (Aoyama et al., 2022; Slining et al., 2010). To test this hypothesis, it will be necessary to replicate the L2Cycle program in a larger sample, with a greater representativity of various levels of motor competence and of body composition.

Bearing in mind that the BB's functional properties seem to diminish the negative impact of some children's individual constrains and, considering also that the BB allows for a higher motor variability, which revealed to be a facilitating factor in the adaptation to the autonomous use of a TB (Chapter 7); we consider that it is pertinent to test the L2Cycle program with children with disabilities, e.g., cerebral palsy (e.g., Kyvelidou et al., 2018; Kyvelidou et al., 2013) or development coordination disorder (e.g., Schoemaker et al., 2003). The iCanBike program already used the roller bicycle for these children, however with a mean rate success of nearly 60% (Chapter 2). Maybe, the use of BB could increase this success rate, since although the roller bicycle allows some bicycle's lateral oscillations by replacing increasingly tapered rollers at the ends, this approach may be too stable for some children (Cain et al., 2012).

Chapter 6 presented the first categorization of the BB's cycling patterns that we know of, identifying seven distinct patterns. Nevertheless, it is possible that more patterns may emerge with increasing experience in the BB or with older children, e.g., children may perform "wheelies" with TB, perhaps they can also do it with a BB. A larger number of patterns as well as their subcategories can be explored in future studies.

Still in Chapter 6 the velocity is pointed out as a possible control parameter for the BB's cycling patterns, despite the data pointing to this hypothesis, it is necessary to develop a data collection methodology that allows testing this hypothesis properly, e.g., manipulating velocity to test the catastrophe flags and hysteresis (Gilmore, 1981).

Considering that presently there are several non-linear methods that, beside the Lyapunov Exponent (used in Chapter 7), can help to gain a better insight of the process of learning to cycle, some of those methods can be used in future studies. Some examples are the recurrence quantification analysis (RQA) (Altenburg et al., 2021; Mercê et al., 2018), cross recurrence quantification analysis (CRQA) (Dutt-Mazumder et al., 2018), or the refined composite multiscale dispersion entropy (RCMDE) (Brigída et al., 2021). These methods allow to collect diverse information about the non-linear dynamics of the system behaviour but should be tested using specific experimental designs (e.g., exploring the synchrony between the handlebars and the frame or between body and bicycle oscillations through the CRQA).

This thesis thus presented an odyssey about learning to cycling process, offering some answers to the literature's gaps, but always leaving new questions unanswered. This is in essence the mission of science, a continuous search for knowledge. Like Albert Einstein once said, "life is like riding a bicycle, to keep your balance you must keep moving" (1930), in science to improve your knowledge we must keep investigating.

8.5. References

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Appendix 1. Learning to Cycle Manual

Framework and Purposes

This is the protocol of the L2Cycle programme addressing the fundamental aspects and methods to promote its replicability. Learning to cycle is an important motor milestone for all children (Zeuwts *et al.*, 2020, Zeuwts *et al.*, 2015). Therefore, investigating which is the most effective and efficient training bicycle is an important aspect to promote earlier learning. So, L2Cycle has a main pedagogical purpose that consists in help children without disabilities to learn how to cycle, and another main investigation objective which consists in study and compare the using of bicycle with lateral training wheels (BTW) and the balance bike (BB) during the learning.

The programme is framed by ecological dynamics theory, which argues that the learning is a nonlinear process that occurs through the self-organization within the relation learner-learning environment under the interaction of the constraints (Chow *et al.*, 2007). Therefore, the teacher's role during sessions should be based on guiding the child's discovery and not describing his/her action. For these reasons, all program sessions incorporated two components, one with free exploration, in which the child could explore and play with bicycle without any instructions, so he/she can discover the instrument by his/herself; and another component whit planned tasks designed to combine constraints manipulations in order to introduce noise, create instability and promote the exploration of functional and adaptive movement solutions (Chow *et al.*, 2007). The programme also considered the tips list for cycling learning programmes presented in a recent systematic review (Mercê *et al.*, 2021c).

Training Schedule and Details

The programme includes two groups, which carry out part of the intervention with different training bikes, one trains with the balance bike (BB) and the other with bicycle with lateral training wheels (BTW). And it is divided in four phases: i) baseline assessment; ii) first phase of intervention, with training bicycle; iii) second phase of intervention with traditional bicycle (two wheels bicycle with pedals and no training wheels, and simultaneously, post assessment; iv) follow-up assessment.

- The baseline takes place in the week before the intervention, and includes the measures of body composition (height and weight), motor competence, parent survey and child motivation (pictorial Likert scale).

- The formation groups are done according all the variables collected in initial assessment in order to form groups without significant differences.
- The bicycle intervention runs for two weeks, six sessions with the training bicycle, BTW or BB, (phase ii), and 4 sessions with the traditional bicycle (phase iii).
- Sessions are daily and last 40 minutes, 10 minutes for preparation and equipment, 30 minutes for effective practice.
- The participants are grouped in sessions of five elements, maximum of six.
- Two teachers participate in each session, securing a rate of one-to-two or one-to-three.
- To promote greater optimization of time and use of resources, two sessions can take place simultaneously (one BB and one BTW) as long as there is enough space and at least 4 teachers (2 for each session).
- The facility should be a spacious flat floor area with no or few obstacles, could be indoor or outdoor.
- Trainers should familiarize themselves with the program, in particular by carefully reading this appendix.

Due to the L2Cycle programme simplicity, it can be applied by sports professionals, teachers (namely primary teachers in their physical education or motor expression activities), educators, parents or family members. Its easy replicability, whether for research purposes, including intervention with several children in two groups; or simply its application in a small group or individually (using only the BB), is one of its strengths.

Equipment

Preferably, the LittleBig Balance Bike (Ireland) model should be used. This 3 in 1 model, has two main characteristics that led to its choice, it is adaptable through the rotation of its frame, which allows it to be used by small children, from 2/3 years old, up to 6/7 years old; and includes the pedalboard, when the researcher wants to transition to TB, he/she only needs to mount the pedalboard and retains all the ergonomic features of the training bike. If the programme includes older children this model may not be appropriate, in this case another model should be chosen and the same one should be used in the two intervention groups.

The BTW group also uses the LittleBig Balance Bike but with the pedal crank and two lateral training wheels incorporated.

- All children should use helmet in all sessions. This aspect ensures their own security and promote the helmet's use in future (Spinks *et al.*, 2005).
- All the bicycles are fitted individuality before each session.
- The BB is fitted according to instruction of the manufactures (Evans, n.d.; Strider, 2017). The seat height is stablished at the inseam's child height (measured with shoes) less 2,5 cm (one inch), and the handlebar height is stablished at belly button level, see figure below.
- In BTW, the seat is stablished at a height that provides the same level of knee flexion as the adjustment shown above, the handlebar height is stablished at belly button level.
- In TB, the seat is stablished at a height that allows the child to comfortably rest their feet on the floor, so they feel more secure and be able to explore the self-launch. The handlebar height is stablished at belly button level.
- The bicycle adjustments defined above are recommendations, if the child does not feel comfortable and asks for a different adjustment, their will and comfort must be respected, as long as it does not harm their safety.
- Tire air pressure and brake condition should be checked daily before sessions start.

Training Strategies for Motivation

The children's motivation is important during their learning process (Mercê *et al.*, 2021c). So, trainer should identify the children less motivate, pay special attention, and try to extra motivate them. According to the characteristics of the children participating in the project, teachers can apply various strategies:

- Promote a fun environment throughout the intervention.
- If children are not all practicing at the same time, let the more willing children to go first, the other children might become more motivated and gain trust.
- If the children show fear of falling, the teacher can run alongside them until they overcome this fear.
- Use outline and congratulate the small achievements.

Training Progression and Sessions' Plans

According to a previous systematic review (Mercê *et al.*, 2021c), progressively increase the task's complexity is one of the key points to successfully teach children how to cycle. In this sense, the training sessions are organized by a progressive increasing difficulty, divides in six training plans presented below, see also sessions' schedule.

In Plan 1 the targets are: i) introduce the bicycle, ii) introduce the helmet and its importance, and iii) let children freely explore the bicycle. In Plan 2 and 2.1 the targets are: i) explore and acquire the braking, and ii) explore more velocity on the bicycle. In Plan 3 and 3.1 the targets are: i) continue to explore and master the turning, namely with more velocity; ii) reinforce braking in unexpected situations and in ramps. In Plan 4, the last with the training bicycle, aims to: i) reinforce all the learning from previous training, ii) increase the difficulty of bicycle's control by introducing exercises which involve transporting objects and keeping the cycle direction while turning their head to interact with the trainers

The Plan 5 is the first plan with the TB, so the targets are to acquire: i) self-launching, ii) balance, and iii) braking in the TB. In these sessions trainers help children to initiate, accompanied them during their attempts to balance, intervening whenever necessary to prevent falls, and help children to brake. Trainers should intervene whenever necessary but, as little as possible, in order to let children to explore the TB and self-organize in this new instrument. The Plan 6 is just applied when children already acquire the independent cycle, and consists in an initial part of self-exploration, 10', and the performing of the exercise of "Bicycle Rodeo" presented in Plan 4 below but now with the TB.

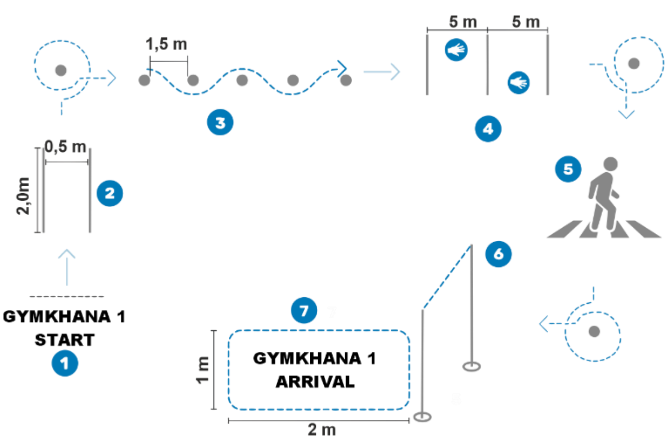
Sessions' Schedule

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Week 0	Initial assessment: body composition, motor competence, parent survey, child motivation				
Week 1	Plan 1	Plan 2	Plan 2.1	Plan 3	Plan 3.1
Week 2	Plan 4	Plan 5	Plan 5	Plan 6	Plan 6

Notes: BC - body composition, MC - motor competence, PS - parent survey, CM - child's motivation; Colour notes: sessions with training bicycle; sessions with conventional bicycle

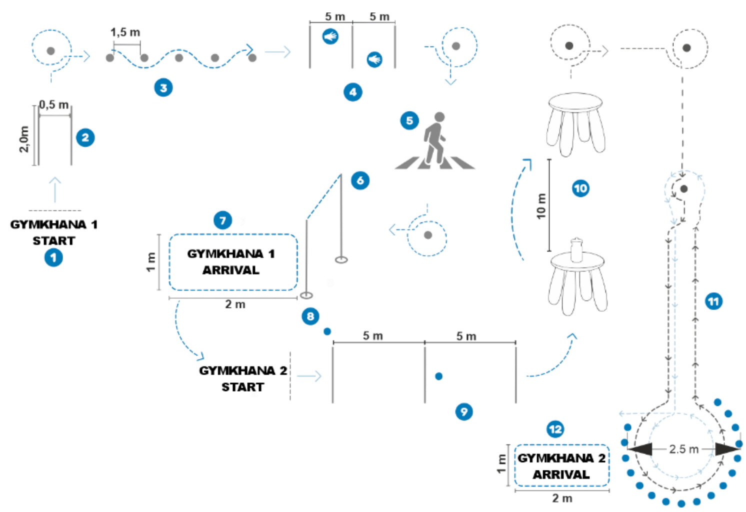
Plan 1: Introduction		
Activity	**Description / Explanation**	**Time**
Putting on and adjusting the helmet	- Ask the children if they know what the helmet is for and how important it is - Exemplify the importance of the helmet so that children understand it ("Imagine that I lose balance and fall... is the helmet good for anything?") - Put and verify the adjusting of the helmet in each child - Adjust the bicycle for each child	5'*
Naming bike parts	- Ask the children if they know the parts of the bike (e.g., wheels, steering wheel, frame, brakes, pedals) - Ask them to point to the parts of the bike	3'
Free exploration beside bike	- In a large space and level space (training pitch) just free exploration ("just play with the bicycle while you are beside it)	5'
Free exploration on bike	- Same exercise as above but now on the bicycle - Trainers could incentive the exploration ("What happens if I turn the handlebars? What is it for? What if I hit the brakes?") - In braking on BB alert for feet on the ground when braking	20'
Stretching	- During stretching ask children if they liked and reinforce the essential keys (helmet and bike parts)	2'
Note: *This 5' are included in the 10' for preparation and equipment		

Plan 2 and 2.1: Brake and Accelerate		
Activity	**Description / Explanation**	**Time**
Free exploration	- Free exploration with the bike in a large and level floor without any instruction	5'
Braking exploration	- 1st) Continuing free exploration, introduce stop signals in the space without any instruction – see if the children recognize the signals - 2nd) Ask the children if they recognize the sign and what it is for - 3rd) Ask the children to keep playing (free explore) but, so that whenever they pass the stops signals, they stop	5'
Braking unexpectedly	- Carry out a route that simulates the road with stop signs and crosswalks ("Now we're just going to walk on the road, be careful because pedestrians can cross the road") - Trainers carry out crossings on and off the crosswalks to promote an unexpected brake situation	18'
*Accelerate "Running game"	- 1st) Create an acceleration course and incentive children to increase velocity more and more - 2nd) Divided the session into teams and children perform a run team vs team	8'
Stretching	- During stretching ask children if they liked and reinforce the essential keys (Stop signal, the function of brakes)	2'
Note: * The "Accelerate" exercise is just performed in the second day of Plan 2 application (Plan 2.1), for its application, the exercise "Braking unexpectedly" should be shortened to 10'		

Plan 3 and 3.1: Twist and Turns		
Activity	**Description / Explanation**	**Time**
Free exploration	- Free exploration with the bike in a large and level floor without any instruction	5’
Free exploration with cones “Bomb camp game”	- Continuing free exploration and introducing cones scattered across the field (“Let's play the bomb game, each cone is a bomb, we can't touch it”) - As children demonstrate ability to turn, trainers can add more cones or decrease play space to promote tighter turns	5’
Zig Zag with Busy intersection	- Carry out the gymkhana below with zig zag and crosswalks (adapted from PCF, 2018a)  Stations: 1. Check helmet and mount the bike 2. Pass between the lines 3. Slalom 4. Cycle with only one hand, alternating 5. Stop at the crosswalk while the trainers cross it 6. Cycle under the wire 7. Stop and dismount the bike inside the rectangle *Note* - the gymkhana could be adapted to the available space and materials	9-10’
Ramp Exploration	- Explore the ramp, let children cycle: - Down the ramp - Up the ramp - Down faster - Down with an obstacle (trainer) at the end to promote braking	9-10’
Stretching	- During stretching ask children if they liked and reinforce the essential keys (function of the handlebar, crosswalks)	2’
Note: *The Plan 3.1 is the same as Plan 3 just with the change that the “Gymkhana” lasts 5’ and the exercise of “Ramp exploration” lasts 15’		

<table>
<tr><th colspan="3">Plan 4: Bike Dynamic Rodeo</th></tr>
<tr><th>Activity</th><th>Description / Explanation</th><th>Time</th></tr>
<tr><td>Free exploration</td><td>- Free exploration with the bike in a large and level floor without any instruction</td><td>5’</td></tr>
<tr><td>Bicycle Rodeo</td><td>

- Carry out a dynamic and big gymkhana with zig zag, crosswalks, and objects’ transportation (adapted from PCF, 2018a, PCF, 2018b)



Stations:

1. Check helmet and mount the bike
2. Pass between the lines
3. Slalom
4. Cycle with only one hand, alternating
5. Stop at the crosswalk while the trainers cross it
6. Cycle under the wire
7. Stop and dismount the bike inside the rectangle, remount the bike and cycle to the next station
8. The coach raises his fingers
9. The cyclist looks back and confirms the number of fingers raised while cycling
10. Take the bottle out of the bank, cycle, put the bottle on the other bank while cycling
11. Carry out the roundabouts following the directions provided
12. Stop and dismount the bike inside the rectangle

Note - the gymkhana could be adapted to the available space and materials
</td><td>10’</td></tr>
<tr><td>Ramp Exploration</td><td>- Explore the ramp, let children cycle:
- Down the ramp
- Up the ramp
- Down faster
- Down with an obstacle (trainer) at the end to promote braking</td><td>13’</td></tr>
<tr><td>Stretching</td><td>- During stretching ask children if they liked and reinforce the essential keys (how fun can it be to cycle)</td><td>2’</td></tr>
<tr><td colspan="3">Note: *The Plan 3.1 is the same as Plan 3 just with the change that the “Gymkhana” lasts 5’ and the exercise of “Ramp exploration” lasts 15’</td></tr>
</table>