

## ORIGINAL ARTICLE

# Mastering balance: The use of balance bicycles promotes the development of independent cycling

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**Abstract**

Children who learn to cycle at a young age do this by using training bicycles that simplify control requirements compared with regular bicycles, such as bicycles with training wheels or balance bikes without pedals. The primary purpose of the current study was to investigate whether the two types of training bicycles result in a different age of onset of independent cycling on a regular bicycle. We asked parents of 4- to 6-year-old children ( $n = 173$ ) to complete a questionnaire regarding their child's bicycling history. The results showed that children who had practised with a balance bicycle started practising at a younger age, had shorter practice duration, and were able to cycle independently at a younger age in comparison to children who had practised with a bicycle with training wheels (or with both training bicycles). We argue that the observed advantage of balance bicycle is associated with the balance bicycle actively challenging postural control. Further research is needed to uncover the impact of training bicycles on the further development of the foundational skill of cycling.

**KEYWORDS**

cycling, degrees of freedom, foundational skills, modified equipment, motor development

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## INTRODUCTION

Locomotion is the act of moving from one place to the other while navigating through the environment (Reed, 1988). Broadly speaking, its development starts a few months after birth with (belly) crawling. Subsequently, it transitions, around 1 year of age, towards unsupported walking on two legs, often with a phase of cruising or supported walking in-between. The last decades have seen a surge in research investigating how children in the first 2 years of life, for each mode of locomotion, learn to maintain balance, move forward, orient and steer and so discover an ever-expanding environment (for a review, see Adolph, & Berger, 2015). The present study addresses the development of cycling, a further progression in the development of locomotion that has been largely overseen in the literature, notwithstanding there being arguments to consider it as a foundational skill (Hulteen et al., 2018; Kavanagh et al., 2020). Foundational skills refer to movement skills that underpin lifelong engagement in physical activity, including the fundamental movement skills (e.g., running and throwing) and other important skills, such as cycling and swimming (Hulteen et al., 2018). Accordingly, in many countries, like for instance the Netherlands, where cycling has been considered a quasi-natural phenomenon (Stoffers, 2012), most children learn to bicycle at an early age, around the age of four when they start attending primary school, and are then gradually introduced into traffic. Unsurprisingly perhaps, primary school children are overrepresented in bicycle-related accidents; yet, most injuries do not result from collisions with other road-users but from single-bicycle crashes, suggesting (poor) cycling skills as a cause for accidents (e.g., Hansen et al., 2005; see also Schepers & Brinker, 2011).

Cycling is a complex locomotor skill that requires a child to learn to mount, balance, pedal, steer, break and dismount (Briem et al., 2004; Zeuwts et al., 2016, 2020). To support learning to cycle, parents typically provide children with a constrained or modified bicycle that simplifies the requirements for control and learning compared with regular bikes. Traditionally, at least in the Netherlands, a bicycle with two training wheels at the side of the rear wheel is used (Figure 1). The training wheels simplify cycling by temporarily reducing the number of degrees of freedom that need to be controlled, diminishing the necessity for children to hold the bicycle upright and thus actively maintain balance and allowing them to master pedalling and steering first. In fact, the training wheels allow children to strongly lean to one side without adverse consequences. Accordingly, Cain et al. (2012) suggested that on bicycles with training wheels children may not learn to maintain balance by steering in the direction of the lean as is required on regular unsupported bicycles. Only after the side wheels are removed, and often with initial support by parents, children learn to hold the bicycle upright and maintain balance while pedalling. More recently, a different modified training bicycle has become increasingly popular. This so-called balance or runner bike has no pedals (and no added side wheels) and is propelled by walking or running (Becker & Jenny, 2017; Figure 1). Rather than pedalling, the initial emphasis is on learning



FIGURE 1 A balance or runner bicycle (left) and a bicycle with training or support wheels (right)

### Statement of contribution

#### *What is already known about this subject?*

- Cycling is a foundational skill, which underpins lifelong engagement in physical activity.
- Research into the development of independent cycling is largely restricted to improvements in motor, perceptual, cognitive and behavioural abilities after the children have mastered independent or unsupported cycling.

#### *What the present study adds?*

- Practising on balance bikes results in earlier onset of independent cycling than practising on bikes with training wheels.
- The advantage of balance bicycles is likely caused by the balance bicycle more actively challenging postural control.
- Parents with tertiary education more often provide their children with a balance bike than parents with lower educational backgrounds.

to hold the bicycle upright and steer (Kavanagh et al., 2020). Once a child can actively maintain an upright orientation with the bicycle and navigate in the environment, a bicycle with pedals is provided (or the pedals are added) to then accomplish propulsion by pedalling, presumably requiring no or only little support by adults.

The current study investigates whether the type of training bicycle (i.e., a balance bicycle or a bicycle with training wheels) affects the age of onset of independent cycling on a regular bicycle without the support of side wheels and/or parents. The developmental time-course from age of onset of practice to age of onset of independent cycling may vary as the two types of training bicycles set different requirements for maintaining an upright posture. Additionally, it may be that the age at which children are provided with either bicycle or start practising differs (anecdotally, affluent families sometimes introduce wooden balance bicycles in home at a very young age). This is both of practical, as mentioned above, and theoretical relevance. Research to date has specifically focussed on the development of cycling skills once children have mastered independent or unsupported cycling (for a recent overview, see Zeuwts et al., 2020). As far as we are aware, there are no studies examining how young children acquire the skill to bicycle without support. Clearly, a necessary achievement for the child in learning to bicycle is the ability to maintain an upright orientation while sitting and propelling the bicycle (Kavanagh et al., 2020). In other words, like other modes of locomotion, cycling is embedded within postural control. In fact, learning to actively maintain orientation relative to the environment (i.e., controlling posture) is considered an integral part in the development of action (Witherington et al., 2002). For example, Assaiante et al. (2000) argued that anticipatory postural adjustments are immediately present in newly walking children. They showed that the emergence of independent walking was associated, albeit infrequently, with children producing postural responses in preparation for and prior to the stepping movement, such as tilting the pelvis sideward and shifting the body weight towards the stance leg (see also Ivanenko et al., 2005). In other words, in learning to walk, and presumably for learning other forms of locomotion, children must learn to make anticipatory postural adjustments to counter the imbalances caused by the moving body. As such, the development of locomotion and other actions is preconditioned upon and inseparable from the development of posture (Bernstein, 1996; Reed, 1989; Savelsbergh & van der Kamp, 1993).

The two modified bicycles used for children contrast in their requirement for active postural control. A bicycle with training wheels allows a child to locomote with little need to actively hold the bicycle and themselves upright. Consequently, the accumulated experience is with fewer anticipatory postural adjustments through coordinated shifts in body weight and steering (Cain et al., 2012). Moreover, if anything, children may get used to heavily lean over to one side, a posture that would certainly result

in a fall once the training wheels are removed. A balance bicycle, by contrast, immediately provides the child experience in actively maintaining an upright orientation of the bicycle while moving forward (Kavanagh et al., 2020), allowing early task-specific linkages of anticipatory postural adjustments and steering. Consequently, we hypothesize that a balance bicycle is conducive for learning to cycle independently at a younger age compared with bicycles with training wheels. This early age of onset is thought to originate from a shorter practice period as the balance bicycle increases demands for active anticipatory postural control. Additionally, the age at which children are provided with either bicycle may also differ (for various socio-economic reasons) and potentially affect the development of independent cycling, if indeed, the young child is *ready* or capable to profit from an early start of practice (Anderson et al., 2012).

The aim of the current study was to determine if the type of training bicycle affects the developmental time-course of cycling independently. To this end, parents of 4- to 6-year-olds filled in a questionnaire regarding their child's bicycling history, including information regarding the type of training bicycle. We then assessed if, as implied by our considerations on the requirements for active balancing, a balance bicycle does indeed result in earlier independent cycling, and whether this is in addition to differences in the age of onset of practice, if any.

## METHOD

### Participants

A total of 173 parents of children between 4 and 6 years of age from the first two levels of primary school (age  $M = 5.4$  years,  $SD = 0.8$  years; 77 girls) participated in the study and completed a custom-made questionnaire concerning cycling development. Parents were recruited through primary schools ( $n = 104$ ) and online through social media feeds of a local traffic education organization (i.e., Verkeersplein Amsterdam;  $n = 69$ ). Twenty-four schools located in the five biggest cities of the Netherlands were contacted, of which six schools participated. Two schools were in Utrecht ( $n = 28$ ), two in Amsterdam ( $n = 36$ ), one in Rotterdam ( $n = 17$ ) and one in Den Haag ( $n = 16$ ). Two schools were in neighbourhoods with low social economic status (SES) according to Statistics Netherlands (Centraal Bureau voor de Statistiek, 2020).

Of the 173 questionnaires, seven were excluded due to incomplete data. For each child, the highest education level of the parents was asked, which served as an approximation for SES (Sirin, 2005). Three levels were distinguished, namely, primary education (i.e., primary school until 12 years of age, or none), secondary education (i.e., secondary or vocational school until 18 years) and tertiary education (i.e., applied university and higher, above 18 years of age). Ethical approval was obtained from the local university's Ethics Committee (VCWE-S-19-00100). Parents provided informed consent before filling in the questionnaire.

### Questionnaire

Parents were asked to fill in a custom-made questionnaire regarding their children's cycling history. The questions were adopted from parental questionnaires on bicycling previously used by Ducheyne et al. (2012) and Zeuwts et al. (2016). The articulation of the questions was analogous to items of the validated Developmental History Questionnaire for Athletes (Hopwood, 2013). To assure clarity of questions, five adult volunteers completed an earlier version and based on their feedback, adjustments were made in the structure of the questionnaire and the wording of the questions. Two of the volunteers performed a final review. The first half of the questionnaire addressed the developmental milestones in cycling, including the age at which the child started to practise, the type of training bicycle they (had) used, if

any (e.g., training wheels and/or balance bicycle), and the age at which the children started to bicycle independently, if at all. Ages were asked in years and months. Parents were instructed to consult diaries and/or photo albums to verify their answers (Hopwood, 2013). The second part of the questionnaire included general demographic information, including the child's age and gender, and the parents' highest education level.

## Procedure

An information letter and the questionnaire, both written in English and Dutch, were distributed among the parents via children's primary school teachers in print and/or *online* using Qualtrics (Qualtrics). The parents recruited through the local traffic education organization received the questionnaire *online* only. Parents completed either the hard copy or the *online* version of the questionnaire. Printed versions were handed in at the school, while the online version was directly submitted to the researchers' database.

## Data analysis and statistics

Based on the questionnaire, we first categorized each child as a cyclist, in the case that they were able to ride a regular bicycle with pedals independently, that is, without support of side wheels and/or parents; or as non-cyclist, in the case that they were not (yet) capable of independent cycling. We also determined for each child what bicycle(s) they (had) used to practise cycling, distinguishing between the balance training bicycle, the training bicycle with training wheels, a combination of these, or only a regular bicycle. Next, the youngest age at which children made use of one of the bicycles was defined as the age of onset of practice. The age of onset of independent cycling was defined as the age at which children were able to ride a regular bicycle with pedals without support of side wheels and/or parents. Finally, practice duration was the time between the age of onset of practice and the age of onset of independent cycling. If, however, children were non-cyclists, practice duration was defined as the time between the onset of practice and the time of completing the questionnaire. Note, that the latter underestimates the eventual practice duration.

Mann–Whitney  $U$  tests were used to compare cyclists and non-cyclists for current age, age of onset of practice, and practice duration, while Fisher-Freeman-Halton tests were used to compare if cyclists and non-cyclists (had) used different types of training bicycles and to assess if parents had different educational background. Next, we focussed analyses on the cyclists only. Kruskal–Wallis analyses were used to compare the ages of onset of practice, the ages of onset of independent cycling, and practice duration between children that had used different types of training bicycles (i.e., balance bicycle, bicycle with training wheels, a combination, or a regular bicycle only). In addition, a Fisher-Freeman-Halton test was run to examine differences in parents' educational background between children grouped according to the type of training bicycle. Non-parametric tests were used because assumptions of normality (as indicated by Shapiro-Wilks tests) and/or equal variance were violated. Finally, a two-step hierarchical regression analysis was conducted to predict the age of onset of independent cycling. In the first step, we determined whether the age of onset of practice predicted the age of onset of independent cycling, while in the second step, the type of training bicycle was added to the model. Finally, effect size  $r$  was calculated for the Mann–Whitney  $U$  tests with  $r \geq .1$  and  $\leq .3$  interpreted as small,  $r$  and  $r \geq .3$  and  $\leq .5$  as medium, and if  $r \geq .5$  as large (Cohen, 1992). For the Fisher-Freeman-Halton tests, we calculated Cramer's  $V$  ( $\phi_c$ ), which were interpreted as small when  $\phi_c \geq .06$  and  $\leq .17$ , medium if  $\phi_c \geq .17$  and  $\leq .25$ , and as large when  $\phi_c \geq .25$  (Cohen, 1988). Finally, Cohen's  $f^2$  was determined for each step of the hierarchical regression analysis and interpreted as small when  $f^2 \geq .02$  and  $\leq .15$ , medium if  $f^2 \geq .15$  and  $\leq .35$ , and as large for  $f^2 \geq .35$  (Cohen, 1988).

## RESULTS

### Comparing non-cyclists and cyclists

85% ( $n = 142$ ) of the parents indicated that their child could cycle independently, while 15% ( $n = 24$ ) indicated that their child could not cycle on a regular bicycle without support. As can be seen from Table 1, the cyclists were significantly older than the non-cyclists,  $U(1) = 1001, p = .001, r = .25$ . Also, the type of training bicycle distinguished the two groups. Compared with the non-cyclists, more cyclists had only practised on a balance bicycle (i.e., 8% vs. 35%, respectively) and fewer had only used a bicycle with training wheels (i.e., 63% vs. 20%). Indeed, a Fisher-Freeman-Halton test confirmed that cyclists and non-cyclists used different types of training bicycles,  $\chi^2(3) = 17.30, p < .01, \phi_c = .35$ . In addition, the cyclists had started practising at a significantly younger age than the non-cyclists,  $U(1) = 967, p = .001, r = .26$ . Yet, practice duration was shorter for cyclists compared with non-cyclists,  $U(1) = 1161, p = .012, r = .19$ . Finally, it was found that parents' educational background differed between the two groups. Among the non-cyclists, less than half of the parents had tertiary education, while among the cyclists, this amounted to almost three quarters (i.e., 38% vs. 73%). This difference in parental background was confirmed significant using a Fisher-Freeman-Halton test,  $\chi^2(2) = 14.42, p = 0.001, \phi_c = .32$ .

### Comparing type of practice bicycle among cyclists

As reported above, among the cyclists four groups were discerned according to the type of training bicycle they had used (Table 2). Children who first practised using a balance bicycle (i.e., including the combination group that later proceeded with training wheels) started to do so at younger age as children who first practised on a bicycle with training wheels. Kruskal–Wallis test confirmed a significant main effect of group for age of onset of practice,  $\chi^2(3) = 73.0, p < .001$ . Post hoc analyses indicated that the balance bicycle and combination groups had earlier onset compared with the bicycle with training wheels' group, that in turn had an earlier onset as the regular bicycle group. The balance bicycle only and combination groups did not differ. In addition, Kruskal–Wallis test showed a significant main effect of group for the age of onset of cycling independently,  $\chi^2(3) = 24.8, p < .001$ . Post hoc analysis indicated that the balance bicycle group cycled independently at a younger age compared with all the other groups. A final Kruskal–Wallis test for practice duration revealed a significant main effect of group,

TABLE 1 Characteristics of cyclists and non-cyclists

	Cyclists ( $n = 142$ )	Non-cyclists ( $n = 24$ )
Current age (years $\pm$ SD)	5.4 $\pm$ 0.9	4.9 $\pm$ 0.5
Age of onset practising (years $\pm$ SD)	2.5 $\pm$ 0.8	3.0 $\pm$ 0.8
Age of onset independent cycling (years $\pm$ SD)	4.0 $\pm$ 0.8	–
Practice duration (years $\pm$ SD)	1.5 $\pm$ 0.8	1.9 $\pm$ 0.8
Type of training bicycle ( $N, \%$ )		
Balance bicycle	50 (30%)	2 (1%)
Bicycle with training wheels	29 (17%)	15 (9%)
Combination	57 (34%)	7 (4%)
Regular bicycle	6 (3%)	0 (0%)
Educational level parents ( $N, \%$ )		
Primary education	21 (13%)	12 (7%)
Secondary education	17 (10%)	3 (2%)
Tertiary education	104 (63%)	9 (5%)



TABLE 2 Comparing cyclists as a function of the type of training bicycle

	Balance bicycle ( <i>n</i> = 52)	Training wheels ( <i>n</i> = 44)	Combination ( <i>n</i> = 64)	Regular bicycle ( <i>n</i> = 6)
Age of onset practising (years ± SD)	2.1 ± 0.5	3.2 ± 0.7	2.2 ± 0.5	4.5 ± 1.1
Age of onset independent cycling (years ± SD)	3.5 ± 0.6	4.5 ± 0.9	4.0 ± 0.7	4.5 ± 1.3
Practice duration (years ± SD)	1.4 ± 0.5	1.3 ± 0.9	1.8 ± 0.8	0.0 ± 0.4
Educational level parents ( <i>N</i> )				
Primary education	3	19	8	3
Secondary education	2	4	13	1
Tertiary education	47	21	43	2

$\chi^2(3) = 29.6, p < .001$ . Post hoc comparisons between groups showed that the combination and regular bicycle groups showed significantly longer and shorter practice durations, respectively, than the other groups. However, practice duration did not differ between the balance bicycle and the training wheel group ( $p < .05$ ). Finally, nearly all the parents of the balance bicycle group had received tertiary education (i.e., 90%), while amongst the training wheel and regular bicycle groups this was only half of the parents (i.e., 48% and 50%, respectively) with the other half mostly having received primary education (i.e., 43% and 50%). Parents from the combination group also had primarily received higher education, with over half of the parents (i.e., 67%) having tertiary education, while percentages of parents with secondary and primary education were similar (20% vs. 13%). The different education levels across groups were confirmed significant by a Fisher-Freeman-Halton test,  $\chi^2(6) = 34.4, p < .001, \phi_c = .33$ .

Finally, Table 3 summarizes the results of the hierarchical regression analysis, which examined if age of cycling independently was predicted by age of onset of practice in the first step and type of training bicycle in the second step. In addition, it was decided to include an additional third step concerning parental education level, since groups were observed to differ in this regard. For type of training bicycle and education level dummy coding was used. The assumptions of homoscedasticity, error-independence (i.e., Durbin–Watson = 1.637, which is lower as the critical value of 1.693 with 150 respondents and five predictors), multicollinearity (i.e., VIF-values <4.0, tolerance >0.2), and normal distribution of errors were verified before conducting the analysis. In the first step, the age of onset of practising was found to significantly predict the age of onset of independent cycling,  $F(1, 140) = 21.3, p < .001, f^2 = .32$ . For each year, a child started practising later, nearly half a year ( $B = 0.55, p < .001$ ) must be added to predict the age of onset of independent cycling. In the second step, adding the type of training bicycle resulted in a significant model,  $F(3, 138) = 27.2, p < .001, f^2 = .45$ , with a significantly improved model fit,  $\Delta R^2 = .113, p < .001$ . The analysis shows that the balance bicycle group cycled independently almost half a year earlier ( $B = .42, p < .05$ ) compared with the training wheels and the combination group ( $B = .45, p < .001$ ). Adding parental education level to the model in the third step further improved the model fit,  $\Delta R^2 = .031, p = .046$ , to an overall significant model,  $F(5, 136) = 14.0, p < .001, f^2 = .51$ . Yet, the comparison of tertiary education with secondary ( $p = .052$ ) and primary education variables ( $p = .06$ ) did not enter the final model.

## DISCUSSION

Research towards the development of locomotor activities after 2 years of age is scarce. In cycling, studies are limited to assessing the development of various cycling skills in older children who have already managed independent cycling (Zeuwts et al., 2020); this work does not address how younger children or toddlers learn to cycle independently. Hence, we conducted a retrospective study to assess how practice

TABLE 3 Hierarchical regression model with age of independent cycling as dependent variable

Dependent variable	Age of independent cycling			$R^2$	$\Delta R^2$
	<i>B</i>	[95% CI]	<i>P</i>		
Step 1 (age of onset of practising)				.242 ( $p < .001$ )	
Constant	2.62				
Age of onset of practising	.55	[0.39, 0.72]	.000		
Step 2 (type of practice bicycle)				.309 ( $p < .001$ )	.066 ( $p < .001$ )
Constant	2.54				
Age of onset of practising	.47	[0.27, 0.67]	.000		
Group (balance bicycle vs. training wheels)	.42	[0.05, 0.79]	.027		
Group (balance bicycle vs. combination)	.45	[0.20, 0.70]	.001		
Step 3 (education level parents)				.339 ( $p < .001$ )	.031 ( $p < .05$ )
Constant	2.44				
Age of onset of practising	.53	[0.33, 0.74]	.000		
Group (balance bicycle vs. training wheels)	.45	[0.09, 0.82]	.015		
Group (balance bicycle vs. combination)	.50	[0.25, 0.76]	.000		
Education (tertiary vs. secondary)	-.35	[-0.71, 0.00]	.052		
Education (tertiary vs. primary)	-.34	[-0.79, -0.06]	.060		

history affects the early development of cycling. It was examined if practising on a balance bicycle promotes the development of independent cycling compared with practising on a bicycle with training wheels. This hypothesis was grounded in considerations that the development of locomotion is typically preconditioned upon and inseparable from the development of posture (Bernstein, 1996; Reed, 1989). In this respect, it is pertinent that while balance bicycles challenge a child to learn to actively hold the bicycle upright and maintain balance while riding, bicycles with training wheels critically reduce these postural requirements (Cain et al., 2012; Kavanagh et al., 2020). The findings are largely in line with this hypothesis. A balance bicycle resulted in children being able to cycle independently at a younger age compared with practising with a bicycle with training wheels (or a combination of both bicycles), and this acceleration was in addition to the balance bicycle being provided at a younger age thus allowing an early onset of practice.

The children who had solely used a balance bicycle were the first to bicycle independently, but importantly, they also had started practising at a younger age. They may thus have accumulated more experience at a particular age. However, the age of onset of practice did not uniquely explain the earlier age of independent cycling, as children from the combined group, who had used both a balance bicycle and a bicycle with training wheels, showed the same age of onset practising, but achieved independent cycling at a later age than children who used a balance bicycle only. This was confirmed by the hierarchical regression analysis that revealed a significant contribution of type of training bicycle, independent of and in addition to the age of onset of practising. These findings indicate that achieving independent cycling is not only due to accumulated practice experience but also to the type of practice that the children undergo. This is further supported by the observation that among the children who had achieved independent cycling, the balance bicycle was used most often as a training bicycle, while among the non-cyclist, the bicycle with training wheels had the highest incidence. We posit that the balance bicycle promotes independent cycling especially because it requires children to actively maintain an upright orientation by coordinating body lean and steering (Cain et al., 2012; Kavanagh et al., 2020). Obviously, also the children in the combination group initially accumulated this experience by first using a balance



bicycle, but this requirement for actively maintaining an upright orientation was removed when switching to a bicycle with training wheels. In fact, maintaining balance is for the most part outsourced to the supporting training wheels, which may upset any previously learned anticipatory postural adjustments to imbalances or steering. Consequently, the switching from a balance bicycle to a bicycle with training wheels slowed down the development of independent cycling.

Next to the type of training bicycle, the age of onset of practice predicted the age of independent cycling. In this respect, it is pertinent that children are provided with a balance bicycle at a younger age than with a bicycle with training wheels. Interestingly, perusal of advertisements in web shops (e.g., Amazon.com and Bol.com) suggests that the balance bicycle is targeted at younger children (i.e., around 2 years of age) than bicycles with training wheels. Presumably, therefore, parents may purchase balance bicycles at a younger age than bicycles with training wheels. A younger age of onset of practising allows for a younger age at which the critical amount of experience is accrued that is needed to achieve independent cycling on a regular bicycle. A further point in case is that cyclists started practising 5 months earlier than the non-cyclists. Yet, we also found that when starting at an older age, children needed less practice time to cycle independently, suggesting that the younger children did profit less from the accumulated experience. This been said, for future research, it is critically important to also determine the factual hours spent for practising (or alternatively the metres travelled), because an earlier possession of the training bicycle not necessarily implies that more hours are spent with the bicycle (cf. Hansen et al., 2005; Zeuwts et al., 2016; see also Ericsson et al., 1993).

Also, socio-economic constraints need consideration. The higher educational background of the parents of the cyclists compared with the parents of the non-cyclists points in this direction. That is, children are raised in diverse (socio-cultural) environments that afford different opportunities engaging in and valuing bicycling (Bronfenbrenner, 1979; Heft, 2001; Rietveld & Kiverstein, 2014). Parents with higher education background typically have more financial resources to purchase (multiple) practice bicycles, while parents with lower education may not prioritize purchasing a single bicycle, and, if they have a migration background, may also value bicycling differently than native Dutch parents (Ferreira et al., 2018; Flóres et al., 2019). We may therefore speculate that parents with higher education more often purchase a balance bicycle at a younger age (e.g., on their child's second birthday), and at a later age (possibly around the child's fourth birthday, when children start attending primary school), buy a second, regular bicycle, while parents with lower education might decide to buy only a regular bicycle with training wheels at that later age (i.e., many bicycles with training wheels allow removal of the wheels turning it into a regular bicycle).

Yet, despite the observed group differences in parents' educational level, with balance bicycles being more frequently used among families with higher educational background, the results did not unambiguously show that parents' educational level significantly contributed to the prediction of age of independent cycling. In fact, if anything, the negative B-coefficients in the resulting regression model might suggest that children from less-educated parents are cycling independently earlier, which conflicts with previous reports that motor development is decreased in children of parents with lower education and/or socio-economic status (Ferreira et al., 2018). Yet, because the hierarchical regression was limited to the cyclists, and children from parents with lower educational background were overrepresented among the non-cyclists, we must await further research that more systematically assesses if and how parents' educational background and socio-economic status affects the development of cycling.

Finally, the present observations sit well with dynamical system theory, which holds that the development of locomotion (or actions in general) emerges from the non-linear interaction of multiple dynamic subsystems or constraints (Smith & Thelen, 2003; Thelen, 1989, 1995). Development does not exclusively originate from constraints that are internal to the developing individual but is as much shaped by task and environmental constraints (Newell, 1986; Orth et al., 2017). Small but critical changes in any constraint can cause the developing system to spontaneously reorganize into new stable actions, or regress to older less-adaptive actions. Accordingly, the development of cycling also involves non-linear interaction of multiple, changing constraints. Differences across individuals in practice history result in variations in the interactions between or (developmental) changes within the constraints as diverse as the subsystems for postural

control, propulsion and steering, the type of training bicycle available, and features of the child's physical and socio-cultural environment. From the perspective of cycling as a foundational skill, this would point researchers and practitioners towards identifying the constraint(s) that limit a child's development in cycling (Thelen & Ulrich, 1991). Importantly, such rate limiting constraint(s) likely vary considerably across individuals, and thus require different kind of interventions from motor remedial teaching in children with developmental coordination disorder, to making balance bicycles available at nursery schools, designing bicycle friendly playgrounds, or introducing parents to the local cycling culture.

## Limitations

As far as we are aware, this is the first study assessing how young children acquire the foundational skill of cycling independently. This comes with limitations, which need to be addressed in future work. First, there are concerns with using a questionnaire, especially given the risk of recall bias due to its retrospective and self-report nature. And although, presumably, parents are fairly reliable in reporting development milestones (especially when revisiting diaries and/or photo albums), it is important to verify the validity and reliability of the current questionnaire. In doing so, it is advised to go beyond estimations of age of onset of practising and independent cycling and additionally determine the number of hours that children had practised. In this respect, it would be important to conduct prospective longitudinal studies to verify the present findings, for example, by using odometers. A second limitation is that our recruitment procedures may have caused an over-representation of parents that value cycling more than average. Because we also did not screen for motor or other developmental disabilities, this may have resulted in lower prevalence of non-cyclists than in the overall Dutch population. Finally, it is important for future research to determine to what degree the current differences in development trajectory influence the further development of cycling, especially regarding skills like stopping and steering. Zeuwts et al. (2016) have shown that age of onset of independent cycling is a significant predictor of cycling skills among 7- to 11-years old, but it is unknown, if and for how long stopping skills differ between children who practised with a balance bicycle compared with children who learned to cycle independently via training wheels. Balance bicycles do not have a brake, and these children may be delayed in stopping skills and thus be more vulnerable. To this end, it is important to validate current cycling tests (Ducheyne et al., 2013) towards assessing cycling skills in younger, novice cyclists. In the context of cycling being a foundational skill (Hulsteen et al., 2018), it is important to examine whether, on longer timescales and in addition to other factors such as mentioned socio-economic background and the natural and built environment (Gao et al., 2018), the early developmental trajectory affects later participation in cycling activities (e.g., in sports, transportation and/or leisure).

## CONCLUSION

This study is the first to explore the early development of independent cycling, which in many societies is a foundational milestone for navigating the world outside home. The findings show that practising on a balance bicycle is associated with an earlier age of onset of practice and an earlier age of onset of independent cycling compared with practising on a bicycle with training wheels. We argue that the advantage of the balance bicycle arises because they challenge children more to actively maintain balance. In addition, indications were found that parental educational level influences the type of bicycle children are provided to practise with. Yet, further research is needed to clarify if and how parental educational background and/or socio-economic status also impacts the age of onset of independent cycling. Dynamic systems theory may provide an adequate framework for such a study.

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## CONFLICT OF INTEREST

All authors declare no conflict of interest.

## AUTHOR CONTRIBUTION

**Biko Blommenstein:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Writing – original draft; Writing – review & editing. **John van der Kamp:** Conceptualization; Formal analysis; Investigation; Methodology; Project administration; Supervision; Writing – original draft; Writing – review & editing.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in DataverseNL at <https://doi.org/10.34894/GIVKUK>.

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