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ABSTRACT

Introduction: Self-regulation of effort during exercise (i.e. pacing) is a determinant of exercise performance, which develops during childhood and adolescence. Yet, the various aspects of pacing under development, such as the capability to use task experience and retain the task goal in the presence of other competitors, have remained relatively unexplored. **Methods:** 9 adolescents (14.9 ± 2.1 years old) and 14 adults (24.2 ± 3.2 years old) completed four 4-km cycling trials in a well-controlled laboratory setting. After one familiarization visit, trials were performed in random order: alone, with the goal to finish the trial as fast as possible (AloneTime), with a competitor and the same goal (CompTime), or with a competitor and the goal to finish first (CompFirst). Within each age group, repeated measurement ANOVAs ($p<0.05$) examined the differences in the estimated task duration, pacing behavior (distribution of mean power output per 500m) and performance (finish time) between visits (4) or conditions (3). **Results:** In contrast to adults ($p<0.05$, $\eta^2p>0.20$), adolescents did not exhibit a change in estimation of task duration, pacing behavior or performance over repeated visits ($p>0.05$, $\eta^2p<0.10$). Adolescents altered their pacing behavior in the presence of a competitor independent of the task goal (CompTime & CompFirst), whereas adults only demonstrated this alteration when instructed to finish first (CompFirst). **Conclusions:** Adolescents are still developing the capability to 1) use experience from previous tasks to adjust their pacing behavior, and 2) inhibit the intuitive action of engaging with the competitor to retain the more abstract task goal of finishing the trial as fast as possible. These findings establish novel experimental evidence for the underpinnings of pacing behavior development.

Key Words: ACQUISITION, LEARNING, ADOLESCENCE, EXERCISE, CYCLING, OPPONENT

INTRODUCTION

A decisive factor for success in sports is the athletes' capability to match the distribution of their available energy to the task demands (1). Before and during exercise, individuals continuously decide whether to increase, decrease or maintain the current level of effort, in order to reach the task goal (2). This goal-directed decision-making process regarding the self-regulation of effort distribution is termed pacing (2-4). The overall outcome of this process has been termed the individual's pacing behavior (5) and is generally quantified by expressing a measure of effort over time (1). Following Newell's constraints-led approach (6), the multitude of interacting factors that influence an individual's pacing behavior can broadly be categorized as the task (e.g. task duration (7)), the environment (e.g. behavior of competitors (8)) and the individual (e.g. previous experience (5)). Focusing on the influence of the individual, a series of longitudinal studies established that pacing behavior is not innate, but rather develops during childhood and adolescence (9-11). As a result, children and adolescents experience difficulty in adopting a pacing behavior which best suits the task demands (including both task characteristics and environmental factors) (5, 12). Suboptimal pacing behavior could have negative implications for competition, but also for training (e.g. misinterpreting training dose) (13). Long-term misdistribution of effort could decrease the individuals' feeling of competence and enjoyment during exercise and contribute to overexertion, injury and drop-out of sports and exercise (5, 14). A better understanding of the differences in pacing behavior between adolescents and adults could expose the mechanisms underpinning pacing behavior development and provide a basis for the design of interventions aimed at aiding the self-regulation of effort distribution in children and adolescents (4, 5).

A multitude of studies has established that adults engage in a cyclical process in which previous experience is used to plan an appropriate distribution of effort in a exercise bout of a similar nature (5, 15). For example, the estimation of an exercise task's duration is a key factor in the pre-exercise planning of a pacing strategy (16) which improves with task experience (17). However, Menting et al (2023) demonstrated that younger adolescents experience difficulty engaging in meta-cognitive processes before and during an exercise trial (18). Meta-cognitive processes involve thinking about one's own thoughts and actions, and include reflecting upon a task's characteristics and planning how to deal with the challenges of the task at hand (e.g. task duration) (4, 18). Additionally, various studies have revealed that children and adolescents do not change their pacing behavior over repeated bouts of a similar exercise task (19-21). It might therefore by hypothesized that the capability to use previous experience to inform the planning of effort distribution in future iterations of a similar exercise task is an aspect of pacing that develops during adolescence. However, more rigorous testing, including a direct comparison with a control group of adults in a well-controlled laboratory environment, is needed to provide further evidence for this hypothesis.

Micklewight et al (2012) demonstrated that the development of pacing behavior is likely underpinned by cognitive development, more specifically the emergence of the ability to consider abstract, prospective thoughts (12). It was proposed that younger individuals struggle to engage in deliberative decision-making in which they have to make considerations about the abstract, hypothetical prospective consequences that result from the decisions they are making in the present (22). Menting et al (2023) demonstrated that younger adolescents are less accurate in formulating prospective thoughts about their own performance, such as estimating the time it would take to complete an exercise task, or engaging in tasks which require abstract thought, such as cycling at a set goal velocity without the help of external feedback (e.g. speed gauge)(18). It is suggested that children and adolescents engage more in intuitive decision-making, as it requires less cognitive effort and allows individuals to deal with complex situations by making decisions based on association and a small number of cues ("just keep up with the competitor")(22). Indeed, a study by Lambrick et al (2013) revealed that children's 800m running performance was negatively impacted by the presence of the competitors (20). The authors of that study speculated that the possibility of beating the other competitors might have overruled the abstract and prospective task goal of finishing the given distance in the fastest time possible. Unfortunately, previous studies investigating the pacing behavior of children or adolescents in the presence of competitors did not feature a control group of adults (20, 21). Furthermore, to determine whether younger individuals are more prone to engage with competitors as opposed to achieving an abstract and hypothetical task goal, a comparison should be made between trials with different task goals (e.g. finish the task as fast as possible vs. finish ahead of the competitor). In laboratory studies, adults performing cycling tasks with the goal of completing a given distance in the fastest time possible, adopted a fast-start followed by a relatively evenly distributed power output, and with a significant end-spurt (23, 24). When tasked with finishing the trial ahead of the competitor, the end-spurt became less pronounced as it no longer deemed to contribute to goal achievement, given that in most scenarios the participants were either too far ahead or too far behind the competitor (24). If younger individuals are indeed more prone to using intuitive decision-making, it would be expected that such as difference in pacing behavior would be absent in children and adolescents, as they are would intuitively engage with the competitor, regardless of whether the task goal was to beat the competitor or to complete the trial in the fastest time.

Although previous large-scale observational studies have been successful in demonstrating the development of pacing behavior during adolescence (9-11), questions remain regarding specific aspects of pacing under development during this period (4, 5). The current study aimed to experimentally investigate the influence of 1) repeated exposure to similar exercise tasks and 2) the presence of competitors, on the estimation of task duration, pacing behavior and performance of adolescents and adults performing a 4-km cycling trial, in a controlled laboratory environment. It was hypothesized that in comparison to adults 1) adolescents would experience more difficulty in adjusting their assessment of the task duration and their pacing behavior over repeated iterations of a similar exercise task, and 2) adolescents would demonstrate a more intuitive pacing behavior aimed at finishing ahead of the competitor, regardless whether this is the task goal.

METHODS

Participants

Nine adolescents (14.9 ± 2.1 years old, 22% female, height: 167.9 ± 9.7 cm, body mass: 66.0 ± 9.2 kg) and fourteen adults (24.2 ± 3.2 years old, 36% female, height: 171.9 ± 8.6 cm, body mass: 72.7 ± 13.5 kg) participated in the study. All participants were healthy (PAR-Q) (25) and moderately to highly active (IPAQ) (26). None of the participants had previous experience with cycling time trials, and none reported cycling on a regular basis for the six months prior to the start of the study. Before starting the study, written informed consent was obtained from the participants, and the parents or legal guardians if participants were under 18 years old. Participants were asked to refrain from any strenuous exercise and alcohol consumption in the preceding 24 hours, and from caffeine and food consumption, respectively, four and two hours before the start of the visit to the laboratory. The study was approved by the ethical committee of the local university (reference number: 15746) in accordance with the Declaration of Helsinki.

Experiment proceedings

Participants visited the laboratory a total of four times, with a minimum of one week and a maximum of two weeks between visits. Each visit was completed around the same time of the day (±2 hours) to minimize circadian variation. Each visit consisted of a warm-up and a 4-km cycling trial. The Velotron cycling ergometer was used for all cycling, measuring power output, time and distance covered (25Hz) (27). Using the Velotron 3D software, a straight 4-km track, including an avatar which represented the participant, was projected onto the wall in front of the ergometer. Before starting the 4-km cycling trial, the participant performed a warming-up consisting of seven minutes of cycling at 70% of the mean velocity achieved during a 4-km trial. During the first visit, this was based on sex and age-matched normative data from previous studies (adolescent male: 23.2 km/h, female 21.0 km/h; adult male: 26.0 km/h, female: 23.5 km/h) (21, 23, 28, 29). During the second, third and fourth visits, it was set individually for each participant, based on the 4-km trial of the first visit. During the 4-km trial in visit one, only the participants' avatar was visible and the participants received the instruction: "finish the 4-km cycling trial as fast as possible". During visits two, three and four, the participants performed the trial in any of three following conditions (in a randomized order): 1) only the participants' avatar was visible and the goal was to complete the task as fast as possible (AloneTime), 2) alongside the participants' avatar, a competitor avatar was visible and the goal was to complete the task as fast as possible (CompTime), or 3) alongside the participants' avatar, a competitor avatar was visible and the goal was to complete the task before the competitor (finish first: CompFirst). To accommodate for the increase in performance following familiarization (21), the competitor was individualized for each participant using 105% of their finish time during the first visit. Previous studies have suggested that 105% might be too fast (30), however this type of competitor does present participants with a clear moment of decision-making in the CompTime trial: do I keep following the competitor or do I focus on my own performance? As the competitors were constructed manually by the researcher, the finish time of the resulting competitors was 105.1% (±0.3%) of the participants. When asked, the participants were told the competitor was of a similar performance level as the participants. The competitor avatars were created to gradually increase velocity over the first 250m towards a mean velocity which then was constant until the end of the trial (31). When all instructions were given, participants were asked to provide an expected finish time for the 4-km cycling trial ("In what time do you think you will complete the trial? The trial is 4-km which equals 2.5 miles"). The estimation of task duration was calculated as the absolute percentage deviation between the predicted and actual finish time. As numerical feedback could impact participants' estimation of task duration throughout the four visits, no numerical feedback (i.e. finish time, power output, velocity, distance covered) was provided before, during or after the trials. The participants thought the rate of perceived exertion (RPE) was measured at random moments. In reality, the RPE was measured before the trial, during the trial at 1, 2 or 3-km (two were chosen at random for each trial), and immediately after completion, using the OMNI 0-10 cycling scale (32, 33). Trials were conducted at an ambient temperature between 19°C and 21°C.

Data analysis

The effect of repeated visits (4) or conditions (3) was investigated separately for adolescents and adults. As the assumption of normality was violated, Friedman's one-way analysis of variance by ranks was used to investigate the estimation of task duration between repeated visits or conditions. Performance was analyzed by using a set of one-way repeated measures ANOVA's, with mean power output and finish time as dependent variables and repeated visits or conditions as within-subject factors. On an individual basis, the finish time of the participant in the CompTime and CompFirst conditions was compared to the finish time of the competitor, in order to establish whether the participants finished the trial ahead of the competitor. To investigate pacing behavior, a set of two-way repeated measures ANOVA's was used, in which mean power output during each 500m segment was the dependent variable and repeated visits or conditions the within-subject factor. Additionally, a variable for end-spurt was defined as the percentage change in power output from the 3000-3500m to the 3500-4000m section. A set of one-way repeated measurement ANOVAs, using end-spurt as the dependent variable and repeated visits or conditions as within-subject factors, was performed. Linear regression models, using RPE as dependent variable and measurement point (start, 1-km, 2-km, 3-km, 4-km) as well as visit or condition as independent variables, were used to test the effect of visit or condition on RPE throughout the trial duration.

In all the above tests, a statistical significance of 0.05 was used. Furthermore, if a significant effect was found, a post-hoc analysis of a pairwise comparison with Bonferroni correction was used to differentiate between the visits or conditions, Cohen's d was used to report effect size (small: $d = 0.2$, medium: $d = 0.5$, large: $d < 0.8$). In the analysis of variance, if the assumption of sphericity was violated, the Greenhouse-Geisser correction was used, partial eta squared ($\eta 2p$) was used to report effect sizes (small: $\eta 2p = 0.01$, medium: $\eta 2p = 0.06$, large: $\eta 2p < 0.14$).

RESULTS

Mean (± standard deviation) values of measures for expected finish time, estimation of task duration, performance, and end-spurt, are presented in Table 1. The outcomes of the statistical tests are presented in Table 2, with the results of the post-hoc test in Table 1.

Repeated visits

Over the course of the repeated visits, the adolescents did not become more accurate in their estimation of task duration. The pacing behavior (Figure 1), end-spurt and performance (finish time and mean power output) of the adolescent group did not change over repeated visits. Contrary, over the repeated visits, the adult group gradually became more accurate in their estimation of task duration. Additionally, adults gradually altered their pacing behavior, by increasing their power output in the 1500-4000m section (Figure 1), yet there was no change in the end-spurt. The adults' finish time, but not mean power output, improved over repeated visits. The slope of RPE throughout the trial did not differ between repeated visits, for both adults ($t=0.78$, $p=0.44$) and adolescents ($t=1.60$, $p=0.11$) (Figure 2).

Conditions

Neither adolescents nor adults altered their estimation of task duration before the different conditions. The adolescents altered their pacing behavior between conditions, evidenced by a higher power output in sections 0-500m (CompTime) and 500-1000m (CompTime, CompFirst) compared to AloneTime (Figure 3). Furthermore, the adolescents exhibited a less pronounced end-spurt in CompTime and CompFirst compared to AloneTime. The adolescents performed best in the CompTime condition, achieving a 5.1% better finish time compared to AloneTime. Of the adolescent group, 44.4% finished ahead of the competitor in the CompTime condition and 22.2% in the CompFirst condition. The adult group did not exhibit a statistical difference in pacing behavior between conditions. However, the adult group adopted a 7.3% higher mean power output during the first 2000m of the CompFirst, compared to the AloneTime condition (Figure 3). Additionally, the adults adopted a less pronounced end-spurt during CompFirst, compared to AloneTime and CompTime. The adults exhibited the best finish time in CompFirst, completing the trial 1.9% faster compared to AloneTime or CompTime. In the CompTime and CompFirst conditions, respectively 35.7% and 50% of adult participants finished the trial ahead of the competitor. The slope of RPE throughout the trial did not differ between conditions, in both adolescents ($t=1.33$, $p=0.19$) and adults ($t=0.40$, $p=0.69$) (Figure 4).

DISCUSSION

To investigate the development of pacing behavior, the current study investigated the influence of 1) repeated task exposure and 2) the presence of competitors, on adolescents and adults performing a 4-km cycling trial in a well-controlled laboratory environment. When repeatedly exposed to a similar exercise task, the adults improved their accuracy in the estimation of task duration, adjusted their pacing behavior and improved their performance. In contrast, the adolescents provided with the same level of task experience, did not exhibit a change in their estimation of task duration, pacing behavior or performance. Using task experience to inform pacing behavior in future iterations of a similar exercise task, therefore, seems to be an aspect of pacing behavior which is under development during adolescence. Second, it was hypothesized that adolescents would demonstrate a pacing behavior aimed at finishing ahead of the competitor, regardless of whether this was the task goal. The adults only adjusted their pacing behavior when they were tasked with finishing ahead of the competitor (CompFirst). Yet, adolescents adjusted their pacing behavior in the presence of the competitor, both when the goal was to finish before the competitor (CompFirst) or to set the fastest time (CompTime). The adolescents, therefore, seem disposed to a more intuitive approach to their decision-making regarding effort distribution by focusing on the (virtual) competitor, whereas the adults are able to retain focus on the more abstract and prospective task goal of finishing the trial as fast as possible. The confirmation of both hypotheses provides novel experimental insights into the aspects of pacing behavior under development during adolescence.

Task experience

When individuals are faced with a new and unfamiliar exercise task, there is a need to select a fitting pacing behavior (5). Through exposure to similar exercise tasks, individuals are theorized to reassess task demands as well as recalibrate the match between the task demands and their performance capabilities (5). This allows them to adjust their pacing behavior and increase exercise performance in future iterations (5). Whereas evidence for this cyclical process has been consistently reported in the adult population (5, 15, 34), previous studies in children and adolescents demonstrated no adjustment of their pacing behavior through repeated task exposure (19-21). The current study was the first to test whether there was indeed a difference in the effect of task experience on the pacing behavior of adolescents and adults performing the same tasks in well-controlled laboratory conditions. The absence of change in pacing behavior over the repeated visits in the adolescent group confirms that adolescents need relatively more experience with a new exercise task to adjust their pacing behavior to match the task demands. These findings parallel previous studies which demonstrated that the rate at which individuals learn to differentiate what behavior is advantageous or disadvantageous, is linked to the development of the prefrontal cortex (35, 36). The adult participants needed a relatively low amount of trials to be able to determine what behavior resulted in a reward or punishment, adolescents needed considerably more trials and younger children did not seem to be able to recognize this relationship at all (35). Similarly, in the current study, the adults seem to be able to recognize that an adjustment in their pacing behavior might provide them with a reward (e.g. increased performance), whereas this process seems to occur at a slower rate in the adolescents. A potential explanation for the lack of adaptation could also be found in notion that younger individuals prefer a more intuitive approach to effort distribution ("I just go as fast as possible"), and therefore engage less in deliberate reflection upon the task characteristics and planning of the various ways to overcome the challenges posed by the task at hand (12, 22). In the current study, the adolescents, in contrast to the adults, were unable to improve their accuracy of the estimation of task duration over repeated visits. Menting et al (2023) demonstrated that the accuracy of the estimation of task duration improved throughout adolescence, and linked it to resulting differences in pacing behavior between adolescents and adults (18). The current results expand upon these findings by providing evidence that the capability to adjust the assessment of the task demands using task experience, also differs between adults and adolescents. It, therefore, seems that the meta-cognitive process of reflection upon one's own (pacing) behavior is an aspect of pacing behavior under development during adolescence.

Applying the findings of the current study more broadly, it was recently demonstrated that adolescent swimmers and speed skaters who eventually progressed towards the elite level in adulthood differentiated themselves by demonstrating a pacing behavior that better fits the task demands (9, 11). Likewise, studies have demonstrated that in adolescent athletes performing those same sports, the more successful athletes also score higher on measurements for self-reflection (37, 38). In light of the results of the current study, it could be hypothesized that these athletes' higher level of self-reflection provides them with an increased capability to recognize whether or not their pacing behavior optimally matches the task demands, and if they might need to adjust their pacing behavior to improve performance during future iterations of the task. These athletes might therefore be able to better adjust their pacing behavior to the task demands, even when provided with a similar amount of task experience as their peers. The higher capability of self-reflection could therefore be the reason why some athletes differentiate themselves from their less successful peers through their pacing behavior. Although potentially holding value for talent identification and development, further research is needed to further establish the hypothesized link between self-reflection and pacing behavior development in talented athletes.

Competitors and the task goal

The current study is the first to compare the effect of introducing a (virtual) competitor as well as the relation of this competitor to the task goal, between adolescents and adults. A contrast between the age groups occurred when the competitor was present, but the goal of the task was to finish the trial as fast as possible (CompTime). The pacing behavior of the adults in this condition is similar to when they were cycling alone (AloneTime). The adults likely realized early on that the competitor was too fast to keep up with, and deliberately focused on adopting a pacing behavior which would allow them to finish the task as fast as possible. Such a realization was likely not present in the adolescents, as this group demonstrated a pacing behavior more resembling the trial in which they were tasked with finishing ahead of the competitor (CompFirst), with a relatively higher power output during the initial section and a less pronounced end-spurt. Conform the hypothesis, adolescents intuitively set finishing ahead of the competitor as a primary goal, regardless of the instructions provided by the researcher (e.g. finish the trial as fast as possible). More evidence for this notion is provided by the finding that, in contrast to the adults, the adolescents finished the trial faster when they were instructed to finish the trial as fast as possible (CompTime), compared to when they were tasked with finishing ahead of the competitor (CompFirst). This observation is likely due to the notion that when the adolescents were unable to stay ahead of the competitor in the CompFirst condition, they felt like they had already failed the task goal, and considerable effort expenditure was therefore not needed (24). Yet, in the CompTime condition, even if it was not deemed possible to finish ahead of the competitor (i.e. the primary goal as set by the adolescents), it was still possible to cover the distance in the fastest possible time (i.e. the original goal as set by the researcher). A continuation of effort exertion was therefore still required, resulting in a relatively lower finish time in the CompTime condition. Collectively, these results provide experimental evidence for the view that adolescents are more inclined to engage with competitors, whereas adults are better able to retain the focus on achieving the task goal (5).

In explaining this age-related difference, it should be reiterated that the goal of finishing the task as fast as possible requires the participants to engage in self-regulation and deliberative decision-making including abstract and hypothetical considerations, as they need to make decisions in the present which determine their goal achievement in the future. This requires individuals to self-monitor and adapt their effort expenditure during exercise, a capability that is still developing during adolescence (4, 18). Contrary, trying to finish ahead of the competitor allows for more intuitive decision-making, as it encapsulates the complex task of self-regulating the distribution effort over the duration of the task into a more concise task ("just keep up with the competitor"). Intuitive decision-making uses relatively fewer cognitive resources, in comparison to deliberate decision-making (2, 39), and could therefore favored by individuals who possess a lower level of (meta-) cognitive functioning (14, 40). The finding of the current study that adolescents place engaging with the (virtual) competitor ahead of achieving the task goal provides experimental evidence to support this view.

In the current study, the adolescents' more intuitive approach to effort distribution, as afforded by the presence of the competitor, resulted in faster completion of the trial. Yet, this approach could also lead to sub-optimal performance, as previously demonstrated by Lambrick et al (2013) (20). It would, therefore, be valuable to familiarize athletes with the unique invitations for actions afforded by competitors (41). This could, for example, be done through the introduction of a competitive aspect in training exercises or participation in (lower level) competitions (41). Furthermore, it should be recognized that although differences between the age groups became evident, there was considerable variation in the response to the presence of the competitor in both age groups. One explanation for the variation in the adolescent group could be the due to range in age (12-17 years old), and the associated variation in cognitive development. Menting et al (2023) demonstrated that meta-cognitive processes related to pacing, such as reflection, planning, monitoring and adaption of effort distribution, differ within this age range (18). Additionally, the within-group variation could be explained by the notion that both the processes of pacing and the interaction with a competitor are complex, and multiple factors aside from age impact how an individual integrates the presence of a competitor into their pacing behavior (8). Factors such as the level of self-efficacy and mental fatiguability have been recognized to impact the interaction with competitors (24, 42). A combination of these factors could have influenced the reaction to the competitors in the current study, resulting in variation within both age groups.

Practical applications

The findings of the current study provide practitioners guidance for designing practice exercises to support the self-regulation of effort in children and adolescents. Making individuals aware of their pacing behavior and designing practice sessions to engage with this behavior seems to positively impact the acquisition process (43, 44). For example, Tijani et al (2021) demonstrated that providing adolescent swimmers with details about their pacing behavior and exercises based on their race pace, resulted in an adjustment of their pacing behavior and improved 400m freestyle performance (44). More generally, practitioners can also aid this process by using questions such as: “what worked well and/or did not work well for you in the last task?” or “what will you do differently next time?”, to engage children and adolescents in reflection upon their pacing behavior, stimulating them to find new ways to possibly adjust this behavior to better fit the task demands (45, 46).

Building upon this, the finding that adolescents are especially prone to engage with a (virtual) competitor could also be used to improve the acquisition of pacing behavior. In general, the presence of a competitor could increase motivation and the willingness to engage in sports and exercise (47), keeping individuals engaged in the acquisition process for longer. The presence of (virtual) competitors could allow individuals to explore actions that were not thought of as possible when exercising alone (43, 48). Yet, it should be pointed out that the acquisition process is (partly) facilitated by internal stimuli such as pain and fatigue experienced during the exercise task (5, 15). The attention given to these stimuli could be reduced through the inclusion of competitors (49). Practitioners should therefore be aware that an overreliance on competitor-induced variation could hamper the pacing skill acquisition process. In addition, an opposite form of competitor-induced variation is also valuable in sports like short-track speed skating, where athletes train and race with competitors (50). Coaches could explore the self-regulatory capabilities of these athletes by integrating training exercises where the athletes perform their competitive events alone. These exercises would thus force the athletes to explore the variation within their pacing behavior by shifting towards more deliberative decision-making regarding effort distribution, including monitoring and adapting of effort during exercise and reflection afterwards.

CONCLUSIONS

The current study demonstrated that, in contrast to adults, adolescents struggle to improve their accuracy in the estimation of task duration, and alter their pacing behavior or improve their performance over repeated tasks. Children and adolescents are therefore expected to need more task experience, feedback and instructions from the social environment (e.g. coaches, teachers, instructors) in order to adjust their pacing behavior in novel exercise tasks. Furthermore, in contrast to the adults, the adolescents altered their pacing behavior in the presence of a competitor, regardless of whether the goal of the task was to finish ahead of the competitor or to finish the task as fast as possible. Adolescents seemed to favor intuitive decision-making afforded by the competitor ("just keep up") over the more abstract and prospective notions related to the original task goal (i.e. finish the trial as fast as possible). Overall, the current study provides experimental evidence for the aspects of pacing behavior development during adolescence. Detailing these aspects provides a basis for the design of interventions aimed at supporting the self-regulation of effort distribution in children and adolescents.

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FIGURES LEGENDS

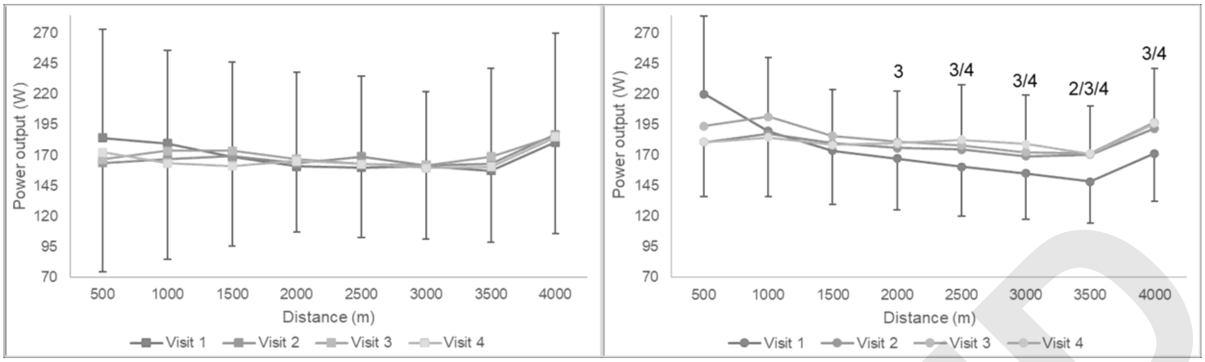
Figure 1. Pacing behavior of adolescents (squares, left) and adults (circles, right) over repeated visits expressed as power output over 500m sections. Difference between Visit 1 and Visit 2, Visit 3 or Visit 4 ($p<0.05$, $d>0.80$).

Figure 2. Rate of perceived exertion of adolescents (squares, left) and adults (circles, right) per section during repeated visits.

Figure 3. Pacing behavior of adolescents (squares, left) and adults (circles, right) in different conditions expressed as power output over 500m sections. Virtual competitor visualized by the dotted line. Difference between conditions: A = AloneTime, B = CompTime, C = CompFirst ($p<0.05$, $d>0.80$).

Figure 4. Rate of perceived exertion of adolescents (squares, left) and adults (circles, right) per section in different conditions.

Figure 1



270
245
220
195
170
145
120
95
70
Power output (W)
500
1000
1500
2000
2500
3000
3500
4000
Distance (m)
Visit 1
Visit 2
Visit 3
Visit 4
270
245
220
195
170
145
120
95
70
Power output (W)
3
3/4
3/4
2/3/4
3/4
500
1000
1500
2000
2500
3000
3500
4000
Distance (m)
Visit 1
Visit 2
Visit 3
Visit 4

Figure 2

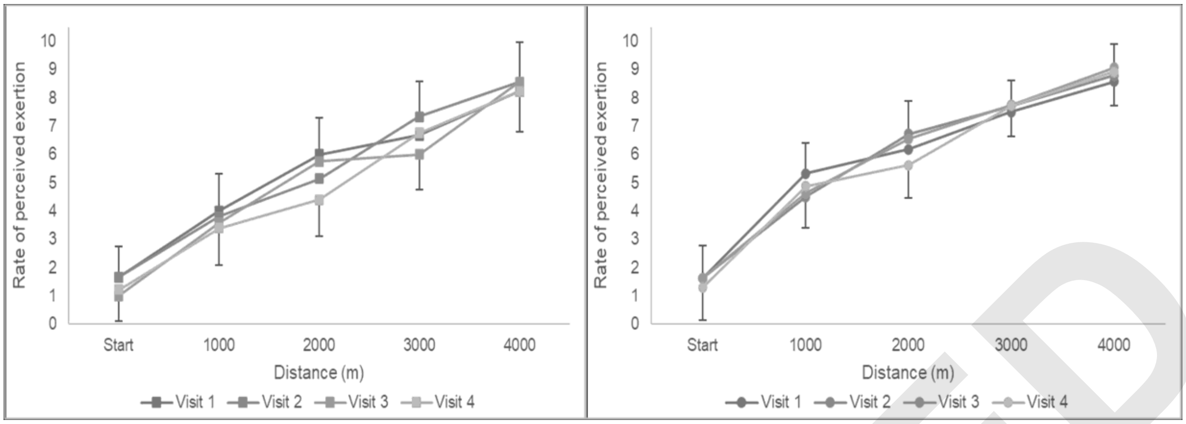
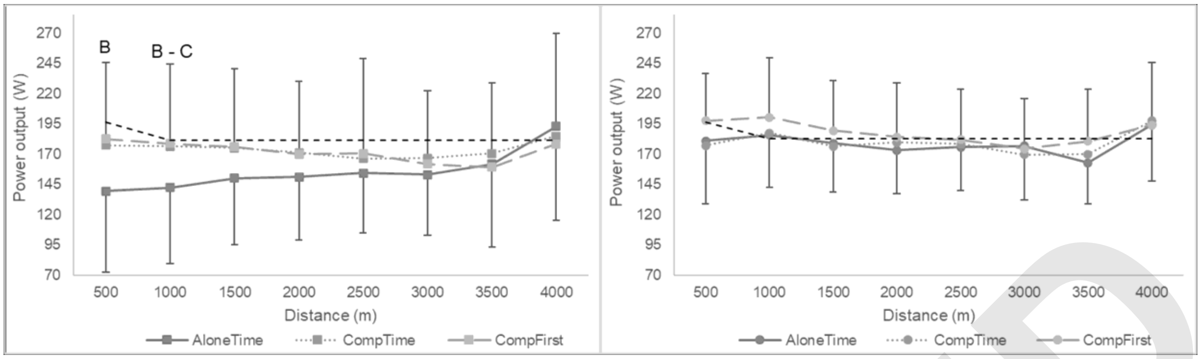

Rate of perceived exertion
10
9
8
7
6
5
4
3
2
1
0
Start
1000
2000
3000
4000
Distance (m)
Visit 1
Visit 2
Visit 3
Visit 4
Rate of perceived exertion
10
9
8
7
6
5
4
3
2
1
0
Start
1000
2000
3000
4000
Distance (m)
Visit 1
Visit 2
Visit 3
Visit 4

Figure 3


270
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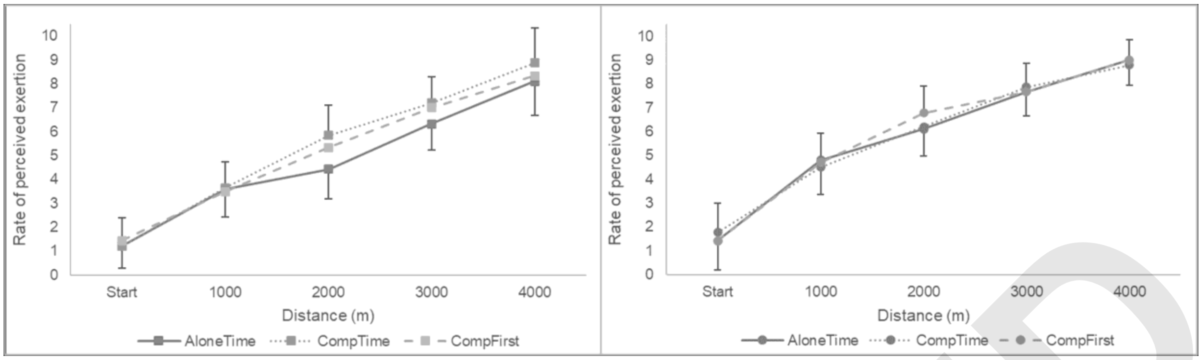
Power output (W)
B
B - C
500 1000 1500 2000 2500 3000 3500 4000
Distance (m)
AloneTime
CompTime
CompFirst
270
245
220
195
170
145
120
95
70
Power output (W)
500 1000 1500 2000 2500 3000 3500 4000
Distance (m)
AloneTime
CompTime
CompFirst

Figure 4



Rate of perceived exertion
10
9
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Start
1000
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Distance (m)
AloneTime
CompTime
CompFirst
Rate of perceived exertion
10
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6
5
4
3
2
1
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Start
1000
2000
3000
4000
Distance (m)
AloneTime
CompTime
CompFirst

		Power output (W)	Finish time (s)	Expected finish time (s)	Estimation of task duration (%)	End-spurt (%)
Adolescents	Visit 1	169.1 (±64.3)	492.9 (±84.8)	443.3 (±229.4)	34.2 (±29.1)	13.5 (±9.7)
	Visit 2	168.0 (±62.9)	489.3 (±74.7)	506.7 (±185.8)	22.8 (±24.6)[V3]	14.2 (±9.1)
	Visit 3	170.1 (±69.9)	497.1 (±98.3)	583.3 (±267.1)	44.4 (±26.1)[V2]	9.9 (±11.3)
	Visit 4	166.3 (±67.2)	502.7 (±97.0)	616.7 (±314.3)	44.9 (±35.2)	16.7 (±11.8)
	AloneTime	155.6 (±58.8)	509.7 (±91.6)[CompTime]	643.3 (±295.1)	43.7 (±37.7)	19.7 (±12.1)[CompTime, CompFirst]
	CompTime	175.8 (±64.0)	483.8 (±76.4)[AloneTime]	543.3 (±239.3)	38.5 (±27.9)	9.1 (±11.6)[AloneTime]
	CompFirst	169.9 (±73.5)	498.5 (±99.0)	520.0 (±240.5)	29.2 (±24.8)	11.7 (±7.3)[AloneTime]
Adults	Visit 1	173.4 (±38.9)	472.1 (±42.3)[V3]	537.9 (±267.0)	40.0 (±30.5)[V4]	15.9 (±11.8)
	Visit 2	178.9 (±40.5)	466.4 (±41.2)	520.5 (±194.3)	31.3 (±28.6)	13.4 (±12.6)
	Visit 3	185.3 (±37.7)	457.8 (±37.3)[V1]	510.0 (±179.2)	23.6 (±27.5)	15.3 (±16.8)
	Visit 4	181.8 (±37.1)	461.3 (±37.2)	465.0 (±123.8)	20.0 (±13.0)[V1]	15.3 (±11.5)
	AloneTime	178.6 (±34.8)	464.8 (±35.2)[CompFirst]	520.7 (±184.4)	29.1 (±24.4)	19.3 (±14.8)[CompFirst]
	CompTime	179.6 (±39.6)	464.7 (±41.7)[CompFirst]	471.3 (±129.1)	21.0 (±14.3)	16.9 (±13.8)[CompFirst]
	CompFirst	187.8 (±40.3)	456.0 (±38.5)[AloneTime, CompTime]	503.4 (±187.2)	24.4 (±32.9)	7.9 (±9.3)[AloneTime, CompTime]

[V1, V2, V3, V4] = significantly different from visits 1, 2, 3 or 4 (d>0.70). [AloneTime, CompTime, CompFirst] = significant difference from conditions: alone, set the fastest time (AloneTime), with a competitor, set the fastest time (CompTime), with a competitor, finish first (CompFirst) (d>0.60). The estimation of task duration = |(Expected finish time - Finish time/(Finish time))*100|.

Age group	Variable	Visits			Conditions		
		Statistics	Significance	Effect size	Statistics	Significance	Effect size
Adolescents	Power output (W)	$F_{3,24} = 0.07$	$p = 0.97$	$\eta^2p = 0.01$	$F_{2,16} = 3.09$	$p = 0.07$	$\eta^2p = 0.28$
	Finish time (s)	$F_{3,24} = 0.75$	$p = 0.54$	$\eta^2p = 0.09$	$F_{2,16} = 4.43$	$p < 0.05$	$\eta^2p = 0.36$
	Estimation of task duration (%)	$\chi^2_3 = 9.40$	$p < 0.05$		$\chi^2_2 = 0.90$	$p = 0.64$	
	Pacing behavior (power output per 500m)	$F_{3.22,25.73} = 0.69$	$p = 0.58$	$\eta^2p = 0.08$	$F_{2.67,21.5} = 3.63$	$p < 0.05$	$\eta^2p = 0.31$
	End-spurt (%)	$F_{3,24} = 0.90$	$p = 0.46$	$\eta^2p = 0.10$	$F_{2,16} = 5.68$	$p < 0.05$	$\eta^2p = 0.42$
	Rate of perceived exertion (RPE per 1-km)	$F_{12,203} = 0.94$	$p = 0.51$	$\eta^2p = 0.05$	$F_{8,152} = 0.45$	$p = 0.89$	$\eta^2p = 0.02$
Adults	Power output (W)	$F_{3,39} = 3.11$	$p = 0.12$	$\eta^2p = 0.14$	$F_{2,26} = 2.98$	$p = 0.07$	$\eta^2p = 0.19$
	Finish time (s)	$F_{3,39} = 3.90$	$p < 0.05$	$\eta^2p = 0.23$	$F_{2,26} = 3.76$	$p < 0.05$	$\eta^2p = 0.22$
	Estimation of task duration (%)	$\chi^2_3 = 10.87$	$p < 0.05$		$\chi^2_2 = 1.86$	$p = 0.40$	
	Pacing behavior (power output per 500m)	$F_{3.44,44.75} = 3.57$	$p < 0.05$	$\eta^2p = 0.22$	$F_{2.92,38.0} = 1.01$	$p = 0.40$	$\eta^2p = 0.07$
	End-spurt (%)	$F_{3,39} = 0.12$	$p = 0.95$	$\eta^2p = 0.01$	$F_{2,26} = 5.22$	$p < 0.05$	$\eta^2p = 0.29$
	Rate of perceived exertion (RPE per 1-km)	$F_{12,124} = 0.56$	$p = 0.87$	$\eta^2p = 0.05$	$F_{8,93} = 0.48$	$p = 0.87$	$\eta^2p = 0.04$