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Factors Affecting Cadence Choice During Submaximal Cycling and Cadence Influence on Performance

Ernst A. Hansen and Gerald Smith

Cadence choice during cycling has been of considerable interest among cyclists, coaches, and researchers for nearly 100 years. The present review examines and summarizes the current knowledge of factors affecting the freely chosen cadence during submaximal cycling and of the influence of cadence choice on performance. In addition, suggestions for future research are given along with scientifically based, practical recommendations for those involved in cycling. Within the past 10 years, a number of papers have been published that have brought novel insight into the subject. For example, under the influence of spinal central pattern generators, a robust innate voluntary motor rhythm has been suggested as the primary basis for freely chosen cadence in cycling. This might clarify the cadence paradox in which the freely chosen cadence during low-to-moderate submaximal cycling is considerably higher and thereby less economical than the energetically optimal cadence. A number of factors, including age, power output, and road gradient, have been shown to affect the choice of cadence to some extent. During high-intensity cycling, close to the maximal aerobic power output, cyclists choose an energetically economical cadence that is also favorable for performance. In contrast, the choice of a relatively high cadence during cycling at low-to-moderate intensity is uneconomical and could compromise performance during prolonged cycling.

Keywords: pedaling, pedal rate, rhythmic motor behavior

The choice of cadence during cycling has been a subject of intensive curiosity and debate for around a hundred years among cyclists, coaches, researchers, and others involved with the activity of cycling. And it still is being debated—perhaps more than ever. Multiple circumstances contributed to the development of such considerable interest and the following factors are merely two of many potential examples. First, cycling was at the beginning of the twentieth century one of the first professional sports, with great focus on performance as a natural consequence. Second, research within exercise physiology had at that time already revealed the fact that excessive energy expenditure could cause early exhaustion during prolonged submaximal exercise. As early as in 1913, Benedict and Cathcart

The authors are with the Department of Physical Performance, Norwegian School of Sport Sciences, Oslo, Norway.

reported that one of their subjects freely chose a cadence that was relatively high and energetically uneconomical.[1] It appears from their paper that the two exercise physiologists were quite surprised. Why would their subject, who was an expert cyclist in the form of a professional bicycle rider, waste energy by pedaling at a high cadence? Apparently, it is not imperative for cyclists to minimize the physiological responses of oxygen uptake and energy expenditure by choosing a particular, relatively low, cadence. Since then, it has been shown that, in addition to competitive cyclists,[2–4] children,[5] recreationally active adults,[6] and trained runners[4] all freely choose a relatively high cadence accompanied by a higher rate of oxygen uptake and energy expenditure than what could have been attained by simply pedaling slower but with higher gearing.

This phenomenon has been designated the cadence paradox.[7] The common understanding of the paradox has to do with the fact that despite investigations of a number of physiological and biomechanical variables, researchers have had difficulty in finding characteristics that are optimized at the freely chosen cadence or strongly correlated with the freely chosen cadence. Thus, as late as in 2007—almost a century after the work by Benedict and Cathcart (1913)[1]—it was stated that "the underlying reasons leading to the choice of a particular pedaling cadence (freely chosen cadence) in cyclists have yet not been clearly established".[8] Nevertheless, as the present review article will demonstrate, novel insight into the old mystery of cadence choice during submaximal cycling has emerged through recent research. This brief review will examine and summarize the current knowledge of cadence choice during submaximal cycling as well as the importance of cadence choice for performance.

The Base of Cadence Choice

In a review of fundamental factors affecting temporal patterns, Delcomyn (1980) summarized the most important connection: "Timing of the repetitive movements that constitute any rhythmic behavior is regulated by intrinsic properties of the central nervous system rather than by sensory feedback from moving parts of the body".[9] Subsequently, the term *central pattern generator* was introduced to refer to a functional network located in the spinal cord that generates the rhythm and shapes the pattern of the bursts of motoneurons. Whereas most investigations of central pattern generators have been conducted on animals, in recent years experiments have been conducted on humans with an overall main purpose of improving the incorporation of rhythmic movements in post-neurotrauma rehabilitation strategies. Even more recently, some research has focused on the importance of central pattern generators for the control of voluntary rhythmic movement behavior during exercise such as in pedaling.[10–12] For example, Zehr (2005) outlined a common core hypothesis that rhythmic motor patterns in human locomotion share common central neural control mechanisms and further suggested that these are enabled by presumed central pattern generators that regulate arm and leg movements during locomotion.[10] Subsequently, Sakamoto et al (2007) investigated how the coupling of arms and legs was coordinated during independent rhythmic movement of the arm and leg in pedaling.[11] Their study showed that leg cadence was not affected by voluntary changes in arm cadence. In contrast, arm cadence was altered when leg cadence was changed. These results suggest the existence of a robust control of leg cadence. Recently, Hansen and Ohnstad (2008) reported not only that freely chosen cadence was unaffected by increased loading on the cardiopulmonary system at constant mechanical loading and vice versa,[12] but also that the cadence was steady in a 12-week longitudinal perspective at the same time as it was highly individualistic. Taken together, the authors' interpretation was that the freely chosen cadence is primarily a robust innate voluntary motor rhythm, likely under primary influence of central pattern generators that again are minimally affected by factors internal and external to the cyclist during submaximal cycling.

Based on the hypothesis by Zehr (2005)[10] and the briefly described studies by Sakamoto et al (2007)[11] and Hansen and Ohnstad (2008),[12] it is less mysterious that oxygen uptake and energy expenditure are not minimized at the freely chosen cadence and that a considerable between-individual variation exists in freely chosen cadence whether individuals are recreationally active cyclists[6] or professional cyclists.[13] Instead, each individual's freely chosen cadence might be an outcome, or result, of the characteristics of that individual's central pattern generators involved during pedaling.

What might still appear peculiar is the fact that humans during walking[14] and running[15,16] freely choose a step cadence that results in a minimum energy expenditure. However, from an evolutionary point of view this is not particularly surprising. Consider that walking and running have been performed from the very beginning of human evolution whereas cycling has been performed for only a small fraction of that time.[17] The minimization of energy expenditure during unrestricted walking most likely has been a criterion for natural selection in human evolution because spared energy could then be used for other purposes, such as growth or reproduction, or for walking longer distances.[18] It appears reasonable that the freely chosen step cadence and the energetically optimal step cadence have evolved to similar points for walking and running, but a similar evolutionary development has not (yet) been seen for cadence during cycling at low-to-moderate intensity.

The present suggestion that central pattern generators form the base of the cadence choice is novel and probably requires more evidence from future investigations to be more strongly supported and generally accepted. Historically, other suggestions have been made on the basis of experimental results in an attempt to explain cadence choice. For example, it has been advocated that the high maximal peak crank power that is obtainable at relatively high cadences around 120 rpm should stimulate cyclists to pedal fast while, at the same time, an increasing negative muscle work at cadences above 90 rpm should stimulate cyclists to not exceed that moderate cadence.[19] Another related suggestion was that cyclists choose the cadence that results in a minimum muscle activation.[20] Unfortunately, neither of the latter two studies included the measurement of freely chosen cadence with their subjects. Rather this was assumed to be 90 rpm, or increasing with power output. Nor was the significance of the considerable variation between subjects in freely chosen cadence considered with respect to the hypotheses.

The main message from this section is that the freely chosen cadence during submaximal cycling has a highly individual and at the same time robust base, which is perhaps largely influenced by characteristics of central pattern generators

(Figure 1). This does not at all exclude the influence that factors internal and external to the cyclist under certain circumstances can have on the choice of cadence. The next section deals with such factors that have been reported to affect cycling cadence.

Factors Affecting Cadence Choice

Changing cadence during cycling has multiple consequences for the loading of the body and the perception by the brain. For example, muscle forces, the output of which can be measured indirectly at the pedal, stimulate the mechanoreceptors as well as affect the energy demand to which the cardiovascular and cardiorespiratory systems respond. It is thus obvious that, in addition to the already described robust base of the freely chosen cadence, there is also some supplementary influence on the cadence choice of factors internal and external to the cyclist during certain circumstances. Further, that the summed effect of these influences most likely is a compromise of maximizing and minimizing different physiological demands, responses, and sensory feedback.

Two research strategies have been frequently applied to gain better understanding of the choice of cadence. For example, factors external to the cyclist (eg, power output) have been changed during submaximal cycling while monitoring the cadence. Alternatively, factors internal to the cyclist (eg, age) have been correlated to the freely chosen cadence. In this context it should be recognized that correlation studies do not provide direct evidence for factors affecting freely chosen cadence. Rather they provide inspiration for generation of hypotheses and

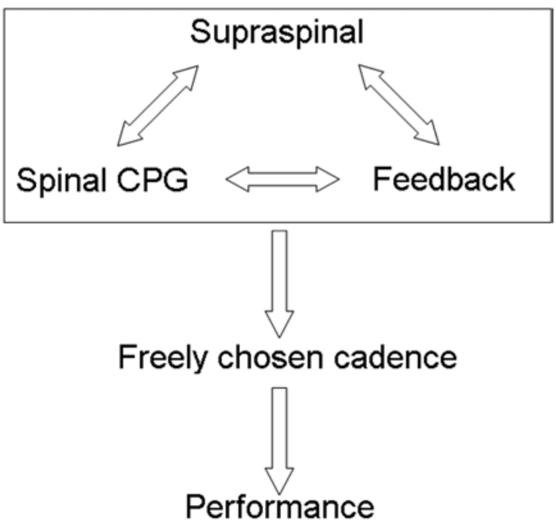

Figure 1 — General outline of the interrelationships between spinal central pattern generator (CPG) activity, supraspinal input, and sensory feedback arising during pedaling in creating the freely chosen cadence and influencing performance during submaximal cycling. Based on previous work.[58]

other types of studies that can provide direct evidence. Table 1 lists factors that have been shown to influence the choice of cadence.

Now let us briefly consider factors internal to the cyclist. Preferred cadence has been observed to reduce with age.[21,22] This is particularly interesting from the perspective of central pattern generators shaping the base of the freely chosen cadence. Another largely individual innate nervous-based rate within the human

Table 1 Factors Affecting the Freely Chosen Cadence During Submaximal Cycling

Factor	Effect on freely chosen cadence	Additional details	References
Age	Lower cadence with higher age.	Cadence declined by 3 rpm per decade for 25- to 63-year-old cyclists. In the second study, a 12 rpm lower cadence (mean value) for 57 ± 4 compared with 28 ± 3 year-old cyclists during a 16.1 km time trial was reported.	21 22
Maximal aerobic power output	Higher cadence with higher maximal aerobic power output.	Using linear regression, cadences from 85 to 100 rpm could be predicted for individuals with maximal aerobic power outputs of 300–460 W, during cycling at 92% of the maximal aerobic power output.	59
Power output	Higher cadence with higher power output during treadmill and road cycling.	Cadence increased about 6 rpm (mean value) for a 100 W increase of power output during treadmill cycling. Cadence increased 10 and 14 rpm for 74 and 300 W increases in power output, respectively, during road cycling. Higher cadence for higher speed (and thereby oxygen uptake and, assumable, power output) during road cycling has also been reported.[60]	37 6 61 13 62
Gradient	Higher cadence during level compared with uphill road cycling.	Cadence was 6–32 rpm (mean values) higher during level compared with uphill cycling at similar heart rate or power output.	39 38 40
Crank inertial load	Higher cadence with higher crank inertial load.	Cadence was 6–9 rpm greater (mean values) with high crank inertial loads (87–100 kg·m^2) during cycling at similar power output.	37
Drafting	Higher cadence during drafting.	Cadence was about 5 rpm higher (mean value) during drafting compared with cycling alone in cycling sections (of a triathlon) performed at similar speed.	43
Duration of cycling	Decrease in cadence during prolonged cycling.	Cadence decreased by 7–18 rpm (mean values) when cycling was prolonged for 1–5 h.	44 45 46 47 48

body, the heart rate, also decreases with age during exercise.[23] Although the mechanism for this decrease is not yet uncovered, there may be some neural network relationship to aging that affects both heart rate and cadence during cycling.

Other internal factors have been investigated and will be briefly described in the following. The percentage of type I muscle fibers in vastus lateralis tended to correlate positively with freely chosen cadence. From linear regression, cadences from 59 to 92 rpm could be predicted for individuals possessing 0% to 100% type I fibers. The phrasing "tended to correlate" has been used since the correlation was modest and found for merely one of two cycling bouts that the participants completed.[6] Cycling experience is another factor that perhaps affects the choice of cadence. Still, the studies that have investigated this are not unanimous and, because they are cross-sectional in nature, it appears too early to say whether years of training affect the cyclist to pedal faster or whether a natural selection causes those who have an initial high freely chosen cadence to be most successful and thereby continue their cycling career longer. One research group found no difference in freely chosen cadence when groups of runners and cyclists were compared.[24,25] In support, it was recently reported that novice and highly trained cyclists chose similar cadences during submaximal cycling.[26] On the other hand, two other studies showed that preferred cadence was higher for cyclists than for trained noncyclists[27] and that freely chosen cadence was higher for trained competitive cyclists compared with recreational cyclists.[28] In the studies by Marsh et al (1993 and 2000)[24,25] and Takaishi et al (1998),[27] the compared groups were matched for maximal oxygen uptake and thus the groups worked at the same relative intensity. Leg strength per se is a factor that appears not to be related to the freely chosen cadence.[6,29] This is particularly interesting because 12 weeks of heavy strength training has been shown to cause an 8- to 10-rpm reduction in freely chosen cadence.[30] However, leg strength and freely chosen cadence were not significantly correlated. The authors suggested that factors other than leg strength per se—for example, nervous factors—could have been affected by the heavy strength training and thus resulted in the considerable change in cadence behavior. Recently, it was reported that previous eccentric heavy knee-extension exercise caused well-trained cyclists to reduce their cadence by on average 10 rpm during 10 minutes of cycling at on average 69% of their maximal aerobic power output.[31] Still, as with the findings of Hansen et al (2007), the mechanism for the change in cadence behavior following heavy muscle exercise was not clarified.[30] It is possible that variables such as leg mass, leg inertia, and intersegmental energetics could affect the freely chosen cadence.[32] However, according to the best of our knowledge, this has been neither confirmed nor rejected in previous literature. In a number of our previously performed studies, though, we have not observed significant correlations between variables such as leg mass and inertia and freely chosen cadence (unpublished observations).

The external factors in Table 1 and some additional factors that have been investigated are briefly discussed in the following. Several studies listed in Table 1 have shown freely chosen cadence to increase with increasing power output during treadmill and road cycling. Still, it remains an unexplained curiosity that a number of other studies concurrently have shown cadence to be unaffected by power output during cycling on electromagnetically braked ergometers.[12,33,34] Perhaps the dissimilar findings have to do with the source of mechanical resistance that is applied (air, rolling, friction, and gravitational resistance vs electromagnetically generated resistance), the magnitude of crank inertial load (low for many cycle ergometers compared with fast road or treadmill cycling), and the perceived exertion related to overcoming the crank inertial load and resistance.

Crank inertial load is the effective rotational inertia about the crank axis due to the moment of inertia of the flywheel or rear wheel and has the effect of resisting changes in the velocity of the cranks.[35] It has been shown that during cycling at a fixed power output and cadence, an increase in crank inertial load changes the crank torque profile in a way that peak crank torque increases.[36,37] Further, if the cyclist is allowed to freely choose cadence, this is greater at high compared with low crank inertial load.[37] On this basis, it was suggested by Hansen et al (2002) that the participants in their study increased their cadence during cycling at high crank inertial load to reduce the peak crank torque.[37] This is in line with reports of cyclists choosing higher cadences during level compared with uphill cycling.[38–40] Crank inertial load is greater during level compared with uphill cycling[37] because it increases as a quadratic function of the bicycle gear ratio.[35] Therefore, during road cycling where a cyclist maintains the same cadence and power output, conditions with low and high crank inertial load occur during uphill and level cycling, respectively. The reason for the low crank inertial load during uphill cycling is that the gear ratio in this cycling condition is low, as a consequence of the low speed. In contrast, the gear ratio is high during level cycling, as a consequence of the high speed in this cycling condition. For example, if a cyclist with a body mass of 70 kg performs cycling at 90 rpm at the same power output on a very steep uphill road at 10 $km \cdot h^{-1}$ and subsequently on a level road at 50 $km \cdot h^{-1}$ with gear ratios of 26/28 (chain wheel / free wheel) and 52/12, respectively, the change in gear ratio from 26/28 to 52/12 results in a change in crank inertial load from approximately 8 to 180 $kg \cdot m^2$. In the study by Hansen et al (2002), a change of the crank inertial load from around 18 to 115 $kg \cdot m^2$ caused the freely chosen cadence to increase around 7 rpm.[37]

During drafting, a higher cadence is chosen compared with nondrafting.[43] While the reason for this choice is unknown, it is known that the capability to produce maximal peak crank power and acceleration is largest at high cadences of about 120 rpm[6] (consult this paper for additional references). Perhaps cyclists, when drafting, choose a relatively high cadence to be able to accelerate more promptly, for example, to adjust the distance to the cyclist in front. In support of this proposal, it has also been reported that cyclists chose an average of 17 rpm higher cadence during cycling with alternate leading and drafting, which involves considerable acceleration and deceleration, compared with cycling with continuous drafting, which is steadier in nature.[41] In addition, the freely chosen cadence has been reported to be on average 9 rpm higher during cycling at variable power output compared with constant power output at a similar average power output of 70% of maximal aerobic power output.[42] A decrease in cadence with cycling duration has also been observed and is of unknown cause.[44–48] Perhaps the decrease in cadence has to do with fatigue of the neural networks constituting the central pattern generators or perhaps changed output from these. Another possibility is that peripheral fatigue affects freely chosen cadence. For example, if central drive is unaffected, excitation of specific muscles could be slowed with a delayed or interrupted uptake of local metabolites or due to a local chemoreceptor response to an increase in metabolic by-products. Thus, excitation and relaxation kinetics of muscle activation could be a factor in cadence choice. It should be noted that two studies have shown cadence to be unaffected by 30 to 60 min of cycling.[49,50] Future research is required to elucidate this.

Finally, circadian rhythm might slightly affect the choice of cadence as indicated by a previous study that showed a significant circadian variation from 90 rpm in the morning to 96 rpm in the evening.[51] On the other hand, the very limited amount of research in this field calls for more clarification; for example, a subsequent study from the same group of researchers did not find cadence to be affected by circadian rhythm.[52]

A thorough understanding of factors affecting the choice of cadence is one of the prerequisites for useful recommendations of cadence strategies. Another is insight into the studies that have directly investigated the effect of cadence (including the freely chosen) on performance—these studies are reviewed in the next section.

Importance of Cadence Choice for Performance

A range of different models may explain contributions to fatigue and, in consequence, performance during prolonged cycling.[53] At the same time, it is generally agreed that a single factor such as excess energy expenditure alone will attenuate endurance performance. With this in mind, it is interesting to consider the energy expenditure at the freely chosen cadence compared with other preset cadences. There is a parabola-like relationship between cadence and oxygen uptake or energy expenditure (for an example of individual and mean curves, the reader is referred to a previous paper[3]). Recall that the freely chosen cadence during low-to-moderate submaximal cycling is higher than the cadence resulting in minimum energy expenditure; that is, the freely chosen cadence occurs on the ascending limb of the parabola-shaped curve of energy expenditure vs. cadence. The excess energy expenditure when cycling at intensity of 54% to 65% of maximal oxygen uptake at the freely chosen cadence as compared with the energetically optimal cadence amounts to around 5%.[3,12] But interestingly, the difference between the energetically optimal cadence and the freely chosen cadence decreases with increasing intensity, primarily because of an increase in the energetically optimal cadence, and the two cadences are identical at intensity close to the maximal oxygen uptake.[54] Considering energy expenditure to be of major importance for performance, this suggests that freely chosen cadence is reasonable with regard to performance optimization during high-intensity submaximal cycling whereas performance is compromised by applying the freely chosen cadence during low-to-moderate intensity submaximal cycling.

This idea is clearly supported by a thorough review of relevant papers (Table 2). In short, Nesi et al (2004)[55] and Bessot et al (2006)[52] investigated cycling at intensity close to maximal oxygen uptake and performance measured in terms of time to exhaustion. Both studies showed that the freely chosen cadence resulted in as good performance as a lower cadence (80% of freely chosen) and as good or better performance than higher cadences (120% and 115% of freely chosen, respectively). At the other end of the intensity scale, Hansen et al (2006) studied

Table 2 Importance of Cadence Choice for Performance During Submaximal Cycling

Approximate duration and intensity	Cadences investigated	Importance for performance	References
2.5 h at 56% of maximal oxygen uptake.	Energetically optimal (73 ± 11 rpm) Freely chosen (95 ± 7 rpm)	Less increase of rate of perceived exertion at the energetically optimal.	3
27 min at 84% of maximal oxygen uptake.	60 rpm 80 rpm Freely chosen (90, min–max: 74–100 rpm) 100 rpm 120 rpm	Faster completion of time trials at 80 rpm, freely chosen, and 100 rpm compared with 60 rpm and 120 rpm.	2
12 min at 92% of maximal oxygen uptake.	90% of freely chosen (83 ± 6 rpm) Freely chosen (92 ± 2 rpm) 110% of freely chosen (101 ± 6 rpm)	Faster completion of time trial at 90% of freely chosen compared with 110% of freely chosen.	63
9 min at power output corresponding to 90% of maximal oxygen uptake.	75% of freely chosen (59 ± 8 rpm) Freely chosen (78 ± 11 rpm) 125% of freely chosen (98 ± 13 rpm)	Longer time to exhaustion at 75% of freely chosen and freely chosen compared with 125% of freely chosen.	54
7 min at 98% of maximal oxygen uptake.	Freely chosen (94 ± 4 rpm) 115% of freely chosen	Longer time to exhaustion at freely chosen.	55
4 min at 95% of maximal aerobic power output.	80% of freely chosen (72.4 ± 10.4 rpm) Freely chosen (90.4 ± 14.6 rpm) 120% of freely chosen (108.7 ± 15.7 rpm)	Longer time to exhaustion at 80% of freely chosen compared with 120% of freely chosen.	52

performance during and following 2.5 h of cycling at intensity around 54% to 58% of maximal oxygen uptake at the energetically optimal and the more energy requiring freely chosen cadence.[3] They reported that a direct performance measurement obtained following the prolonged cycling, mean power output in a 5-min all-out time trial, was not different between the two cadences. Thus, it is possible that for well-trained cyclists exercising for 2.5 hours below 60% of maximal oxygen uptake, slightly higher energy expenditure is trivial for performance. On the other hand, it gives food for thought that an indirect performance measurement obtained during the prolonged cycling, rate of perceived exertion, increased less during cycling at the energetically optimal cadence compared with the higher and more energy–requiring freely chosen cadence.

The message from this section is that when it comes to the importance of cadence choice for performance, intensity should be taken into account. Thus, it is not a simple question of whether the freely chosen cadence is reasonable with regard to performance. Instead it is likely that a relatively low, energetically optimal, cadence could be beneficial for performance during submaximal cycling of low-to-moderate intensity whereas the freely chosen cadence is usable during submaximal cycling of high intensity. On the basis of this, some specific perspectives for cyclists, coaches, and others involved with cycling are given in the next section.

Perspectives

On the basis of the present review, it is recommended that one distinguish between cycling at low-to-moderate intensity in contrast to high intensity with regard to factors affecting cadence choice and cadence influence of optimal performance.

During cycling at low-to-moderate intensity, cyclists typically choose a cadence that is considerably higher than the energetically optimal cadence. This results in an excess energy expenditure of around 5%, which probably compromises performance following hours of prolonged cycling. It is possible that cyclists in a way are being tricked to pedal at a relatively high cadence by a robust innate rhythm, originating from central pattern generators. Still, this innate rhythm can, of course, be superseded by deliberate motor control. This is particularly the situation during easy cruising cycling, in which the cyclist has a general feeling of reserve, compared with more intensive cycling. Consciousness of the applied intensity (power output and heart rate) and cadence combined with a firm strategy to pedal at a low cadence during sections of the race where intensity is low and no fast accelerations are required would definitely save energy and possibly even improve performance. In this context, it should be recalled that reestablishing energy stores is one of the major challenges for cyclists during stage races. It is of further note that 70% of long (>5 h) competitive road races consists of submaximal cycling below approximately 60% to 70% of maximal oxygen uptake.[56,57] This kind of cycling is performed by cyclists in the pack after a breakaway has been established early in the race and while the pack is waiting for the final chase to begin. Still, it should be emphasized that whether a cadence strategy of applying low, energetically optimal cadences during race sections of low-to-moderate intensity would have negative effects on capability to accelerate due to important speed changes and to sprint in the end of a race is not known—only that average power output in a 5-min all-out test is not compromised.[3] Therefore, until more research results are available, cyclists are recommended to experiment on their own with novel cadence strategies during cycling at low-to-moderate intensity in advance of using it in important competitions. That is, by the way, always to be recommended as to individual performance-enhancing interventions because always some individuals deviate from the average individual, which is also true when it comes to the relationship between cadence and performance. In addition, there is always the risk that results from well-controlled laboratory studies do not apply to competitions that offer less constant conditions, for example, in power output.

During cycling at high intensity close to the maximal oxygen uptake, cyclists choose a cadence that is close to the energetically optimal cadence. Thus from an economy perspective, there appears to be no reason to interfere with the cyclists' freely chosen cadence at this intensity. Furthermore, studies that directly have investigated the importance of cadence for performance show that during cycling at high intensity, cadences are chosen that are favorable for performance. Thus, there is no apparent need to interfere with cadence choice during cycling at high submaximal intensity. Examples of high-intensity cycling could be a prologue in a stage race or a 4000 m team pursuit race on track. During road cycling, gears are available so that it is simple to freely choose a cadence. During track cycling, however, the bicycle is fitted with a single gear before the race. Although this fixed gear cannot be changed while riding, nothing hinders a cyclist from choosing an alternative gear for a team pursuit race. This is already being practiced by some national teams. But perhaps the importance of all cyclists using their freely chosen cadence should be emphasized even more in high-intensity track cycling disciplines.

Each time a well-known professional cyclist performs with outstanding results and pedals at a cadence that is in the outer range of the cadences most commonly used, it attracts a lot of attention. This was observed after Bjarne Riis, on the large chain wheel resulting in a large gear ratio and low cadence, had outclassed the ruling champion Miguel Indurain on a mountain ascent in the 1996 version of the Tour de France. Later, Lance Armstrong in a high cadence dominated the Tour de France throughout a number of years. His "Lance dance" was taken as a model by many cyclists and coaches. However, anecdotal reports indicate that it is difficult for cyclists to force a high cadence on themselves, even after special practice, and it appears that many have now realized that it is probably not beneficial for performance either. This does not contrast the common sense of occasionally practicing all cadences, from very low to very high, since that simulates the work demands in cycling. But this review suggests that cyclists cannot improve performance during submaximal cycling by pedaling at higher than their freely chosen cadence. On the contrary—if anything—lower cadence may be beneficial during cycling at low-to-moderate intensity.

Summary

The interest in cadence choice during cycling has persisted for nearly a century. Compared with the beginning of the twentieth century, we now understand much better the background for the cadence choice. On the basis of recent insights, it appears reasonable to suppose that central pattern generators located in the spinal cord form the robust base for the highly individual cadence chosen by each cyclist. Further, a number of factors internal and external to the cyclist, such as age and road gradient, have a contributing effect on the final cadence choice. Cadence affects mechanical loading on the cyclist as well as physiological responses, including energy expenditure, and consequently performance. It appears that cyclists during high-intensity cycling freely choose a cadence that is energetically economical and favorable for performance. However, during cycling at low-to-moderate intensity, cyclists choose a cadence that is higher and thereby energetically uneconomical compared with lower cadences. In addition, research suggests that cycling performance can be improved by using lower than freely chosen cadence, during prolonged cycling at low-to-moderate intensity. However, only little research has investigated the effect on performance of different cadences during prolonged cycling for as long as 2 to 3 hours, such as found during long road races.

Despite a century of exploration, more research will be required to fully understand the paradox of cadence choice. A focus on the connection between central pattern generators and choice of cadence for a better understanding of the underlying neurophysiology affecting the freely chosen cadence is an obvious continued direction. Such research would be interesting from applied, medical, and basic perspectives. In addition, more studies of the importance of cadence for performance during prolonged cycling of more than 2.5 hours should be conducted to better simulate long road races. Until results from such studies are available, cyclists and coaches can gain individualized insights through testing performed during training and less important races.

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