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Dependency between pedal quality and power output in cycling.

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ABSTRACT

Purpose: The aim of this study was to study the possible differences in a pedal cycle at different power intensities. This study used SpinScan (SS) (Racermate One) as a determination of the quality of the pedal cycle and average torque angle (ATA) was hypothesized to have an effect on SS. Power for each intensity was calculated out of each subjects functional threshold power (FTP).

Method: Twelve male medium-trained cyclists cycled for 3 minutes, at five different stages of the FTP (60%, 85%, 100 %, 110% and 120%). SpinScan, cadence and ATA was registered every second with Racermate One.

Results: There was no significant differences between SS at each intensity. There were no significant correlation between ATA and SS at each intensity. The correlation between SS and ATA was higher at 85% (r = 0.71), when ATA was given a number depending on the angle.

Conclusion: Intensity level does not affect SS. Having ATA close to 90° does not affect SS at any power output.

Key Words: POWER, FUNCTIONAL THRESHOLD POWER, SPINSCAN, PEDAL, QUALITY

Content

INTRODUCTION

A cyclist can specialize in different stages in a race (sprinter, mountain climber or a timetrial specialist), or even different types of races during a season (single day race or tour). Having good endurance and high muscular power is something a cyclist needs to achieve success in competitive cycling. The ability to save energy becomes an important asset, especially for sprinters and mountain climbers. Their capability to use the energy at the right time and place would give them an advantage. A factor that affects energy cost is the pedal technique. Pedaling with a smooth pedal stroke would give the cyclist an advantage compared to a cyclist who only produces power during the down stroke. The angle of which the cyclist produces power, might also affect the technique. Producing most power at 90° could change the evenness of a pedal cycle and therefore alter SS in a positive direction.

Racermate One (Racermate inc, Seattle, USA) uses Average Torque Angle (ATA) and SpinScan (SS) as a determination of the quality of a pedal revolution. ATA shows what angle the cyclist applies average torque to the crank arm for both left and right foot. Having ATA close to 90° gives the cyclist a longer work distance to apply power, and it is during the down-stroke with the crank arm fully horizontal and forward, a cyclist generates most power. Since Racermate One shows ATA for both foots, updating at every pedal revolution, the biker receives good feedback on what angle he applies most force. Power distribution is divided into 24 pieces (every 15°) in a pedal cycle.

SpinScan on the other hand, shows the cyclist how even the pedal revolution is, using averaged torque divided by maximum torque multiplied by one hundred (Formula 1) (Racermate). SpinScan gives the cyclist an overall picture of the efficiency of a pedal stroke, where 100% is power during the complete pedal cycle. The higher the number, the more efficient pedal revolution. Elite cyclists achieve SS number at approximate 78-85% at steady-state cycling (pers with Ole Knutsen). During steady-state cycling, the upstroke is a rare phenomenon and is not essential to an efficient pedal stroke in a seated position (Silberman et al., 2005).

$$\frac{Averaged\ Torque}{Maximum\ Torque}\ x\ 100$$

Formula 1: Formula for SpinScan in Racermate One.

Both ATA and SS provides a feedback to the cyclist on how efficient the pedal stroke is. These two combined gives an indication on the pedal technique for the subject. Having high SS indicates high efficiency and having ATA close to 90 ° means the cyclist is applying force at the correct angle. Racermate One has been used as a biofeedback to its users trying to improve the pedal cycle, but not as a program to determine gross efficiency or force efficiency (Swart et al., 2008)

The number of studies on the effect of cadence on cycling performance is very high, the majority focusing on the optimisation of energetic costs. Studies has shown that force efficiency, the ratio between the force component perpendicular to the crank arm and the total force generated on the pedals (Leirdal et al., 2010), and gross efficiency, the ability to convert metabolic energy into work (Arkesteijn et al., 2012), is strongly negatively influenced by cadence. An increase in cadence would reduce both force efficiency and gross efficiency. On the other hand, gross efficiency and force efficiency is strongly positive influenced by work rate (Leirdal et al., 2010).

Pedaling technique vary between different cyclists, with cadence and giving power to different stages of the pedal cycle, changes during a race. The most economical cadence is low (50-60rpm) (Lucía et al., (2000), Leirdal et al., (2011)), compared to what cadence the cyclists adapts (90 -100rpm) (Lucía et al., 2000). Cadence during races depends on type and height of the cyclist, short cyclists tends to adapt a high frequency compared to tall cyclists (Lucia et al., 2000). Lucía et al. (2000) studied cadence at seven elite cyclists in three different major tours (Giro d'Italia, Tour de France and Vuelta a España) and during different types of terrain (uphill cycling, individual time trails on level ground and flat group stages). During high mountain passes, the cyclists where down to 70 rpm but in flat and in time trials the cyclists had a higher cadence (89±1 and 92±1 rpm). During high mountain passes, the cyclist adapt to a more economical cadence, compared to flat and time trials.

A pedal revolution is divided into different stages of the total 360° from top to top in a pedal revolution. Down stroke (propulsive phase) from 0° to 180°, upstroke (recovery phase) from 180° to 360°, top dead center at 0° and bottom dead center at 180°. Low cadence would increase torque at a given velocity, and the cyclists ability to have an even power distribution throughout a pedal cycle would increase gross efficiency (Leridal et al., 2011). Korff et al.

(2007) studied the effect of different pedaling techniques on mechanical effectiveness and gross efficiency at four different pedal techniques with a freely chosen cadence (FCC). Subjects pedaling at a preferred pedaling technique, with focus on the downstroke, and pedaling with focus on the top and bottom dead center, did not improve the mechanical effectiveness but was the most metabolically efficient techniques. Even though if the upstroke is not the most efficient type of pedaling during steady-state cycling, there are places where focusing on the upstroke would benefit the cyclist (sprint or uphill cycling) (Korff et al., 2007)

Bieuzen et al. (2006) studied at the influence of maximal strength capacity during cycling on three different cadences (50rpm, 110rpm, and FCC). Muscle activity on three muscles, vastus lateralis, rectus femoris and biceps femoris, was measured with EMG and the subjects were split into two groups F_{min} and F_{max}. Where F_{min} was the group who produced the least amount of power, and F_{max} produced the highest amount. Their study showed that F_{max} had an earlier muscle activation on rectus femoris and biceps femoris on all cadences compared to F_{min}. This indicates that max power and cadence affects "lower extremity muscular activity during cycling" (Bieuzen et al., 2006).

Leirdal et al. (2010) was the first to look at the top- and bottom dead center in a pedalstroke as a variable in gross efficiency and force efficiency. Their results showed that reducing top- and bottom dead center size would increase gross efficiency. Previous studies have looked at top- and bottom dead center (Korff et al., 2007, Edwards et al., 2008), where Edwards et al. (2008) concluded that dead center is not a good indicator on how good the pedaling technique is. They found a "significant negatively correlation between minimum torque and gross efficiency at all work rates above 100W" (Edwards et al., 2008). Same study also found a strong correlation between cycling experience and gross efficiency. Leirdal et al. (2011) showed in a study that by reducing cadence, both gross efficiency, dead center and force efficiency decreases. This could be explained by physiological and biomechanical constraints of the athlete.

During a race, the cyclist need to adapt to different types of work rates. Cámara et al. (2012) looked at different types of intensity zones' impact on the pedaling technique. The different zones was below their lactate threshold (LT), on LT and on onset blood lactate accumulation (OBLA) values, pedaling at a freely chosen cadence. Their results showed that at on the LT, "there was a significant correlation between gross efficiency and mean torque and evenness of torque distribution" (Cámara et al., 2012). At OBLA, the cadence increased and gross efficiency decreased.

In the author's knowledge, there is no study investigating the pedal revolution quality on different intensity zones based on power. In this study, the purpose was to investigate the possible changes in the pedalstroke with increasing power output, with a freely chosen cadence. Intensity zones was calculated from functional threshold power (FTP) and set to 60%, 85%, 100%, 110% and 120% of the FTP. The hypothesis is that with increasing power, SpinScan (SS) will increase and average torque angle (ATA) will get close to 90°. The second hypothesis is that there is a correlation between ATA and SS. Having a high SS number, means ATA is close to 90°, and low SS number would give you ATA above 100°.

METHOD

Experimental Approach to the Problem

To study the question if the quality of a pedal cycle is affected by intensity, and if SS is dependent on ATA, five intensity stages on 12 male cyclists with average cycling experience were selected. A pretest was done to determine each subjects functional threshold power (FTP). The subjects FTP were then used in the main test to set five different stages of intensity that the subjects were asked to maintain for 3 minutes.

Subjects

Twelve male cyclists volunteered for the study (age 42.4 ± 6.6 yr, body mass 86.95 ± 7 kg, height 183.98 ± 6.76 cm, FTP 246.7 ± 35.9 Watt). All of the participants had at least 1500 km (3000 ± 935.4 km) on the bike during the last 12 months.

Functional threshold power test

A warmup sequence was done by a pre-programmed circuit in the RacerMate One (Racermate inc, Seattle, USA), and lasted for 6.4km, with a calibration after 2 minutes, and after 6.0km in the warmup. If the calibration number was 0.2lbs above or below 3.0lbs, a new calibration was done right after the end of the warmup. There was an active break for 3 minutes before the FTP test. To find FTP, a 20 min test with the grade set on 1.5º was selected (figure 1). The subject had to use the gear to find suitable cadence to last for 20minutes until exhaustion. The cyclist was not allowed to stand or talk under the warmup sequence nor during the test. Every 2 min, RPE (table 2) was asked for and heart rate was registered using a Polar FT80 (Polar Electro Inc, Kempele, Finland).

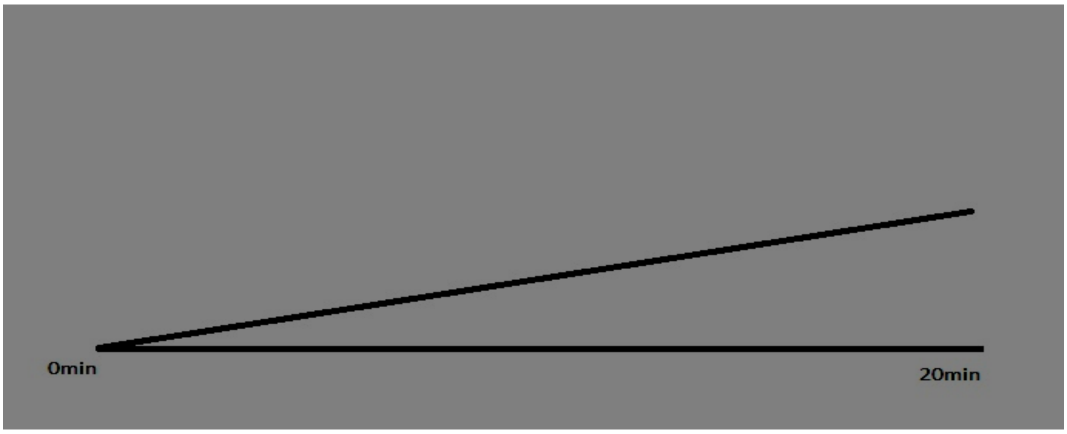

Figure 1: Functional threshold power test. X-line being time with Y-line showing the grade at 1,5º throughout the test.

Stepwise increasing power test

On the second visit the main-test (stepwise increasing power test) were completed were the data was collected. Before the stepwise increasing power test, warmup was done the same way as the FTP test, with a 4 min break between warmup and stepwise increasing power test. Functional threshold power was calculated with the average power (watt) during the pre-test, minus 5% (formula 2).

$$FTP = \frac{Average\ Watt}{100\ \%}\ x\ 95\ \%$$

Formula 2: formula for FTP, where Watt average is the average watt from the 20 min pretest

The stepwise increasing power test was divided into five intervals lasting 4 min and 10sec with grade set on 1.5º, at 60%, 85%, 100%, 110% and 120% of the FTP. There was a 1 min active break between each stage (Figure 2). The subject was allowed to pedal at a freely chosen cadence (FCC) at all time. The first 70sec at each stage was to let the test subject stabilize correct power (Watt). Subject was instructed to navigate from the constantly updating Watt presented on the screen in front of them. During the last 3 minutes, SpinScan (SS), SpinScan

Left and Right, Averaged Torque Angel Left and Right (ATA Left and ATA Right), Cadence (rpm) and power (Watt) data was collected. For this test ATA is calculated as the average between ATA Right and ATA Left. SS_{mean} and ATA_{mean} represents the mean value of all intensity zones for the stepwise increasing power test. Each level of intensity were saved before the next stage, by exiting the SpinScan modus and pressing "Save" on the popup window. This ensured that we did not need to restart the entire test if any problems occurred during a sequence. Heart rate (HR) was registered using a Polar FT80 (Polar Electro Inc, Kempele, Finland), which saves every 5 s, and transferred to a computer using Polar Flowlink (Polar Electro Inc, Kempele, Finland).

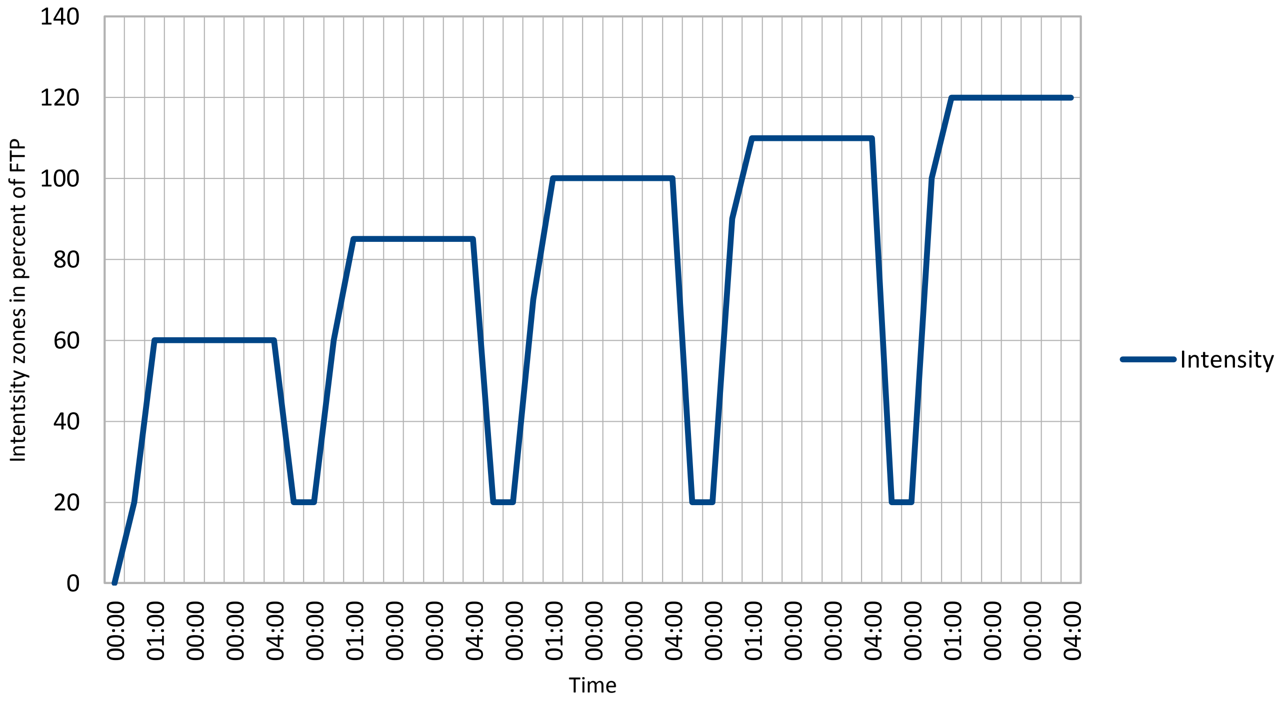

Figure 2: Showing each intensity zone from 01:00 to 04:00 lasting 3 min, with a break for 1 min between 04:00 to 00:00. The subjects adapts to a new intensity from 00:00 to 01:00, with a new intensity starting at 01:00.

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Procedures

Each test subject answered a questionnaire before the pretest. This included name, age, height, weight, number of kilometers the 12 months (since 01.03.2014) and a classification of experience (poor, below average, average, above average and good). RacerMate Computrainer was used on both tests, with RacerMate One version 4.0.2 computer program. The FTP test and the stepwise increasing power test was adjusted manually to 1.5º climb using the standing control panel within the SpinScan modus on RacerMate One. The warmup circuit was a preprogrammed circuit (Capital City Dirt triathlon) on RacerMate One,

The rear tire on the bicycle (Vipera R333) was checked that it had 6 bar of pressure before every test. The optical sensor was placed right below the right pedal, when the pedal was at the bottom of the cycle, with the short end with the wire facing forward. The dynamic load generator was adjusted so the rear tire had resistance. RacerMate One was calibrated with the standing control panel by pressing “identify” at the first screen when starting RacerMate One, and a random button on the standing panel. Each test subject was given a personal user where name, height and weight was typed in. Calibration of the resistance of the dynamic load generator was done 2 minutes in the warmup and at the end of the warmup. Calibration number was set to be between 2.85 lbs and 3.20 lbs (numbers recommended from RacerMate). The bike was adjusted to fit each subject and was at the same position on both tests. RPE was listed using Borg scale 0-10 (table 2). Two bikeframe sizes were used (46 and 51), depending on the height on the test subject. To find a better correlation between ATA - SS and ATA - cadence, ATA was given a value where 90 ± 5 ° being the optimal angle, ATA_{nr}. The numbers for ATA_{nr} was calculated as shown in Table 1.

Table 1: Averaged torque angle and the number given depending on the angle for the subject. Averaged torque angle (ATA) is the average between ATA right and ATA left.

ATA	Number
80 ° - 84,9 °	3,0
85 ° - 89,9 °	4,0
90 ° - 94,9 °	4,0
95 ° - 99,9 °	3,0
100 ° - 104,9 °	2,0
105 ° - 109,9 °	1,0

Table 2: The category-ratio scale of perceived exertion (Borg, 1982)

0	Nothing at all		(just noticeable)
0.5	Very, very weak		
1	Very weak		
2	Weak		(light)
3	Moderate		
4	Somewhat strong		
5	Strong		(heavy)
6			
7	Very strong		
8			
9			
10	Very, very strong		(almost max)

Statistical analyses

The statistical analysis was done using Microsoft Office Excel 2007 (Microsoft inc, Albuquerque, New Mexico, U.S.). Statistics were computed using Statistical Package for Social Sciences 21.0 (SPSS, Inc., Chicago, IL). Using Pearson and Spearman correlation coefficient, repeated measures analysis of variance (ANOVA) was performed to look at differences between SS, ATA and Cadence at each intensity. When significant differences were obtained, Bonferroni post-hoc tests were conducted. Multiple regression analysis was used for indicating the variables that could affect each other (SS, ATA and cadence). Statistical significance was set to an alpha level of 0.05.

RESULTS

Results from the FTP test are presented in table 3, showing mean ± SD. Due to loosing signal for HR on subject, HR and HR_{peak} equals 11 subjects. The subjects' descriptive numbers at each intensity are presented in table 4. Due to loosing signal for HR on the FPT test for one subject, the "Percent of HR_{peak}" presented in table 4 equals 11 subjects. There were found significant differences on Cadences ($F_{4;44}$= 3.54, P = 0.01, η^2= 0.24). None of the pairwise comparisons (Bonferroni) between intensities approached statistical significance, but there was a tendency towards higher cadence at intensity 110% FTP as compared to intensity 60% FTP (Mean diff.: 4.8 ± 1.5 rpm, P = 0.08).

No significant differences between SS-mean at the different intensities ($F_{4;44}$ = 0.48 P = 0.75, η^2 = 0.42) where found. There was found no significant differences between ATA at the different intensities ($F_{4;44}$= 0.33, P=0.87, η^2= 0.13).

There was correlation between SS and ATA, ATA and cadence nor SS and Cadence (Table 4).

Looking at the correlation between ATA_{nr} and SS there is a slightly difference, but not significant. However, the correlation on 85% of FTP slightly improves. (r= 0.73, P= 0.01). On the other hand, correlation between ATA_{nr} and Cadence gets negative on all intensities, except on 100% of FTP (Table 5).

Table 3: Results from the FTP test. Showing mean numbers ± SD.

FTP results	
Average Watt (W)	259.7 ± 39.43
FTP Watt (W)	246.65 ± 35.89
Cadence (rpm)	92.4 ± 4.37
HR	170.4 ± 49.94
HR_{peak}	179.8 ± 52.42
SS (%)	63.2 ± 5.98
ATA (°)	98.5 ± 5.28

Table 4: Description of HR_{peak}, cadence, RPE, watt and target watt, and ATA_{nr} at each intensity zone for all subjects (± SD).

Intensity zone (% of FTP)	60 %	85 %	100 %	110 %	120 %
Percent of HR_{peak}	74,2 ± 3,9	84 ± 3,4	89,9 ± 2,8	94,0 ± 2,0	97,3 ± 2,2
Cadence (rpm)	89,8 ± 4,4	91,9 ± 3,4	92,7 ± 3,5	94,6 ± 3,4	91,7 ± 3,4
RPE	1,9 ± 0,6	3,5 ± 0,9	5,0 ± 1,2	7,0 ± 1,5	8,8 ± 1,5
Watt	148,1 ± 22,2	209,7 ± 31,9	247,4 ± 36,2	272,4 ± 39,6	294,6 ± 42,0
Target Watt	148 ± 22,5	209,7 ± 31,9	246,7 ± 37,5	271,3 ± 41,2	296 ± 45,0
ATA_{nr}	2,75 ± 0,45	3,1 ± 1,08	2,8 ± 1,03	2,8 ± 0,83	3 ± 1,04

Table 5: Correlation value between different variables at each intensity. Mean equals average of all intensities . (R> 0,07 and P < 0,05)

Intensity zone (% of FTP)	60 %		85 %		100 %		110 %		120 %		Mean	
	R	*P*	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*	*R*	*P*
SS v ATA	-0,12	0,97	-0,71	0,01	-0,45	0,14	-0,42	0,18	-0,46	0,14	-0,56	0,06
ATA v Cadence	0,01	0,98	0,19	0,55	0,29	0,36	-0,22	0,50	0,13	0,69	-0,07	0,84
Cadence v SS	0,11	0,73	0,24	0,46	-0,16	0,63	0,29	0,36	-0,08	0,82	0,09	0,77
ATA_{nr} v SS	0,03	0,93	0,73	0,01	0,47	0,12	0,30	0,34	0,45	0,14	0,60	0,04
ATA_{nr} v Cadence	-0,14	-0,67	-0,08	0,80	-0,47	0,13	0,00	0,99	-0,30	0,35	-0,11	0,72

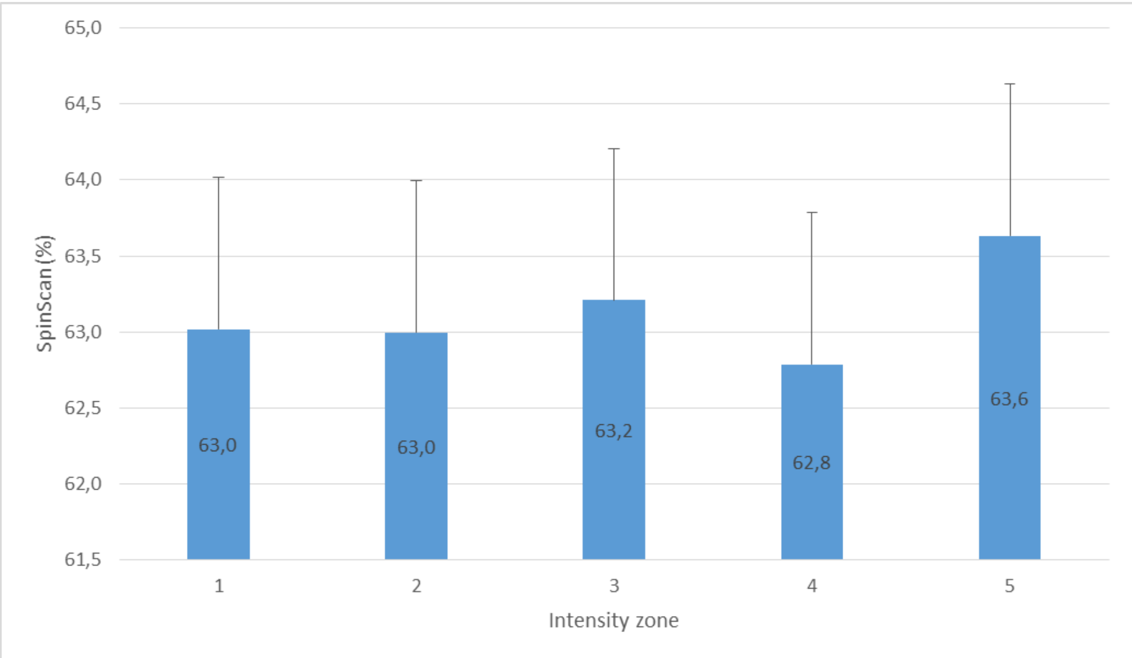

Figure 3: Average SS Left at each intensity zone for 12 subjects (± SD). Intensity zone 1= 60% (± 4.0), intensity zone 2= 85% (± 4.8), intensity zone 3= 100% (± 4.4), intensity zone 4= 110% (± 5.2), intensity zone 5= 120% (± 5.3). (n=12)

Table 6: Showing mean ± SD for cadence and SpinScan at each intensity.

Intensity zone (% of FTP)	60 %	85 %	100 %	110 %	120 %
Cadence (rpm)	89.76 ± 4.43	91.90 ± 3.43	92.74 ± 3.54	94.56 ± 3.39	91.73 ± 3.43
SpinScan (%)	62.5 ± 5.11	63.08 ± 5.02	63.06 ± 4.94	62.52 ± 5.14	63.43 ± 5.61

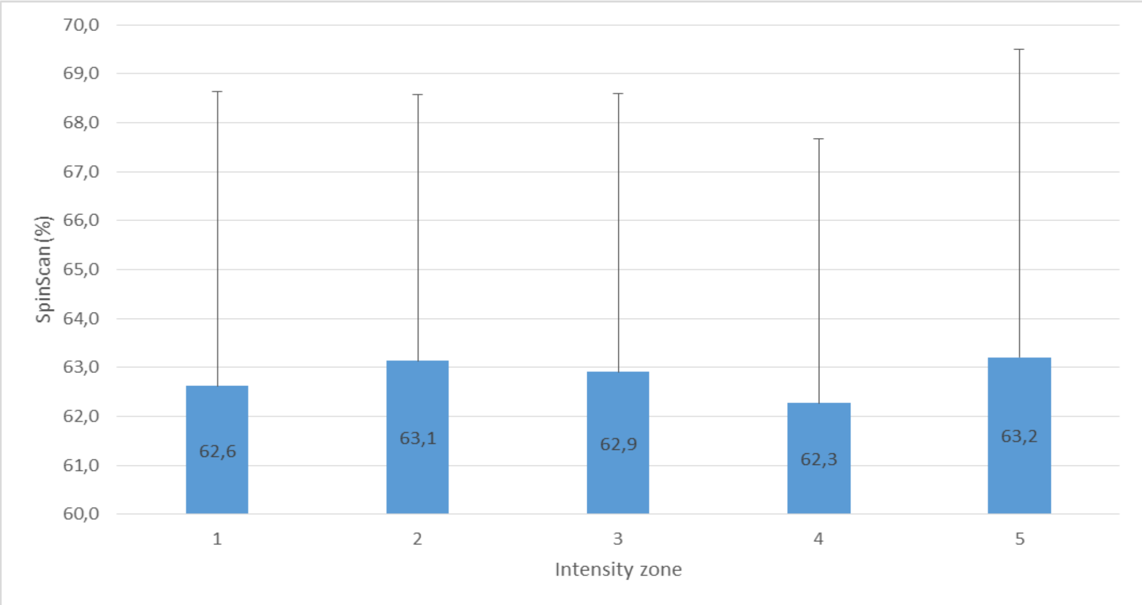

Figure 4: Average SS Right at each intensity zone for 12 subjects (± SD). Intensity zone 1= 60% (± 6.0), intensity zone 2= 85% (± 5.4), intensity zone 3= 100% (± 5.7), intensity zone 4= 110% (± 5.4), intensity zone 5= 120% (± 6.3). (n=12)

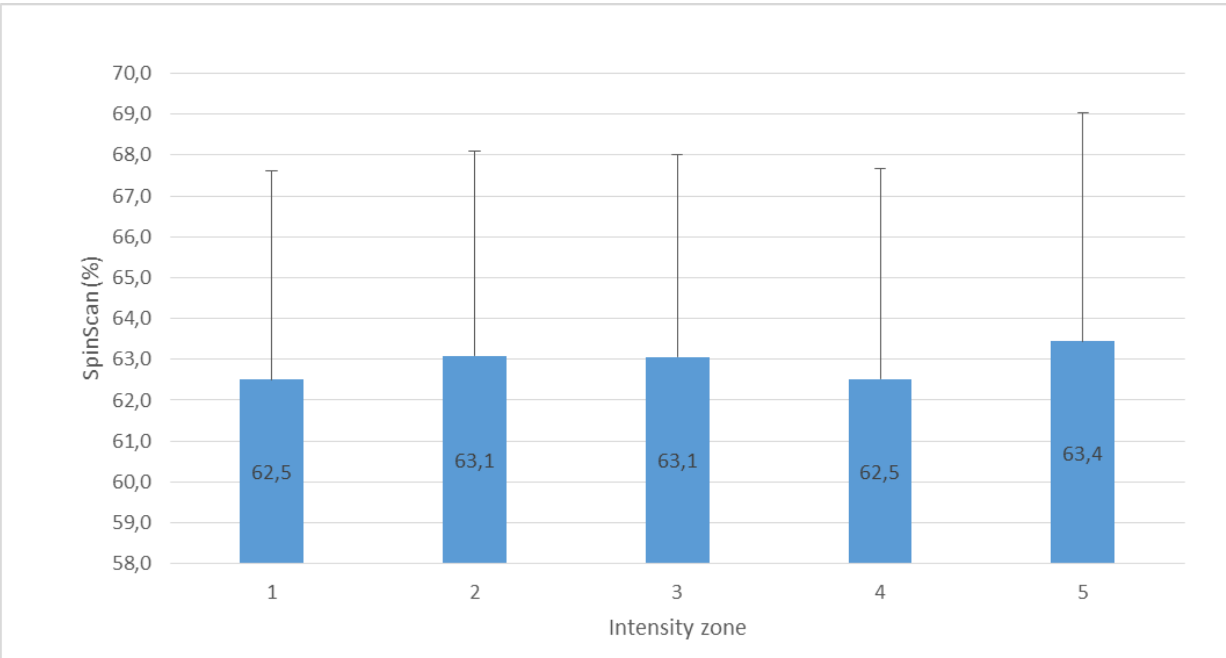

Figure 5: Average SS at each intensity zone for 12 subjects (± SD). Intensity zone 1= 6 % (± 5.11), intensity zone 2 = 85% (± 5.02), Intensity zone 3 = 100% (± 4.94), intensity zone 4 = 110% (± 5.14), Intensity zone 5= 120% (± 5.61).

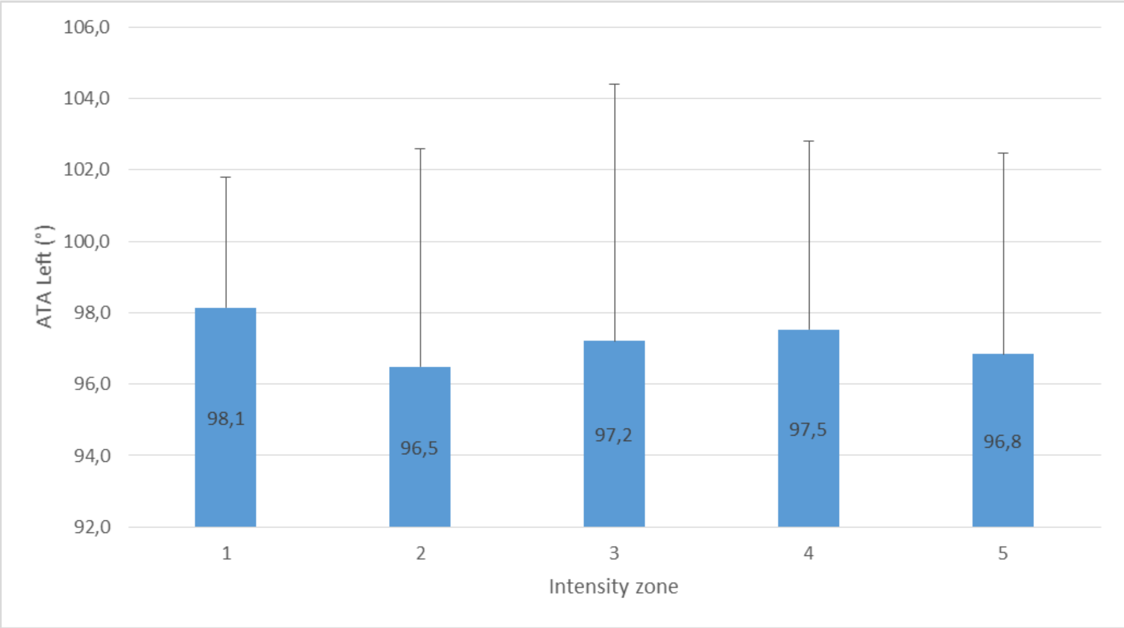

Figure 6: Average ATA Left at each intensity zone for 12 subjects (± SD). Intensity zone 1= 60% (± 3.6), intensity zone 2= 85% (± 6.1), intensity zone 3= 100% (± 7.2), intensity zone 4= 110% (± 5.3), intensity zone 5= 120% (± 5.6).

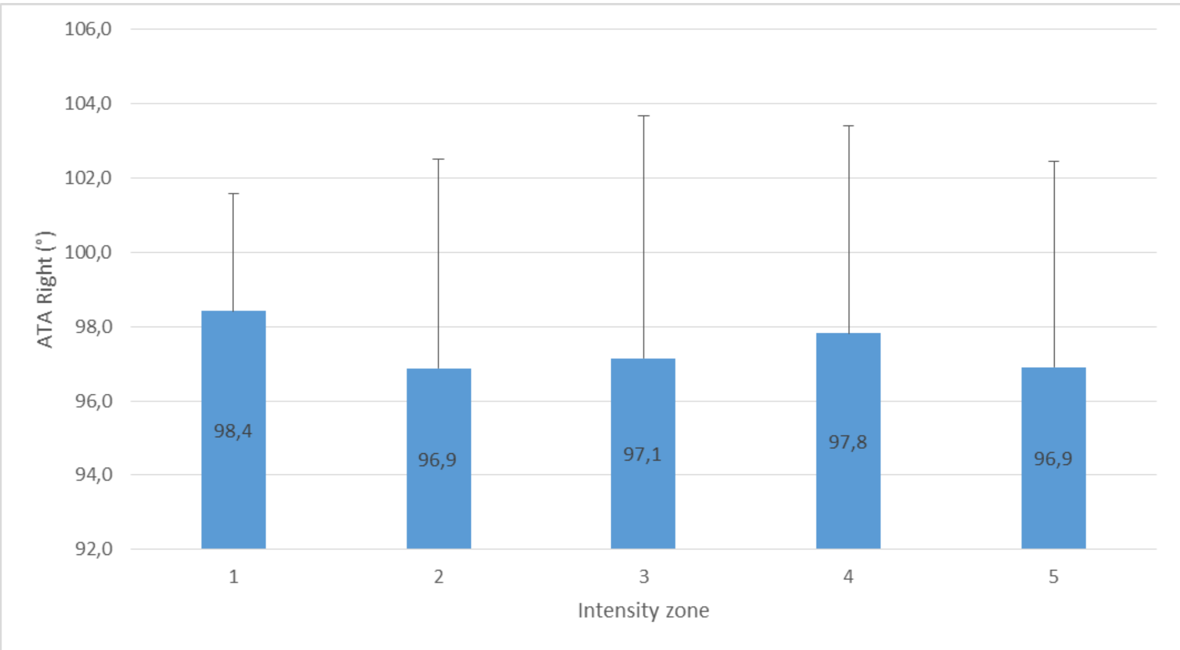

Figure 7: Average ATA Right at each intensity zone for 12 subjects (± SD). Intensity zone 1= 60% (± 3.2), intensity zone 2= 85% (± 5.6), intensity zone 3= 100% (± 6.5), intensity zone 4= 110% (± 5.6), intensity zone 5= 120% (± 5.5).

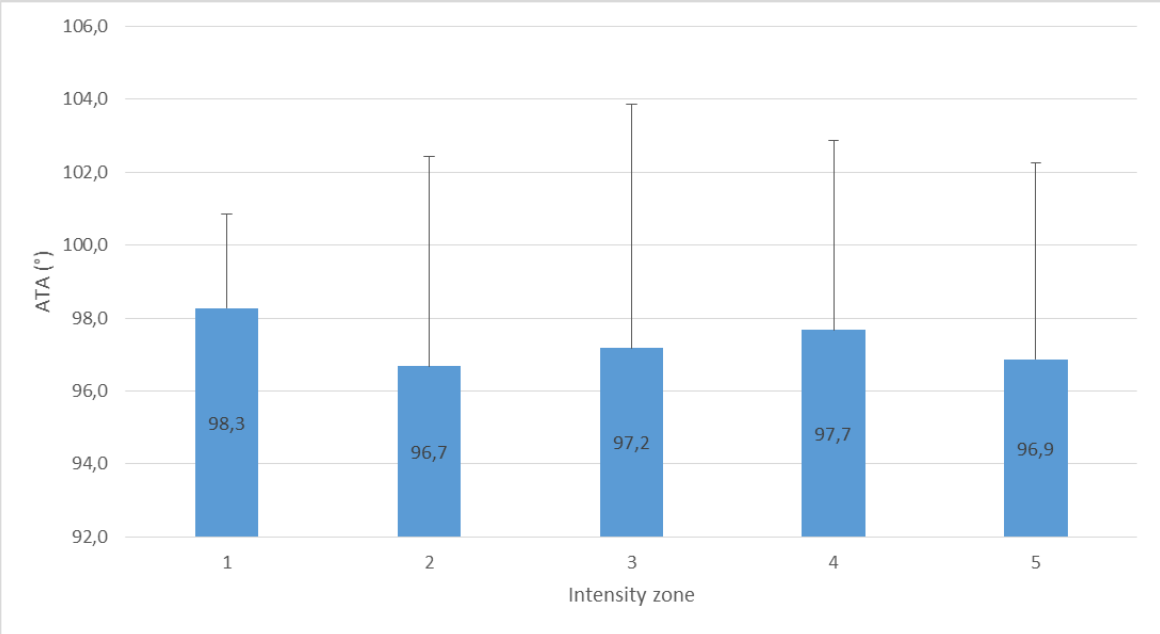

Figure 8: Showing average ATA at each intensity zone for 12 subjects (± SD). Intensity zone 1= 60% (± 2.6), intensity zone 2= 85% (± 5.7), intensity zone 3= 100% (± 6.7), intensity zone 4= 110% (± 5.2), intensity zone 5= 120% (± 5.4).

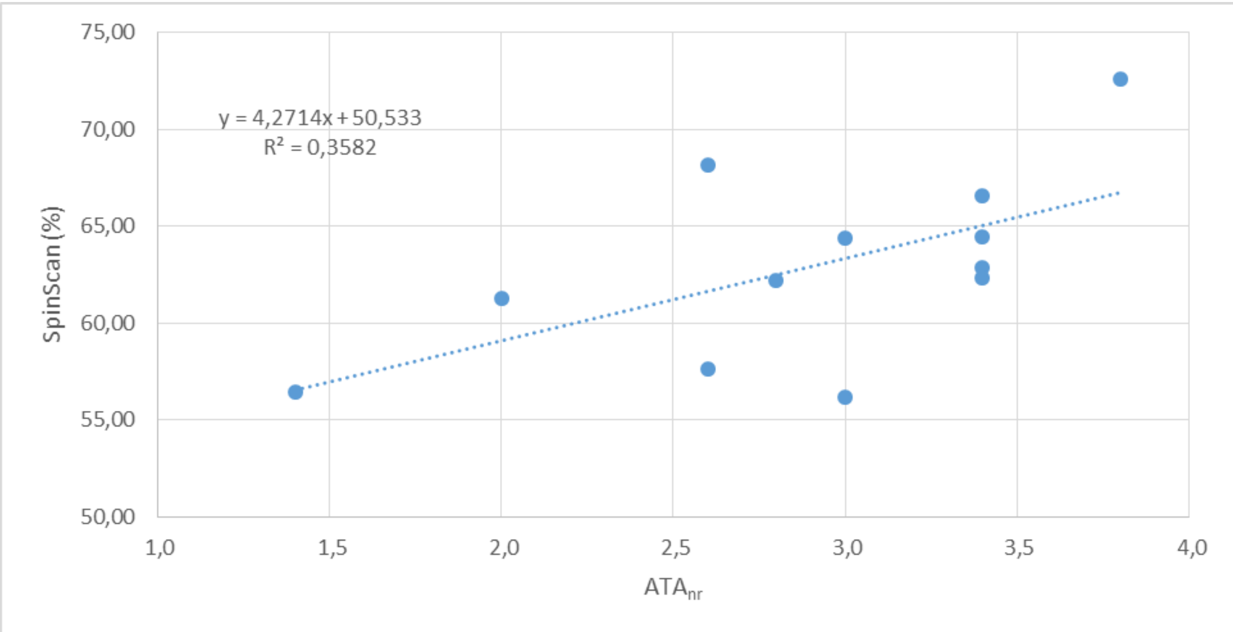

Figure 9: Showing the correlation between SS_{mean} (%) (y) and ATA_{nr} mean (x). ATA_{nr} mean and SS_{mean} is the average of all intensities. (n = 12).

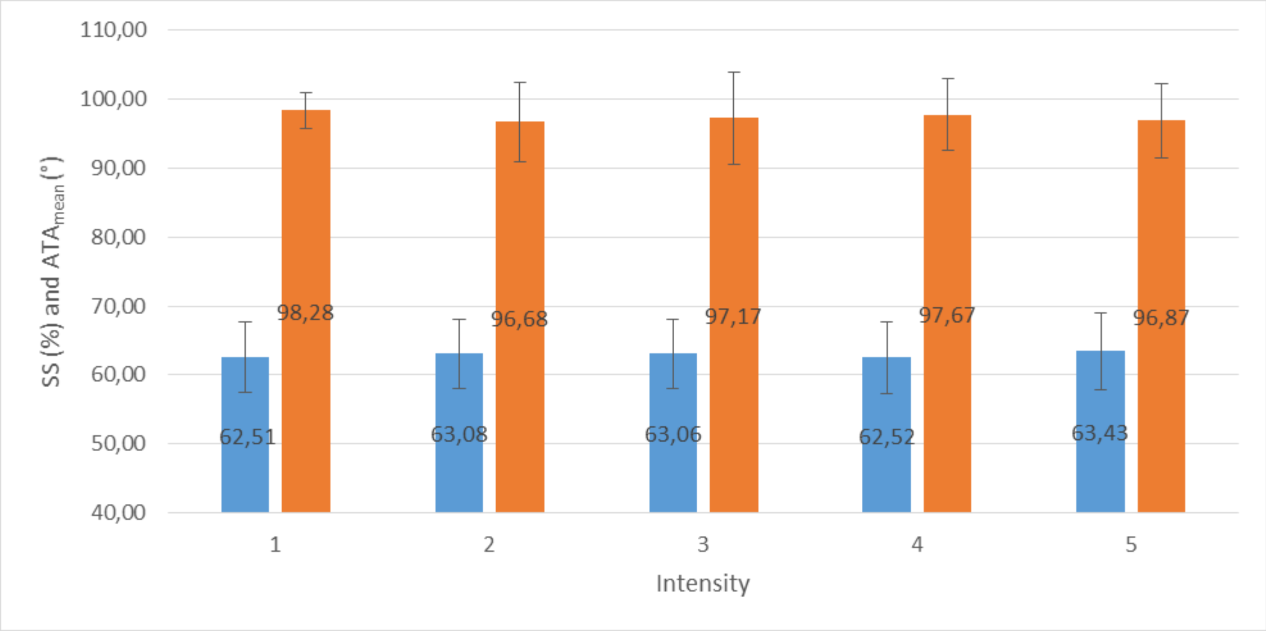

Figure 10: Showing average SS (blue) and ATA_{mean} (orange) at each intensity zone. (± SD). Intensity zone 1= 60% (SS ± 5.11, ATA ± 2.56), intensity zone 2= 85% (SS ± 5.02, ATA ± 5.75), intensity zone 3 = 100% (SS ± 4.94, ATA ± 6.69), intensity zone 4= 110% (SS ± 5.14, ATA ± 5.19), intensity zone 5 = 120% (SS ± 5.61, ATA ± 5.38). (n=12)

DISCUSSION

The aim of this study was to see how the intensity affected the pedal stroke quality, and if ATA was an indicator on SS. The hypothesis was that with increasing power output, a cyclist would need to focus more on the pedal stroke, which would increase SS, and as a result of increasing SS, ATA would be close to 90°. The results of this study does not confirm this hypothesis as there were found no significant differences between SS at low power output and at high power output. The correlation between ATA_{mean} and SS_{mean} were insignificant.

The FTP test was completed with valid data outcome. Every test subject reached 10 on the RPE scale, and both SS and ATA didn't have large deviations on 100% of FTP in the stepwise increasing power test.

There were no significant differences between SS at each intensity. Looking at the correlation between SS and cadence at each intensity, the variation between cadence is high, but the SS numbers is more or less consistent (table 6). A reason for this might be that the evenness of a pedal cycle is not dependent on power output, since adapting to a certain cadence at a power output is easier than changing the technique. However, being that the correlation between Cadence and SS is low at this study, there are many studies confirming that cadence has an influence on the pedal cycle (mainly studies which includes GE, DC and FE) (Korff et al., (2007), Leirdal et al., (2010) and (2011), Arkesteijn et al., (2012)).

The subjects tend to have low cadence at intensities below FTP (60%: 89.76 ± 4.43 rpm) compared to intensity at FTP (92.74 ± 3.54 rpm). However, the subjects has highest cadence at 110% of FTP (94.56 ± 3.39 rpm). The reason might be that the gear ratio and cadence restrictions made it hard to stay on the targeted power for 3 min. Another reason might be that it is an unnatural intensity. At endurance training, power output is below 110% and during interval training, the intensity is above 110% of FTP. SS on the other hand, decreases at 110% of FTP (62.52 ± 5.14), compared to FTP (63.06 ± 4.94), but is almost equal to SS at 60% of FTP (62.51 ± 5.11). Knowing that there is no differences between SS at 60% and 110%, but high differences between the cadences at these intensities, makes it hard to prove that SS is affected by cadence.

Looking at each intensity individually, the correlation between SS and ATA at 85% of FTP is higher than the correlation at 120% of FTP (R= 0.71, P= 0.01 at 85 % and R= -0.457, P= 0.135 at 120%). Using SS is an indication of GE, when combined with ATA, these findings confirm Cámara's study, showing that GE is higher at LT than above LT (Cámara et al. (2012)). On the other hand, the cadence at 85% is approximately equal to the 120% (91,9 ±3,4 at 85% and 91,7 ± 3,4 at 120%), which can not be confirmed by Cámara's study, saying that at higher intensities cadence is reduced compared to low intensities. A reason for this might be that the subjects did the tests on a racing bike, and not on an ergometer bike, making it hard to find the correct gear for the targeted power. Another reason might be that the power output is so high, that to complete the 3 min period, the subjects use the gears to navigate power output, rather than with cadence.

However, looking at the correlation between SS_{mean} and ATA_{nr} mean (Figure 9) shows that the correlation between SS_{mean} and ATA_{nr} mean is more significant than the correlation between ATA_{mean} and SS_{mean}. Setting 90 ± 5° as the highest score (table 1), makes high SS numbers more significant to good ATA angle, indicating that high SS should affect ATA. However, the correlation between ATA_{nr} and SS is not significant. Removing an outlier, gives ATA_{nr} mean and SS_{mean} a higher correlation (r= 0.65, P= 0.02), but still not significant.

The lack of correlation between cadence and ATA shows that the average torque angle is the same, even in high cadences and/or with high or low power output. However, knowing that cadence affects GE, FE and dead centre, it is reasonable to believe that cadence also affects SS at a certain rpm. Leirdal and Ettema (2011) showed that with a cadence at 60 rpm GE and FE was high, but with a cadence up to 120 rpm, both GE and FE dropped in correlation with the increasing cadence.

The difference between bad and good pedal technique is too big within the subjects. On average, the subjects pedaling technique is too low, compared to elite cyclists. To the authors knowledge, just one subject have had systematic training towards better technique, giving him an averaged SS at 72.6 %, which is 4.4 above the second highest. Improving the technique for the subjects, could give a different test result. The correlation between distance and ATA concludes this hypothesis ($r = 0.52$, $P = 0.08$), which shows that the subject with high distance, has the highest ATA. Excluding an outlier, makes the correlation more significant ($r = 0.78$, $P = 0.09$).

The conclusion regarding this test is therefore that power (Watt) does not affect SS at any intensity. Good ATA, close to 90°, does not indicate a better pedal cycle (SS). However, the variation between each sample is too great to provide significant results. With better athletes, an ergometer bike and more test subjects, the correlation might be different. Further research should include an ergometer bike and gross efficiency, to look at the difference between good and bad pedal technique at different power outputs.

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