Bachelor's thesis

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The Effect of Different Warm-Up Protocols on Performance in Aerobic Endurance Sports

Bachelor's thesis in Human Movement Science
Supervisor: Knut Skovereng
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Abstract

(ENG) Warm-up is commonly used by athletes to reduce the risk of injuries and enhance performance by increasing cardiac output and preparing the body for physical stress. Previous research has shown contradicting results on whether warm-up has an effect or not on performance, and how athletes should conduct a warm-up. This literature review focuses on identifying factors that may affect performance, such as duration, intensity and the time between warm-up and competition. Eight studies were investigated involving 94 participants conducting several different warm-up protocols. Six out of eight studies showed no statistical significant differences, indicating that different warm-up protocols do not have any effect on performance. However, the results show positive results after conducting an active warm-up, although the results are not strong enough to become statistically significant. It is recommended to conduct an active warm-up as it seems to be beneficial. The warm-up should not be too intense where the athlete starts with too high levels of blood lactate (>5 mmol*l^-1) which may have a negative effect on performance. More research with bigger populations are needed in this area in order to say for sure how different warm-up protocols affect performance.

Abstrakt

(NOR) Oppvarming er vanligvis gjennomført av utøvere for å redusere risikoen for skader, og for å forbedre prestasjon ved å øke minuttvolum og forberede kroppen på fysisk anstrengelse. Tidligere forskning er motsigende på om oppvarming har en effekt eller ikke på prestasjon, og hvordan utøvere bør gjennomføre oppvarmingen. Denne litteraturstudien fokuserer på å identifisere faktorer som kan ha en effekt på prestasjon, som varighet, intensitet og tid mellom oppvarming og konkurranse. Åtte studier ble undersøkt, med til sammen 94 deltakere, som gjennomførte og sammenlignet flere ulike oppvarmingsprotokoller. Seks av åtte studier viste ingen statistisk signifikante forskjeller, noe som indikerer at ulike oppvarmingsprotokoller ikke har noen effekt på prestasjon. Resultatene viser derimot positive utslag etter gjennomføring av en aktiv oppvarming. Selv om resultatene ikke er sterke nok til å bli statistisk signifikante er det likevel anbefalt å gjennomføre en aktiv oppvarming siden det ser ut til å være fordelaktig for utøveren. Oppvarmingen bør ikke være for intens slik at utøverne starter med for høye blodlaktatnivåer (>5 mmol*1^-1), som kan ha en negativ effekt på prestasjon. Det trengs mer forskning med større utvalg på dette område for å kunne sikkert si hvordan ulike oppvarmings protokoller påvirker prestasjon.

1. Introduction

Warm up (WU) is defined as a process to prepare the body through exercises before doing sport activity (1). WU are widely used by athletes in order to improve performance and reduce injuries (2). For the athletes, the WU are commonly performed to benefit physical, physiological and psychological factors prior to the upcoming exercise.

There are several physical benefits of a WU. The WU can reduce the incidence of muscle injuries by increasing the blood flow to the muscles, which will lower the risk of the muscles to get torn or twisted during exercise (3). WU will also increase the flexibility of the muscles, which will also reduce the risk for injuries (3).

The physiological benefits of a WU can, according to Woods et.al (3), for example be increased temperature, which will lead to vasodilation, that will increase the blood flow to the tissues. Additionally, it will lead to faster muscle contractions and nerve transmissions, which in turn will improve the muscle's efficiency and its reaction time (3). The VO2, the amount of oxygen the body consumes, at rest will be elevated for the upcoming exercise after a WU, since the body will adjust to the physiological demands. In addition, there will be an increase in heart rate, respiration and cardiac output that prepares the body for increased physical activity (4).

The body may need longer time adapting to the rapid change of physical demands on the muscles and respiratory system during a competition without WU. It takes time for the body to meet the requirements of oxygen uptake during physical activity. When the intensity of the exercise increases, the requirements and the oxygen deficit becomes larger (5). There is a relationship between oxygen deficit and blood lactate, where a bigger oxygen deficit results in higher blood lactate (5). A high blood lactate level is related to muscle fatigue, which may reduce the performance level of the athlete (6).

In addition to physical and physiological benefits, WU can have psychological benefits. Ladwig (7) examined the psychological effects that WU gave on students. Those who performed WU before exercise reported higher levels of motivation and greater enjoyment during exercise (7). Performing a WU will also prepare the athletes mentally for the coming exercise, and the concentration will become better (8).

WU can be classified into two separate categories; Passive and active WU. The passive WU involves raising the body temperature by external factors. An active WU involves muscle contractions where the body temperature will be raised, and will induce metabolic and cardiovascular changes (8). The active WU can differ in duration, intensity and recovery periods between WU and performance (4). The active WU is known to have a positive effect on long tasks (>5 min) (4). Therefore, an active WU can be classified as beneficial among the long distance runners and endurance athletes due to its specificity and effect on running economy.

It is commonly known that WU has a positive effect on performance in sports, even though the scientific data shows different results in different settings. Several variables will affect how a WU exercise should be structured, such as intensity, duration, and the recovery period between WU and performance (9). Different sports and the competition time may have an impact on how the athletes choose to plan and conduct their WU routine.

Competing in long distance running (>1500m), or endurance sports where the aerobic energy source is primary, will put different demands on the athletes, such as endurance and speed. To enhance performance, the intensity and duration of a WU must be high enough to meet the demands of the aerobic endurance sport. Bishop (4) has suggested that a WU of a duration of 3-5 min of moderate intensity, is enough to improve short-term performance (>10s), while you will need a longer WU for an intermediate performance (<10s-5 min) to raise the VO2 at rest (4). But researchers are still not sure which type of WU that is shown to have the best effect on performance.

Several studies have been done on WU and performance when investigating factors that may enhance performance, using both active and passive WU. The quantity and variation of WU protocol studies depends on the physical activity or the sport. There seems to be conflicting results whether it has an effect on endurance performance or not based on the previous studies conducted on WU and endurance performance. The aim of this study is to investigate the effect of WU on endurance performance. We will look closer on the duration, intensity and the time following WU on subsequent performance in aerobic endurance sports.

2. Method

2.1 Literature search

To find primary sources to this literature study, studies from the last 15 years (between 2007-2022) were searched for. While searching on Pubmed March 31th 2022, using the words "warm-up, "running" and "performance", it gave 296 results. To narrow it down to get more relevant studies, the word "duration" was added. This gave 46 results. The word "duration" was replaced by the word "intensity", which gave 87 results. The headline of the studies were reviewed, and when someone fitted the aim of the study, the abstract was read. When searching in the databases SPORTDiscus and Oria, similar results were found as when searching in Pubmed. The reference lists from the articles that were found were read to see if there were any relevant articles that were avoided in the literature search, and which met the including-criterias. This did not give any new articles as primary sources, but as secondary sources.

2.2 Inclusion and exclusion criterias

All of the primary sources that are included in this study are peer-reviewed and randomized crossover studies. Other including criterias were that the athletes participating in the studies should have a mean VO2max over 40 ml/kg/min, the different tests within the studies were performed on different days with at least 48 hours between, and the participants of the studies had to be between 18-35 years old. When searching after primary sources, there were many studies done on sprint and/or run of a duration under 3 min, soccer players etc. These were excluded.

2.3 Categorization of different warm ups (WU)

Since the different studies use different names for their WU-protocols, it was necessary to categorize them in order to get a good overview. The WU-routines are categorized based on the duration and intensity of the WU and are presented with the different criterias in Table 1. If there was no active WU before the trials, NWU (No warm up) is used.

The intensity was used as one category since there are physiological factors that are affected by the intensity of WU such as stroke volume. A higher intensity will lead to a greater stroke volume, and it was therefore natural to categorize intensity in low, medium and high. Some other physiological factors take longer time to adapt, such as core and muscle temperature. Therefore it was decided to also categorize using short, medium and long duration of the WU.

Table 1. Categorizing the different WU-routines based on intensity and duration. If there were no active warm up, NWU (No warmup) is being used.

	Low Intensity (LI) <60% VO2-max / <70% HF-max	**Medium Intensity (MI) 61-70% VO2-max / 71-85% HF-max**	**High Intensity (HI) >70% VO2-max / >85% HF-max**
Short Time (ST) ≤10 min	LIST	MIST	HIST
Medium Time (MT) 11-20 min	LIMT	MIMT	HIMT
Long Time (LT) >20 min	LILT	MILT	HILT

3. Results

The eight studies that are included involve 94 participants that performed different warm-up protocols. Some of the studies investigated the effect of the duration or intensity of the warm-up, time of recovery between the WU and the trial, and others on WU or NWU. The different WU protocols were followed by either a time to exhaustion, time trial run or distance trial run. Background of the participants and the main findings from each study are described in more detail in Table 2.

Table 2: An overview of the participants, WU protocols and results of TT in the eight studies. The data is presented in mean value ± standard deviation if nothing else is written.

Study	Anthropometric of participants			Type of WU and (time between WU and TT)	Distance/Duration of test	Outcome
	Quantity, sex and Age, y	**Body mass, kg**	**VO2max, mL/kg/min**			
Spitz et al, 2014 (10)	Rowers: 4M+1W:33±10 Runners: 3M+2W:23±2	Rowers: 83±12 Runners: 65±8	Rowers: 44,1±7,9 Runners: 59,1±5,9	Standardized WU for all four tests: 15 min (10 min 60-70 % VO2max + 5x30 s sprints) followed by 5 or 30 min rest before TT in 24 (T) or 5 (C) degrees celsius MIMT-5T* (5 min), MIMT-5C (5min), MIMT-30T (30 min), MIMT-30C (30 min)	2km row / 2,4km run MIMT-5T: 497,4±78s MIMT-5C: 505,8±86,4s MIMT-30T: 508,8±92,4s MIMT-30C: 517,2±95,4s	No statistically significant difference
Solli et al, 2020 (11)	M(8):20,1±2,1 W(6):20,8±3,6	M:77,8±6,6 W:62,2±9,1	M: 68,1±5,3 W: 63,1±5,2	HIST (5 min): 8x100m 60->95% speed, 1 min break between intervals LIST (5 min): 35 min incl 5 min moderate and 3 min high intensity	1,3km sprint (XC- skiing) HIST: 199±17s LILT: 200±16s	No statistically significant difference

Zourdos et al, 2016 (12)	M(16):21±2	66,5±4,6	69,3±5,1	LIST (2 min): 5 min rest, 6 min submax run (45-65% VO2max), 2 min walk NWU: 13 min rest	30 min distance trial LIST: 7,8±0,5km NWU: 7,7±0,6km	No statistically significant difference
Tilaar et al, 2017 (13)	M/W:N/a (13):23,2±2,3	79,8±8,2	55±5	MIMT (5 min): 10 min 80 % HR + 8x60 m (60-95% max speed), 1 min break between intervals MIST (5 min): 8x60m (60-95% max speed), 1 min break between intervals	3 min distance trial MIMT: (765±80m) MIST: (752±78m)	No statistically significant difference
Takizawa et al, 2018 (14)	M (7): 21,3±2,1	58,4±5,6	73,3±5,8	NWU LIMT (5 min): 15 min 60% VO2-max MIMT (5 min): 15 min 70% VO2-max HIMT (5 min): 15 min 80% VO2-max	Time to exhaustion (90% VO2max) NWU: 786,3±201,9s LIMT: 912±308,8s MIMT: 854,6±224,9s HIMT: 769,6s±264,0s	No statistically significant difference
Paris et al, 2016 (15)	M (7), W (7): 22±1	66,7±3,4	M: 56,8±2,3 W: 43,7±0,8	NWU: 5 min sitting + 5 min stretching MIST (20 min): 1600m run, 80% of max~7 min duration HIST (20 min): 4x400, 1 min rest. 120% of average speed, ~9 min duration	1600 m time trial NWU: 390±18s MIST: 372±18s HIST: 378±24s	MIST 4,4 % better than NWU ($p<0,03$).

Wittekind & Beneke, 2009 (16)	M (9): 26,9±7,4	73,7±10,3	61,9±3,4	NWU LIST (5 min): 10min (60% VO2-max) HIMT (5 min): individually chosen jog at (60% VO2-max) + 6x15s (105% VO2-max), 1 min break between intervals	Time to exhaustion (105% VO2-max) NWU: 290s LIST: 324s (-80, 10) (95% Confidence interval) HIMT: 316s (-77, 43) (95% Confidence interval)	No statistically significant difference
Gonzalez et al, 2018 (17)	M (11): 25,2±3,9	65,4±6,8	68,1±4,8	15 min submaximal run (60 % VO2max) followed by either: LILT (18 min): 7 min run (60% VO2max) LILT+S** (18 min): 10 min + 5 min + 6x6-s level uphill strides (105% VO2-max; 5% gradient) HILT+S (18 min): 10 min + 5 min + 9x20-s level strides (105% VO2max; 1% gradient) The 18 min between WU and TT consist of: 10 min recovery + 5 min submaximal run (60% VO2 max) + 3 min recovery	Time to exhaustion (105% VO2-max) LILT: 144,8±6,6s LILT + S: 160±6,2s HILT + S: 152,6±10,9s	LILT+S better than LILT (p<0,05)

*Categorizing of the WU protocols are described in Table 1. *: 5T = 5 min between WU and TT in Temperature (24 degrees celsius). 5C = 5 min between WU and TT in Cold (5 degrees celsius). 30T = 30 min between WU and TT in Temperature. 30C = 30 min between WU and TT in Cold.*
***: S = Strides* ≤ 20 seconds*).*

The results suggest that there seem to be no significant differences in different WU-protocols as six out of eight studies showed no significant differences. The p-value is used as a method to determine the statistical significance ($p<0,05$) of the results.

3.1 Time spent between WU and performance

One study (10) compared 5 min and 30 min of rest between WU and TT in different temperatures, and showed no significant difference. Two other studies (15,17) showed positive results with a rest incorporated with light activity of 18 min (10 min rest, 5 min submaximal run 60 % VO2max, 3 min rest) (17), and 20 min continuous rest (15) between WU and TT compared to NWU. One study (10) also shows that 30 min is too long in order to have a positive effect on performance, especially in cold weather. The other five studies had less than five min between the WU and the performance test (11-14,16).

3.2 No warm up or warm up

Four out of eight studies have investigated the differences in performance after no WU versus active WU consisting of different duration and intensity (11,14-16). One of these studies showed a significant difference in performance, 4,4 % faster with a moderate-intensity WU, with 20 min rest between WU and time trial, compared to NWU (15). The other three studies didn't show any significant differences, although two of these have slightly better results after active WU (14,16).

3.3 Duration

There were two out of eight studies who investigated the effect of short- and long WU (11,13). None of these studies showed any significant difference in performance between the short and the long WU. In the study done by van den Tillar et al. (13) was the rate of perceived exertion and heart rate higher after the long WU and the time trial compared to the short WU followed by time trial (13).

3.4 Intensity

Five out of eight studies investigated the effect of the intensity of the WU (11, 14-17). Only the study by Gonzales (17) showed a significant difference in performance between the intensities of WU's, where TT was significantly better after uphill WU of high intensity compared to the control WU. Paris et al. (15) found that a time trial after a moderate-intensity

WU was faster than a high-intensity WU, even though this was not statistically significant. Heart rate was significantly elevated from the high- and moderate-intensity compared to the light intensity (NWU) (15).

The most common factor that the studies investigated was the use of strides or short intervals as a part of the WU-routine. This was investigated in five out of the eight studies (11,13,15-17). Four of these showed no significant differences between WU with strides and other types of WU, or no WU-protocols (11,13,15,16). One study (17) showed a significant improvement after short strides on an ascent of 6%.

4. Discussion

4.1 Discussion of results

The purpose of this literature study was to see how different WU protocols will affect endurance performance. 8 studies were included to explore this. 6 out of 8 studies show no statistically significant difference in performance after performing different WU protocols. The two studies that showed differences in performance were both positive to WU, even though the WU protocols were not the same. The study conducted by Paris et al. (15) showed positive results for WU including medium intensity for a short time (MIST) compared to no warmup (NWU). The study performed by Gonzales et al. (17) found that the use of strides in a WU protocol improved performance compared to the same WU protocol without strides.

While six of the studies didn't show any statistically significant difference, there seems to be a clear improvement in performance when performing an active WU. Three out of the four studies that compare active WU to NWU (12,14-16) show results in favor of performing an active WU, even though only one of the studies have results strong enough to make them statistically significant.

Although these studies didn't show any statistically significant difference (12,14,16), the authors still suggest athletes to conduct active WU, since there seems to be a small positive effect for the athletes performing the WU. When competing on a high level, the margin between success and failure is minimal. Based on the studies we have incorporated, there is no evidence that WU has a negative impact on performance. Although for the participants in the studies with VO2 max <60 ml/kg/min, the WU did not show the same positive effect of a WU compared to participants with higher VO2 max at an elite level. Taking this into account the results are still in favor of an active WU, and even though they are not strong enough to be statistically significant in all of the studies, athletes should be encouraged to conduct an active WU when competing in endurance sports.

The discussion on whether it is worth it to put a lot of effort into something that doesn't show any immediate and strong enough results for improved performance is relevant. While the possibility to gain some seconds here and there by conducting an active WU is possible, it is not certain that all athletes will gain a positive effect by doing so when looking at different levels in VO2 max. We still believe that it is worth it to have the knowledge and adaptability to conduct an active WU suitable for different competitions. With these tools, athletes can manage their training load with changes in their WU to gain those extra margins in future competition.

An interesting subject to then discuss is that the physical level of the athletes could have an effect on how they should conduct the WU. The better trained the athletes are, the better they seem to cope with longer and more intense WU protocols. The athletes with lower VO2-max seem to perform worse if the WU is either too long or too intense compared with an active WU that is shorter and less intense (13,15,16). Not so well trained individuals may get exhausted by performing a WU that is too long. It will also take longer for their heart rate to slow down after an intense WU. The result may be that individuals are still fatigued when the test begins.

In order to get enough studies we had to lower the criteria of the participants VO2-max. The original goal was to include subjects with VO2-max above 60 ml/kg/min, but then there was not enough studies to include. We ended up with a lower limit of 40 ml/kg/min. This could have an effect on the study that weakens the strength of the results in order to look at elite performance, since the elite runners may be used to conduct a longer WU. The new criteria gave us the opportunity to compare a wider range of physical fitness among the participants, something that has given us some findings that we wouldn't have seen otherwise.

Paris et al. (15) found that a 1600 m run was optimized when starting lactate concentration was between 2.0 - 4.9 mmol*l^-1 compared to when starting lactate concentration was over 5 mmol*l^-1. This might indicate that a higher intensity in the WU demands a longer time between WU and competition in order to get better performance, by then making sure that the blood lactate has come down to levels below 5 mmol*l^-1. Not so well trained individuals may be more exposed to this since it will take a longer time for them to recover from fatigue compared to well-trained athletes.

4.2 Study designs

Many of the studies contain few participants, ranging from seven to sixteen. In studies with few participants individual differences may have a larger effect on the result. We can see in two of the studies (14,15) that some individual data seem a bit odd, and is likely to have a negative effect on the result. We can't say what causes these differences, but individual differences wouldn't make a significant impact on the result of the studies if the number of participants were higher.

A limitation of the study done by Solli et al. (11) may be that the two different WU protocols were done on the same day with 20 min cooldown after the distance trial, followed by 1 hour and 40 minutes rest before the next WU and distance trial were conducted. This may lead to more fatigue in the second WU-protocol, compared to the other studies where there was at least 48 hours between WU and TT. In addition to fatigue, this may lead to less motivation for the second WU-protocol, since a long day with continuous strain both physically and mentally can take a toll, and have an effect on the subjects when performing the second test. Although this may be a limitation when compared to the other studies. The participants in this study performed the WU protocols in the same order, therefore there was no difference between the participants within the study.

In the study done by Paris et al. (15) a subjective Borg Skala is used as a measure to set the right perceived intensity of the WU. Depending on how familiar the participants are to treadmills and workouts, the use of a subjective measurement may give a false WU-intensity, making a medium intensive WU either more or less intense then planned for. Using VO2-max instead as a way of establishing the correct pace would make a more trustworthy result.

4.3 Implementation of our findings

It's very common for athletes to use an active WU as a part of getting in the right mental state before a competition. These studies do not consider the psychological part of WU, and there will be a difference in the mental state of athletes while completing TT in training, a scientific study and in championships. There will always be individual differences in how athletes choose to perform their WU and what they include in the WU protocol, such as physical and psychological readiness.

In sports where equipment is being used it's also common for the athletes to warm up with the equipment, in order to get familiar and get a good feeling with it, and perhaps do some last-minute adjustments. This may put some natural demands of a slightly longer WU, with testing or adapting to the equipment being part of a WU protocol. The two studies (10,11) that used equipment (rowing ergometer and cross-country skiing, skate style), both conducted their whole WU with the equipment being used in the TT.

The duration and intensity of WU may also play a role in the total training volume of athletes, and it can therefore have a say in how the WU should be performed depending on the purpose or goal with the current period of training. Fitness level of the athletes may have a say as well in how the WU should be conducted. While well-trained athletes can get positive effects of longer WU such as training load, untrained individuals may just get fatigued instead by the WU and miss out on the effect and/or purpose of the exercise/competition.

It is not that important with the training load during competitions, and the athletes have nothing but one goal which is to perform their best. The differences towards training are vital, as the athletes' main goal for training sessions focuses more on training volume and following a well-structured plan. Being flexible in the way athletes conduct WU can also help with the training plans during the training season. Athletes can either increase the training volume with longer WU, or conduct shorter WU in order to get an extra session in instead of longer WU.

Some sports may have many competitions in a short period of time, and if an athlete gets the same performance by conducting a short or long WU, it might be beneficial to conduct a short WU during the busy competitions. The athlete should then be able to save more energy from each competition, and be able to compete with higher energy levels throughout all competitions. Longer WU protocols may risk the athlete in consuming more energy, increasing the occurrence of the athlete running short on energy during the competitions. Thereby the WU could work opposite of it's intention, where the WU may end up lowering the performance level of the athlete.

Our findings can be supported in endurance activities where the competition time is between 3 min and 30 min, and where the athletes are well-trained. The main part of the results in this study shows no statistically significant difference in performance after conducting different WU protocols. The results all indicate that an active WU has a small positive effect, and since there are no signs indicating that it would have a negative impact on performance we suggest that athletes conduct an active WU. The athletes may choose a WU they are comfortable with and have faith in, but should be able to have the flexibility to conduct different WU-protocols. The current training period for the purpose of the training session can have an impact on which type of WU protocol that should be incorporated. A long WU to increase the total training volume, or a shorter one in order to save energy.

The results in this study may be useful for athletes in common environments, but uncertain for competitions in high altitude, extreme weather conditions or other endurance sports like team sports, sport with other equipment or anaerobic sport. Our findings also apply for flat surfaces, since our studies haven't investigated performance in hilly areas or uneven terrain.

4.4 Future research

After this literature search, it is clear that there exist few studies on WU and its effect on intermediate running performance, and with relatively few participants in the studies that are done. More research on how WU affects performance is needed, and it is recommended that the studies contain more participants to make the results more valid. Low number of participants is generally a problem across all the studies, and many of the participants can not be classified as a highly trained athlete. A larger study population with better trained athletes are needed to get a more valid result.

5. Conclusion

Our findings indicate that an active WU is beneficial, especially in top athletes but there doesn't seem to be any clear pattern on which type of WU that is best. It seems to be important not to conduct a WU that is too intense or too close to the race, especially for not so well trained athletes. It can be beneficial to be able to conduct different types of WU depending on where the athlete is in the season in order to get the best training load for that period.

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