Bachelor’s project

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The Effect of Ambient Temperature on Exercise Metabolism and Gross Efficiency

Bachelor's Thesis in Human Movement Science
BEV2900 - Spring 2021

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Kunnskap for en bedre verden

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ABSTRACT

Purpose: T_a affects performance, and there are conflicting findings of alterations in metabolism and GE/economy in various ambient temperatures. It is likely that changes in substrate utilization and exercise metabolism affect GE/economy. Due to the conflicting findings in the research, the purpose of this study was to investigate how T_a affects metabolism and GE/economy, and how alterations in metabolism can affect GE/economy. **Method:** Eight studies were found thru the databases PubMed and SportDiscus and the study had to investigate the effect of ambient temperature on either exercise metabolism or GE/economy between at least two different ambient temperatures (cold, thermoneutral or hot). **Results:** T_a affected substrate metabolism and GE/economy in all studies. **Conclusion:** Comparison of the results are problematic since the results are scattered and the measurements varies between the studies. However, changes in metabolism and GE/economy have been found, but how they impact one another is not clear. Several variables contribute to alterations in metabolism and GE in various ambient temperatures. Variations in subject characteristics and testing protocol of the studies made accurate comparisons difficult, which necessitates the need for further research on this topic.

ABSTRAKT

Formål: T_a påvirker prestasjon, og det er motstridene funn på endringer i metabolisme og GE/løpsøkonomi i ulike temperaturer. Det er sannsynlig at endringer i substratutnyttelse og treningsmetabolisme påvirker GE/løpsøkonomi. Grunnet motstridende funn i forskningen er hensikten med denne studien å undersøke hvordan T_a påvirker metabolisme og GE/løpsøkonomi, og hvordan endringer i metabolisme kan påvirke GE/løpsøkonomi. **Metode:** Åtte studier ble funnet via databasene PubMed og SportDiscus og studiene måtte undersøke effekten av omgivelsestemperatur på enten treningsmetabolisme eller GE/løpsøkonomi mellom minst to forskjellige temperaturer (kulde, termonøytral eller varme). **Resultat:** T_a påvirket substratmetabolisme og GE/løpsøkonomi i alle studiene. **Konklusjon:** Sammenligning av resultatene er problematisk siden resultatene er spredt, og målingene varierer mellom studiene. Imidlertid er det funnet endringer i metabolisme og GE/løpsøkonomi, men hvordan de påvirker hverandre er ikke klart. Flere variabler bidrar til endringer i metabolisme og GE/løpsøkonomi i ulike omgivelsestemperaturer. Variasjoner i personkarakteristikker og testprotokoll i studiene gjorde nøyaktige sammenligninger vanskelig, noe som nødvendiggjør behovet for videre forskning på dette emnet.

Key words: Exercise metabolism, Gross efficiency, Economy, Ambient temperature

1.0 INTRODUCTION

Various athletic competitions are held in different environmental conditions that can affect performance. As known ambient temperature (T_a) is one of these conditions, and it varies greatly depending on the geographical area and time of year – for example tour de France for cyclists in summer and tour de ski for cross-country skiers in winter. From the place you live to the place you compete, major changes in T_a may be challenging for the athletes as the body needs time to adapt to new competitive circumstances. Thermoregulation is important for both the performance and safety of the athlete, and this is a process where body temperature is maintained during several different environmental conditions (1, p. 441). Heat dissipation is the body´s way to get rid of excess heat (2, p. 228), which makes a higher cardiac output necessary to continue to supply blood to the muscles and extra blood to the skin for cooling (3,4). Vasoconstriction and shivering are the body´s way to defend core temperature in the cold (2, p. 238-239) , and shivering seems to create a greater demand of energy where carbohydrates are more needed (5). It is well established that performance is affected by T_a (3,6,7).

Performance can be described by the interaction of different performance-determining variables. For endurance sports, such as cycling and running, there are three main variables that affect performance which is maximal voluntary oxygen consumption (VO_2max), lactate threshold and efficiency (8). VO_2max and lactate threshold work together to determine oxygen consumption that can be maintained for a given period, also called “performance VO_2” (8). Efficiency, or economy, will interact with one’s performance VO_2 to determine the speed or power one can generate at this oxygen consumption (8).

There are multiple definitions of efficiency, of which gross efficiency (GE) is considered the most appropriate measure of whole-body efficiency (1, p. 112). GE is a ratio of work output and energy expenditure input/metabolic power input (PI). During running or level walking, GE cannot be determined, and oxygen consumption or energy expended at a particular speed can be used to determine economy (1, p. 115). Temperature induced changes in GE is a possible explanation for the known deterioration in performance seen in the heat (3). Yet there is still no clear understanding of how T_a affects GE.

Exercise metabolism is the way our body produces metabolic energy from oxidation of carbohydrates, amino acids, and fats, and can be either aerobic or anaerobic. Anaerobic metabolism only allows us to oxidize carbohydrates, while aerobic metabolism allows oxidation of fats, amino acids, and carbohydrates. How much energy needed for completion of a given activity can be determined by aerobic metabolism and it can be assessed by measuring oxygen consumption (VO_2). The ratio at which oxygen and carbon dioxide is consumed and produced in the body is called the respiratory exchange ratio (RER). RER can further be used to assess which substrate (fats or carbohydrates) is the primary source of fuel (1, p. 102-104).

Previous research has found fat utilization to decrease and carbohydrate utilization to increase during cold exposure (9), whereas others have found fat utilization to increase and carbohydrate utilization to decrease in the cold (10). During exercise in warmer temperatures, some have found an increased fat utilization (11), others found it to decrease, and carbohydrate utilization to increase (5). It has also been found that low intensity exercise (50-60% VO_2max) does not enhance fat utilization in the cold (12). At moderate intensities (65% VO_2max) it seems to be elevated (12). Severe cold exposure where rectal temperature (T_r) is lowered seems to increase fat utilization (12). Exposure to the cold temperature prior to onset of exercise seems to elevate CHO utilization, caused by shivering (12). Low intensity exercise in the heat is on the other hand found to enhance maximal fat oxidation (11).

A reduction in mechanical efficiency is found when muscle temperature (T_m) is lowered (12). Alterations in carbohydrate oxidation and oxygen consumption in the cold (4ºC) may indicate alterations in mechanical efficiency (6). There are also findings of improved performance in colder temperatures (3,7), and this may reflect a lower rate of glycogen utilization and is likely related to carbohydrate availability (13). GE (3), power output (14) and running economy (7) are found to be reduced in the heat.

Since there are conflicting results regarding metabolism and GE in various ambient temperatures, a review on this topic is necessary. Based on the previous research conducted on the effect of ambient temperature on metabolism and GE, the aim of this study will be how ambient temperature affects metabolism and GE, and how the temperature induced changes in metabolism can affect GE.

2.0 METHOD

2.1 Literature search

The literature search was conducted using the databases PubMed and SPORTDiscus. Based on the search terms “ambient temperature” AND “exercise” AND “efficiency”, 19 results were found. In addition, the search terms “oxidation” AND/OR “metabolism” AND “ambient temperature” AND “exercise” gave 31 results. A total of 50 results were found. Furthermore, a manual search was conducted in the reference list of the relevant articles to identify whether there were articles avoided in the literature search. Eventually 6 articles from the literature search and two articles from the reference lists fit into the predetermined inclusion criteria.

2.2 Inclusion and exclusion criteria

The inclusion criteria for the current study were: 1) subjects recreationally active to highly trained (15), 2) adults with range 20-30 yrs., 3) testing conducted in cold (0-10 °C) and/or thermoneutral (15-22 °C) and/or hot (>35 °C) temperatures, 4) results compared with either cold, thermoneutral or hot temperatures, 5) possess information about the effect of T_a on exercise efficiency and/or substrate metabolism/oxidation.

2.3 Calculations

Exercise efficiency was not calculable in all studies, but if the workload was stated the same in each trial then PI was calculated with the following formula: $PI = VO_2$ L/s (4940 * RER + 16040) (16). This can provide an estimate of whether exercise efficiency is lower or higher based on PI in the relevant studies.

Mean values for VO_2, skin temperature (T_{sk}), T_r and RER was not included in some of the studies, therefore mean values were calculated from the relevant figures and is marked with “≈” in the current study. In cases where the original study stated significant differences at all time points, the significant difference is presented with the mean value in this review.

3.0 RESULTS

The eight included studies (3,5–7,9–11,14) have either examined the effect of T_a on metabolism or efficiency. Most of the studies were performed by exercise on bicycle, two of them on running. Five studies examined the effect of T_a on metabolism, one on GE, one on running economy and the last one on a 20-kilometer time-trial. The latter three are seen in relation to efficiency. The main findings are presented in table 1.

Table 1: Characteristics and results from the studies included in the analysis.

Study	**Subject characteristics**	**Protocol**				**Results**
	n; sex; training status	Environmental conditions °C (RH%)	Exercise intensity; duration	Exercise bout;	Clothing status; temp. exposure prior to exercise	Thermoregulatory responses, physiological responses
Febbraio et.al (5)	7; males; PL 4	3℃ (50%), 20 ℃ (20%)	65% VO_2max; 40 min	Cycling	NM; 20 min	T_r: C ≈ 37.14*↓, N ≈ 37.84 T_m: C = 38.5±0.3, N = 39.1 ± 0.1 Mean RER: C = 0.89±0.00, N = 0.87±0.01*↓ Mean VO_2: C = 42.3±0.6, N = 42.3±0 (ml*kg^{-1}* min^{-1}) PI: C = 1042.26, N = 1037.23 CHO: C = 142±18 *↓ than N = 196±18 (mmol)
Gagnon et.al. (11)	9; males; PL 2	4.6℃, 34.1℃	Incremental until VO_2peak reached	Cycle ergometer/ treadmill	Lightly clothed; <30 sec	Mean VO_2 treadmill: C = 50.9 ± 6.5, H = 43.3 ± 5.3 (mlO_2 kg min^{-1}) Mean VO_2 cycling: C = 42.4 ± 7.5, H = 35.6 ± 6.0 (mlO_2 kg min^{-1}) Max FO treadmill: C = 0.66 ± 0.31*, H = 0.43 ± 0.23 (p = 0.017) (g min^{-1}) Max FO cycling: C = 0.45 ± 0.24, H = 0.29 ± 0.11 (p = 0.0.76) (g min^{-1})
Galloway & Maughan (6)	8; males; PL 2	4℃, 21℃, 31℃ (70 ± 2%)	70% VO_2max; to exhaustion	Cycle ergometer	Lightly clothed; <30 sec	Mean T_{sk}: C ≈ 23.6*↓, N ≈ 31.4*↑, H ≈ 34.9*↑ than C + N. Mean T_r: C ≈ 38.7, N ≈ 39.0, H ≈ 39.2. H *↑ than C Mean RER C = 0.886, N = 0.872, H = 0.883 Mean VO_2: C ≈ 3.18*↑, N ≈ 2.78, H ≈ 2.64 (L*min^{-1}) Total CHO: C = 168±20g, N = 149±11g, H = 90±6g *↓ than C + N Total FO: C = 51±17, N = 43±5 *↑ than H = 22±4 PI: C = 1082.1, N = 936, H = 897.7
Hettinga et.al. (3)	10; males; PL 3	15.6 ± 0.3℃ (20 ±10.3%), 35.5 ± 0.5℃ (15.5 ±3.2%)	60% VO_2max; 20 min	Cycling	NM; 35min in 15ºC, 50 min in 35ºC	Mean T_{sk}: N = 27,74±0.71, H = 33.39±0.57*↑ Mean T_r: N = 37.03±0.58 H = 37.35±0.63*↑ Mean RER: N = 0.89±0.03; H = 0.90 ± 0.01 Mean VO_2: N = 3,002.8 ± 290.1; H = 3,126.5±268.3 *↑ (ml*min^{-1}) GE (mean%): N = 20.5±1.4 H = 19.6±1.1 *↓
Layden et.al. (9)	9; males; PL 2	0 ± 0.1℃ (38.4%), 10 ± 0.1℃ (49.9%), 20 ± 0.1℃ (50%)	64 ± 5.8% VO_{2peak}; 90 min	Cycling	Lightly clothed + mittens and earmuffs in C; immediate onset	Mean T_{sk}: C1 = 22.7±0.57*↓, C2 = 26.74±0.38*↓, N = 31.54±0.35 Mean T_r: C1 = 37.93±0.26, C2 = 37.86±0.24, N = 37.94±0.18 Mean RER: C1 ≈ 0.963*↑, C2 ≈ 0.928, N ≈ 0.915 Mean VO_2: C1 = 2.61±0.12, C2 = 2.67±0.12, N = 2.77±0.17 (L*min^{-1}) PI: C1 = 915.1, C2 = 928.1, N = 966.4 FO: *↓ in C1 & C2 than N CHO: *↑ in C1 & C2 than N

Munten et.al. (10)	11; 7 males, 4 females; PL 2	0°C, 21°C	90% VO_{2peak}; 10*60 sec	Cycle ergometer	Lightly clothed; 15 min in 0ºC and 21ºC	Mean T_{sk}: C ≈ 21 *↓, N ≈ 32. Mean T_r: C ≈ 37 *↓, N ≈ 37.55. Mean RER: C = 0.94 ± 0.051*↓, N = 0.99 ± 0.029 Mean VO2: C ≈ 30.8, N ≈ 30.4 VO_2 ($ml*kg^{-1}*min^{-1}$). Interval 1 *↓ than 2-10 CHO: C = 2.44, N = 2.87 FO: C= 0.331, N= 0.144*↓
Sandsund et.al (7)	9; males; PL 5	1ºC, 10ºC, 20ºC	67-91% VO_2max; to exhaustion	Running	Clothed; immediate onset	Mean T_{sk}: * between all conditions, N↑ than C1 & C2, C2*↑ than C1 Mean T_r: C1 = 38,4 ± 0.4, C2 = 38,5 ± 03, N = 38,7 ± 0.4. No * between conditions. VO_2: C1 = 47.2, C2 = 48.5, N = 49.5*. N*↑ than C2. Running economy: Reduced in N compared to C
Tucker et.al. (14)	10; males; PL 3	15°C, 35°C (60%)	20 km time trial	Cycling	NM; NM	Mean T_r: N = 38.8 ± 0.4, H = 39.2 ± 0.6 Mean PO: N = 272 ± 45*↑, H = 255 ± 47

n = number, ± = standard error of the mean, NM = not mentioned, RH = relative humidity, T_{sk} = skin temperature, T_r = rectal temperature, GE = gross efficiency, FO = fat oxidation, CHO = carbohydrate oxidation
* = significant difference, *↓ = significantly lower, *↑ = significantly higher
C = cold ambient temperature, N = thermoneutral, H = hot ambient temperature
C1 = cold 0-1°C, C2 = cold 10°C
Lightly clothed = shorts and/or t-shirt
Clothed = full cross country ski suit
PL 2-5 = performance level x (15)

3.1 Main findings

3.1.1 Thermoregulatory findings

Significant differences in T_{sk} was reported in most studies (3,6,7,9,10). T_r did vary insubstantially between H, N and C in some studies (7,9,14), others reported significant differences in T_r between trials (3,5,6,10)

3.1.2 Changes in substrate metabolism

Fat oxidation was reported to be significantly different between temperature exposures in all studies (6,9–11), except for the bicycle trial in Gagnon et al.(11). Most studies found significant differences in carbohydrate oxidation (CHO) between exercise in different temperature exposures (5,6,9) except Munten et al (10).

3.1.3 Efficiency

The estimated and calculated values of GE and economy in this paper show that most studies (3,5–7) found GE/economy to be higher in cold ambient temperatures (C) than in the thermoneutral (N) or hot ambient temperatures (H). There are however conflicting findings in the study of Layden et al (9). Tucker et al. (14) found that mean power output during a 20km time trial was significantly higher in N than in H.

4.0 DISCUSSION

The effect of different ambient temperatures on metabolism or efficiency in relation to exercise have been examined in the included studies. Based on the estimated and calculated values of GE and economy, it is assumed that GE/economy is higher in cold temperatures than in thermoneutral or hot temperatures (3,5–7). However, there are conflicting findings in the study of Layden et al. (9). As seen in table 1, T_a affects metabolism during exercise. FO was found to be higher during exercise in the lower temperatures (6,10,11), but not all of them were found to be significantly different (11). On the other hand, Layden et al. (9) found FO to be lower during the lower temperatures. However, several confounding factors may influence the results as the conditions and terms are different between the studies (12).

4.1 The effect of T_a on metabolism

Layden et al. (9) concluded that the reduced fat oxidation in colder temperatures may be due to a reduction in lipolysis and/or mobilization of free fatty acids or loss of the muscles oxidative capacity. The whole-body fat oxidation was reduced at 0°C compared to 10 and

20°C. This may happen because of the impairment of the muscles oxidative capacity in the cold, in addition to a reduction in oxidation of circulating and intramuscular fat which is supported by Febbraio et al. (5) that has found a significantly lower T_m in 3°C compared to 20°C when exercising at 65% of VO_2max for 40 minutes. T_r was maintained in Layden et al.(9) but was decreased in Febbraio et al.(5) that seems to relate to a different utilization pattern together with a reduction in T_{sk} (9).

The study of Munten et al. (10) found that lipid oxidation increased by 358% when doing high-intensity exercise in cold temperature compared to thermoneutral temperature. Gagnon et al. (11) found similar results in moderate intensity exercise, where the maximal fat oxidation was greater during treadmill exercise in the cold compared to warm temperature. An increase of fat oxidation in the cold in these two studies corresponds to the study of Jett et al. (12) who suggests that cold exposure during exercise can lead to increased lipid utilization when severe enough exposure and lowered T_r. Increased fat oxidation may be explained by an increased oxygen cost of exercise, and as you can see in table 1, the mean VO_2 increases in the cold in the study of Galloway and Maughan (6). It is well known that metabolism and substrate utilization is affected by training status and exercise intensity. Subjects who are highly fit can utilize more fat as substrate during some exercise intensities (12), which can make the results less valid in this study as the subjects are spreading from habitually to highly trained.

Some studies measured RER to be higher during exercise in cold and thermoneutral temperatures than in the heat (5,6,9). Febbraio et al. (5) explains this difference in RER by changes in substrate oxidation since VO_2 levels were identical during both trials. Their carbohydrate utilization was lower in the cold trials than in the warmer trials and stated that the increased RER value may reflect involuntary activity associated with shivering in the muscles (5). Contrary, no significant difference was observed in either T_m or T_r in their study, making shivering an unlikely response in either of their trials (5). Carbohydrate utilization was higher during the cold trials in other studies (6,9) than in thermoneutral and hot ambient temperatures. A higher CHO oxidation in the cold may imply core cooling and shivering thermogenesis (6), which is unlikely in the study of Galloway & Maughan (6), but may be the case in Layden et al. (9) since T_r was below 38.5ºC and CHO oxidation were higher in their cold trial. It based on these findings hard to state why alterations in CHO occur in different temperature exposures, but one possible explanation may be lowered T_r.

4.2 The effect of T_a and metabolic alterations in GE

The observed changes in CHO during exercise in the cold (6,9) is consistent with either an alteration in mechanical efficiency or metabolism (6). Reduced T_m may cause decreased mechanical efficiency and increased CHO utilization (6,12). When estimated PI values, indicating if GE would be higher or lower, are compared to CHO oxidation, one can see that GE would be either higher (6) or lower (9) in the cold, with the same findings of CHO. The findings are however opposite in the study of Febbraio et al (5), where higher CHO oxidation is found in thermoneutral temperatures, and estimated GE higher in the cold. As carbohydrates is a fuel associated with increased energy demand caused by shivering (5) and T_{sk} may be an indirect measure of T_m (7), it is likely that the lowered T_{sk} in Layden et al. (9) caused reduced T_m, which in turn could alter performance (17) and may explain why GE were lower in the cold in this respective study. The conflicting findings when comparing CHO oxidation and GE indicates that the alterations in metabolism found in this review, cannot solely be responsible for the alterations seen in GE. There are however methodological differences between the studies, making it hard to make accurate comparisons.

A fall in oxygen consumption in one trial compared to another could reflect a higher proportion of the work being met by anaerobic sources (5). In the studies included in this review, one can see that some have VO_2 levels that increased in the heat (3) or thermoneutral (5,7) others increased in the cold (6). It is therefore unlikely that exercise metabolism shifts towards anaerobic sources in either of the temperature exposures. The RER value during the coldest trial (0ºC) in Layden et al. (9) however, reached towards 1.0, and VO_2 was measured to be slightly lower (though not significantly), indicating a possible shift towards anaerobic metabolism.

The findings in Layden et al. (9) are conflicting with other findings in this review, where studies using approximately the same T_a found different results (5–7). A difference between Layden et al. (9) and the other studies included in this review (3,5), is time spent in the various ambient temperatures, and the 90-minute exposure in Layden et al. (9) may be at least partially responsible for the different outcomes (12). The extra layer of clothing worn in their study (9) may also have impacted the results. Even though, one would expect the extra layer of clothing worn in their study to protect against the cold.

Nielsen et al. (18) observed that core temperature above 39.7ºC at an exercise intensity of 60% VO_2max at 20 or 40ºC caused exhaustion and suggested that core temperature is a critical factor concerning limited exercise capacity in the heat. As seen in table 1, estimated or calculated GE/economy were lower in the heat/thermoneutral (3,5–7) than in colder temperatures, with Layden et al. (9) put aside. On the contrary, no mean T_r reached above this level (39.7 ºC) in the studies included in this review (3,5–7,9,10,14). It is however possible that T_r reached above this level at some point during the trials but is neglected in this review as only mean T_r are included. It may also be that performance is limited at lower core temperatures than what is found in the study of Nielsen et al. (18). Future studies should therefore investigate core temperature in general and core temperature at different time points further.

It has been found that highly trained individuals tolerate a higher core temperature at exhaustion than less trained individuals (19). In which case, the individuals in Sandsund et al (7) would tolerate heat exposure to a greater extent than the individuals in the other studies. The increased core temperature in some studies (3,6) may therefore affect their calculated/estimated GE as they are not highly trained and had a significant rise in core temperature. This minor increase in core temperature could account for some of the decrement seen in GE but the increase is not large enough to explain the entire decrement found (3). The effect of core temperature on GE are however questionable as minor to no relationship between T_r and GE (3) or PO (14) are found. Tucker et al. (14) stated that the decreased performance in hot T_a may be the result of central regulation of skeletal muscle recruitment preventing the development of thermoregulatory imbalance during exercise in the heat, rather than core temperature. Which should be investigated further in future research.

A significantly higher mean T_{sk} were found in both hot and thermoneutral temperatures (3,6,7). As seen in table 1, some studies conducted their trials in hot and humid environments (>50%) (6,9,14). Both Galloway & Maughan and Tucker et al. had a relative humidity >60%, which would alter evaporative heat loss, and possibly store a greater amount of heat in the body (2, p. 228) which ultimately could account for some of the decrement in time trial PO and GE found in these studies. The higher mean T_{sk} observed in the studies could decrease non-evaporative heat loss as the temperature gradient between the skin and the ambient air would be reduced (6). Further, one would expect an increased skin blood flow and a high rate of sweat production to promote evaporative heat loss (6). The increased skin blood flow would be compensated by increased cardiac output to continue supplying the exercising muscle and respiratory muscles with a sufficient blood flow (3,4), which in turn would be a potential cause for the decreased GE found in the heat (3). The increased sweat production could lead to a decrease in body mass, which is also found to impair thermoregulation and performance (7).

Most studies included in this review with estimated/calculated GE or economy, showed that GE/economy would be higher in the cold than in thermoneutral or hot T_a (3,5–7). All temperatures below 0ºC and between 10 and 15ºC is however omitted from this review and possible alterations in GE in these temperatures are therefore not spotted. The fact that GE seems to increase linearly by decreased T_a in most studies may therefore not be as straight forward as it may seem. The results from this present review aside from Layden et al. (9), may on the other hand indicate that GE increases with temperatures down to about 0ºC, and decrements in GE/economy may be altered at lower ambient temperatures than what is investigated here. It does also seem like a drop in T_{sk} like what is seen in the study of Layden et al. contribute to a reduction in GE in the cold.

4.4 Limitations with the included studies

Due to the small sample sizes in the included studies, where none exceeds 11 participants, there is less precision and higher probability of random errors. It becomes more difficult to distinguish real differences from random differences. As a result of few studies on the current headline it is difficult to ensure equal gender distribution, as most studies have been conducted on men. Other limitations with the current review are the subjects included in the different studies ranging from highly trained to habitually trained. Highly trained individuals may be affected by T_a differently than less trained individuals. Also, different environmental conditions and different protocols between the studies included in this paper made comparisons hard.

5.0 CONCLUSION

Comparison of the results are problematic since the results are scattered and the measurements varies between the studies. However, changes in metabolism and GE/economy have been found, but how they impact one another is not clear. Several variables contribute to alterations in metabolism and GE in various ambient temperatures and alterations in skin/core temperature seems to at least contribute to the differences found in metabolism and

GE/economy. Increased carbohydrate oxidation in the cold may be related to decreased T_m and shivering thermogenesis. It does seem like lowered T_{sk}/T_m in the cold and increased T_{sk} or core temperature in the heat can alter GE/economy. Variations in subject characteristics and testing protocol of the studies made accurate comparisons difficult, which necessitates the need for further research on this topic.

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