RESEARCH AND LITERATURE DEALING WITH WEARING FACE MASKS DURING EXERCISE AND HEALTH IMPLICATIONS THAT RELATE TO FENCING

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I have recently been involved in many discussions by "Zoom" and by phone regarding the difficulties facing coaches, athletes and their families as clubs begin the process of reopening. Everyone is concerned about how to go about this process safely. Unfortunately, there is no easy answer! How do club owners, coaches and athletes find ways to make the transition back to face-to-face individual and group training, bouting and competition safely and responsibly? USA Fencing (posted new return to fencing guidelines in late May), local divisions, and clubs all are dealing with ever-changing local, state, and national restrictions and guidelines.

My hope is to give everyone a better understanding of how wearing face masks during exercise has both a positive and negative impact on health and performance. Everyone concerned needs to understand how complicated the safety implications really are, regardless of any political opinions or Covid 19 issues.

Everyone who has ever worn a face mask for any reason would not say that it is their favorite thing to do. Whether we agree with the politics or not, scientific evidence clearly proves that wearing a face mask provides more protection against the spread of infection that not wearing one. Those who have worn face masks during strenuous exercise for any length of time will also understand that many additional issues go beyond discomfort.

Before introducing the scientific research portion of the material that we need to understand, I think it is also important to compare it to what is often presented in popular literature such as newspaper or magazine articles, and including social media and national and local news programing. All offer a considerable amount of conflicting, incomplete or inaccurate information.

My Ph.D. is largely in exercise science with an interest in Exercise Physiology. In a study published in the February 2016 issue of the “Journal of Biological Engineering”, Arthur T Johnson wrote a study titled “Respirator Masks Protect Health but Impact Performance”. This study presents significant findings that agree with my own educational training.

Respiratory protective masks (called respirators) come in many forms. The findings we are interested in are filtering facepiece respirators (FFRs) or face masks. It should be noted that I am attempting to share Johnson’s information on this topic, not write a scientific paper of my own. The material below is modified from his original data only in that the term face mask is substituted for respirator and 66 numerical research reference markers and references to other forms of respirators other than face masks are omitted. For additional information about the author and to see his original paper and the references cited, please access the following link: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4748517/

Background

Understanding possible physiological and psychological effects of face mask wear requires a thorough understanding of the wearer and possible respirator effects. Face masks may appear to be rather simple, but they can interfere with:

1. respiration
2. thermal equilibrium
3. vision
4. communication
5. feelings of well-being
6. personal procedures such as eating and sneezing
7. other equipment

There are two basic principles relevant to face mask use:

1. Work cannot usually be performed as long or as hard while wearing a face mask compared to when face masks are not worn. Wearing protective clothing plus face masks makes this situation even worse.

2. There is a great deal of wearer variability. Some wearers can tolerate face mask high inspiratory or expiratory resistance or pressure levels, while others cannot. Some wearers are much more anxious about wearing face masks than others. Some wearers can tolerate hot, humid conditions inside face masks, whereas others cannot. Because of this variability, each wearer must be treated as an individual.

Physiological responses

A brief discussion of ergonomics and work physiology is necessary to understand heavy exertion while wearing face masks and protective clothing

Work/performance time tradeoff

- Very hard work cannot be performed for as long a time as work of lesser intensity. This is true even when unencumbered by protective equipment. For different activity levels, there are corresponding physiological limitations consisting of a cardiovascular limitation for very intense work, respiratory limitation for intense work, thermal limitation for moderate work, and what is generally called irritation limits for low-level activity. Protective masks and clothing generally shorten the time that a particular activity level can be sustained.

Physiological adjustments

- The human body is attuned to performing physical labor. What follows the start of muscular activity is a coordinated series of adjustments involving all parts of the body, including the heart, blood vessels, the lungs, digestive system, nervous system, and the kidneys. The ones with most direct bearing on exercise adjustments are described below.

- ### Metabolism

- Muscular movement requires energy. This energy comes from an energy storage molecule called ATP (adenosine triphosphate). When the supply of ATP is exhausted, muscle activity ceases. It is important, therefore, to replenish the ATP supply as quickly as possible in order to maintain muscular work. There is also another energy-rich compound in the muscles called creatine phosphate that can act to replenish the ATP supply extremely quickly. When the muscle starts working there is enough ATP in the muscles to sustain the work for 0.5 sec. There is enough creatine phosphate present to keep the muscle working for up to 2 min. After that, other energy-transforming mechanisms are necessary to replenish the ATP supply.

- This other energy comes from stores of glucose in the blood, glycogen (an animal form of starch) in the muscles and liver, fats in the form of triglycerides in fat tissue, and body proteins. In order to extract the energy from these compounds, they must be respired at the cellular level, and there are two kinds of cellular glucose respiration: anaerobic and aerobic. The difference between the two is that aerobic respiration requires oxygen and anaerobic respiration does not. Oxygen delivery to the muscles begins in the lungs, continues in the blood, and is finally delivered to the muscles. If enough oxygen can be delivered to the tissues, then aerobic respiration can keep up with the energy demands of the muscles. However, there are limits to the rate that oxygen can be supplied, called the maximum oxygen uptake, and, once the maximum oxygen uptake is reached, additional muscular energy must come from anaerobic respiration.
- Very heavy exertion requires at least some anaerobic respiration because oxygen demand exceeds the maximum oxygen uptake. This is called the anaerobic threshold. Anaerobic respiration yields 18 times fewer ATP molecules than does aerobic respiration, and so is not nearly as efficient. However, it does allow movement to continue, at least for a while.
- One of the end products of aerobic respiration is carbon dioxide, which can be removed during exhalation. Carbon dioxide levels in the exhaled breath rarely reach more than 4–5 % even at the extreme, but, if it did climb much higher, carbon dioxide can cause disorientation, confusion, and even death
- The main end product of anaerobic respiration is lactic acid that is released from the muscles into the blood. There are buffering mechanisms in the body that tolerate lactic acid additions, but these mechanisms have limited capacity. Once this capacity is reached, there is no other source of energy for the muscles and all muscular activity must cease. This capacity to tolerate lactate is called the maximum oxygen debt because all the lactic acid must be reformulated into pyruvate at the end of exercise, and this requires oxygen.
- Buffering the blood against lactic acid formation during anaerobic respiration produces extra carbon dioxide that can be exhaled. This extra carbon dioxide acts as a respiratory stimulant that leads to hyperventilation, or harder and deeper breathing.
- All these processes proceed each time a person moves actively. They are much more efficient for younger people than for older people. Maximum oxygen uptake for 20 year olds is about 2.5 l per minute, but declines nearly

linearly to about 1.7 l per minute at age 65. Well-trained individuals can have maximum oxygen uptakes up to twice these values. In addition, the maximum oxygen debt that can be incurred by an individual declines with age and is also affected by training.

- Metabolic responses during exercise, and especially during emergencies, are modified by the release of the adrenal hormones adrenalin (epinephrine) and cortisol. These hormones increase metabolic rate, increase the rate and force of heart contractions, enhance the availability of blood glucose, reroute blood from the gut to the muscles, and mobilize the nervous system. The combined actions of these hormones can affect physical, emotional, and cognitive functions.
- Muscular strength declines with age, making task performance less efficient when more muscles must be recruited to perform a task. Muscular power can be restored relatively rapidly with strength training.
- Drugs and medicines can also affect body metabolism, as can illness. Products of cigarette smoking and caffeine also affect metabolic rate

Cardiovascular adjustments

- The heart adjusts to the physical demands of exertion by increasing its cardiac output, or the volume rate of blood flow through the arteries, capillaries, and veins. This is done to increase the rate of glucose and oxygen supplied to, and removal of lactate and carbon dioxide from, the muscles. The heart rate increases nearly linearly with work rate, beginning to increase nearly as soon as work rate increases. This is due to kinesthetic neural sensors in the muscles and joints that signal the fact that increased oxygen demand is on its way (feedforward control), despite the fact that there is as yet no reduction in blood oxygen concentration or rise in carbon dioxide concentration. Once the concentrations of these gases change, then control of heart response is determined by chemical sensors in the aorta, in the carotid arteries in the neck, and in the brain.
- The stroke volume of the heart, or the volume of blood pumped for each heart beat, increases initially at the start of exercise, but soon reaches its maximum level. Thereafter, increases in cardiac output are determined only by heart rate. Cardiac output at rest is about 5 or 6 l per minute; cardiac output can rise to 25 l per minute during strenuous activity. Blood volume in a somewhat smallish 150 lb (70 kg) person is about 5.6 l. Hence, it takes

about 1 min at rest and 12 s during exercise for blood to make the loop of the whole circulatory system.

- Larger people generally have larger hearts and larger stroke volumes. Well-trained individuals have lower resting heart rates and higher resting stroke volumes. Older individuals can have somewhat lower cardiac efficiencies than younger individuals.
- If body temperature rises due to overheating, then blood is shunted to body surface vessels and there is a secondary rise in heart rate, which puts additional stress on the heart. The water from sweat is derived from the blood plasma, causing the blood to thicken somewhat during prolonged exercise. This also increases stress on the heart, but is alleviated by drinking sufficient amounts of liquid, some of which can be drunk before or during work, if available.
- Cardiovascular adjustments also include shunting the blood from maintenance activities, such as digestion and kidney function, to working muscles where it is needed. Much of the blood in the circulatory system at rest is located in the leg veins; during exercise, most of the blood is shifted to the arteries. These changes occur very quickly after activity begins. Release of the hormones epinephrine and cortisol during psychological stress speeds the heart and constricts some blood vessels to shunt blood to the arms and legs.
- Oxygen delivery to the working muscles can be limited by the maximum cardiac output, given as the maximum heart rate times the maximum stroke volume. Once this maximum has been reached, metabolism continues anaerobically. Depending on the muscles being used and the vascular structure serving those muscles, there may be local regions of anaerobic metabolism occurring while the muscles as a whole are still aerobic.

- ## Cardiovascular limits

- There is a maximum heart rate that can be achieved by an individual. This is age dependent, generally being able to be predicted as 220-(age of the individual). Younger people therefore have higher maximum heart rates. Once this maximum heart rate is reached, cardiac output no longer increases, and oxygen delivery to the muscles becomes static. Anaerobic metabolism is incurred, terminating when the maximum oxygen debt in reached. Cardiovascular-limited exercise normally terminates in 2 to 4 min

- ## Respiration

- Respiration also increases as exercise progresses, but respiratory responses lag activity level changes by about 45 s. There are many respiratory responses that occur: the respiration rate increases, the tidal volume (or the amount of air breathed during each breath) increases up to a maximum amount, the respiratory waveform changes, there are adjustments to the airways, and lung volumes change. Many of these changes appear to be stimulated by carbon dioxide concentration of the blood, but initial respiratory adjustments occur too quickly for that to be the only determinant; kinesthetic sensors may also be important for initial respiratory adjustments.

- Respiration is a multistep process, whereby air is breathed in, travels through the airways, reaches the alveoli (the sacs at the end of the lung where gas exchange takes place), diffuses across the alveolar membrane, dissolves in the blood, and is absorbed by the hemoglobin in the red blood cells. Carbon dioxide diffuses rapidly into the blood, so the concentration of carbon dioxide in the alveoli and the blood are always equal, even during the most intense activity level. Oxygen, on the other hand diffuses more slowly than carbon dioxide, so its concentration in the blood is lower than in alveolar air during inhalation. Diffusion rates of both gases change somewhat with activity level, with those for men being somewhat higher than those for women.

- Inhaled air is oxygen rich and carbon dioxide poor. Exhaled air is oxygen poor and carbon dioxide rich. Because air flow in the airways is bidirectional, the first air that reaches the alveoli is the same as the last air that was exhaled during the previous exhalation. This is an indication of the dead volume of the lung, or that volume that stores carbon dioxide from the previous breath. Dead volume for average adults is about 180 ml, but dead volume of respirators can add to the effective dead volume of the respiratory system and affect performance.

- Carbon dioxide is a very powerful respiratory stimulant. Increasing the concentration of inhaled carbon dioxide increases lung ventilation much more than does oxygen deficiency. Metabolically-produced carbon dioxide is even more effective than inhaled carbon dioxide at stimulating respiration. This is critical for additions of external dead volume, which transforms exhaled metabolic carbon dioxide into carbon dioxide inhaled during the next breath. Once the anaerobic threshold is reached, blood buffering makes it appear that metabolic carbon dioxide increases, and respiration is stimulated so much that lung ventilation increases dramatically as work rate intensifies.

- Working muscles change their efficiencies over time as they heat and tire. Additional oxygen demands of muscles that have been worked for several minutes increases the need for the respiratory system to respond. This leads to a secondary rise in lung ventilation that continues well into the exercise duration.
- Moving the chest wall, lung tissue, and air in the airways requires energy. This energy is equivalent to about 1–2 % of the total body oxygen consumption at rest, but increases during intense activity to 8–10 %. For people with obstructive pulmonary disease, the percentage at rest can be 18–20 %. These people cannot perform strenuous exercise. Oxygen to supply the needs of the respiratory system cannot be used to supply the working muscles, so respiratory demands can definitely limit the rate of work that can be expected of a wearer.
- The work of respiration is supplied by the respiratory muscles. These include the diaphragm, the intercostals, and the abdominals. Inhalation is caused mainly due to the straightening of the diaphragm in the chest. Exhalation at rest for those without obstructive or restrictive pulmonary diseases (normal, healthy individuals) is passive; that is, the force to propel the air to leave the lung comes from the elasticity of the stretched lung. Exhalation during exercise needs to happen a lot faster than during rest, so becomes active when the abdominal muscles push air out of the lung.
- The airways are reactive, and change during exercise. They can constrict somewhat to reduce dead volume, and thus lower wasted breathing effort, but, as they constrict, they resist air flow and increase the work of breathing, so there is a dynamic level of airway tone that is achieved. These same airways may constrict to protect against respiratory irritants reaching the lung, and cause the same symptoms as a severe asthma attack.

- **Respiratory limits**

- Respiration does not usually limit work performances of healthy individuals, but respiration can limit work time when respirators are worn. The most important function of the respiratory system is the removal of carbon dioxide from the body. Adjustments during exercise increase depth and rate of breathing in order to expel this gaseous end-product of aerobic metabolism. Exercise exhalation becomes actively supported by the abdominal muscles, spewing carbon dioxide at faster rates as exercise intensifies. At some point, the rate at which air can be exhaled becomes limited by the distensible airways in the respiratory system. Any further increase in abdominal pressure cannot increase expiratory flow rate. Thus, for normal individuals, there is a limitation when exhalation time decreases to one-half second or so. Carbon dioxide cannot be expelled any faster than this minimum exhalation time allows. Additionally, some people suffer from respiratory impairments that limit maximum pressures that can be generated by the respiratory muscles when they breathe through external resistances or against external pressures. Respiratory-limited work usually lasts 5–20 min.

• Thermal responses

- The large skeletal muscles are only about 20 % efficient. Of the energy supplied to the muscles, approximately 80 % ends up as heat. Thus, heat loss mechanisms are necessary to maintain thermal equilibrium of the human body.

- These mechanisms include vascular adjustments, sweating, and voluntary responses. Voluntary responses include moving to cooler locales, stretching out to lose more heat, drinking cool liquids, or removing heavy clothing. There is a thermal mass to the body that requires some time for heat to build up and cause dangerous body temperatures. There is a normal 6–10 min of activity that can occur before deep body temperature rises significantly. Skin temperature probably increases during this time. If sufficient heat cannot be lost to the environment, then body temperature will continue to rise until it reaches dangerous levels. A core body temperature of 104 ° F (40 ° C) is expected to give a 50 % casualty rate. This condition is characterized by disorientation, convulsions, loss of body temperature control, and death.

- Heat can be lost from the body by convection (usually, air movement), radiation (as to a cold clear sky), or evaporation. Convection and radiation heat loss depends on the difference in temperature between the surface losing heat and the surrounding fluid (usually air, but, in a pool, water). Thus, one adjustment the body makes during thermal stress is to warm the skin surface. It does this by shunting blood from deep veins into surface veins. This is why veins on the surface of the hands seem to stand out more in hot weather than in the cold. There is also a small, but significant, amount of convective heat loss from the respiratory system as air is breathed.

- Evaporating water absorbs a large amount of heat, thus making sweating effective as a heat loss mechanism. Sweating heat loss on the surface of the skin is nearly 100 % effective for losing heat. Sweating through clothing cools the clothing surface where the evaporation actually takes place, and only partially cools the skin. Sweat that drops from the skin is completely ineffective for heat removal. The amount of sweating depends on the cooling necessary, and different parts of the skin are recruited at different times to produce sweat. When fully recruited, the maximum cooling that can be obtained from sweating is equivalent to nearly 12 times the body heat production at rest (or 11.4 mets).

- Women have higher percent body fat than do men. They use this body fat as insulation between their body cores and the outside environment. To lose heat, therefore, women depend more on vascular adjustments that do men. Men sweat more than women and lose a larger fraction of their heat in that way. Acclimation to hot environments can improve sweating efficiency by increasing both the rate of response and amount of sweat produced.

- Some work may be required in very cold temperatures. At the beginning, cold temperatures may limit movement and dexterity. However, heat produced during activity and the extra insulation afforded by protective clothing and respirators soon overcome cold temperature effects on the body. Surface blood vessels in the head do not constrict in the cold, as do similar blood vessels in other parts of the body. Hence, nearly half of the body's heat loss in the cold can come from the uncovered head. Covering the head and face with protective equipment helps to insulate against this large amount of heat loss.

- **Thermal limits**

- The most important work limitation associated with heat is deep body temperature. It must be prevented from reaching 40 ° C. A conservative limit for adults might be 39.2 ° C (102.5 ° F). Beyond this, thermal discomfort becomes overwhelming and death could ensue. Muscular efficiency is reduced at high temperatures and judgment ability becomes impaired. Thus, the overheated individual cannot be expected to recognize his or her own dangerous situation.

- Because of the thermal capacity of the body to store heat, it takes a while before body temperature rises to the point where it can become limiting. Heat-limited work usually occurs in the 10 min to 2 h time range.

- **Prolonged activity limits**
- Physiological limits to long term exercise deal with limitations on blood glucose levels and muscle glycogen stores. Dehydration or electrolyte depletion may occur. These are difficult to quantify for any individual, but frequent eating and drinking can deter them from happening.
- Psychological effects are also important. Feelings of fatigue are common, as are feelings of anxiety and discontent.
- **Face mask effects: vision**
- Sharp vision is important for some of the tasks required during exercise. There is a natural tunneling of vision that occurs during intense exertion: attention is focused on objects straight ahead. Consequently, degradation of vision due to face mask use during high exertion has little effect on the ability to complete the required task. Under normal conditions, this might be advantageous to task performance. In a situation where dangers can come flying from all directions, there may be difficulty recognizing peripheral threats.
- Vision is extremely important for performing fencing tasks. There are many aspects of vision, including visual acuity, peripheral vision, and color detection, and some or all of these may be needed. Face masks should be selected to accommodate requirements for peripheral vision, acuity, and color recognition.

Work/rest cycles

More intense work cannot be sustained as long a time as can less intense work. If athletes are expected to work very hard for a while, they must also be in a position to rest or, at least, slow down for a while. This can be a problem if the athlete cannot control the rate of work, because anaerobic work continued for too long can result in the maximum oxygen debt being reached.

The amount of time that an athlete can be expected to work is related to the fraction of the maximum oxygen uptake represented by the task being performed. Thus, performance time involves the size of the individual as well as age, sex, and physical conditioning. In general, men have higher maximum oxygen uptakes than women, but they have larger sized bodies that use more oxygen to move around. Older people have lower maximum oxygen uptakes than younger people. Wearers in better physical condition have higher maximum oxygen uptakes, and, additionally, are able to perform tasks with lower oxygen use than are less physically-able wearers.

Work performance times can range from forever at rest, to 4 h walking at 3 miles per hour, to 23 min for cross-country running, to 10 min climbing stairs. These are typical times for an unencumbered 40 year old man. The addition of extra protective equipment can reduce these times to one-half or less of the values given, depending on the types of equipment worn.

Rest times are also dependent on the intensity of the task and the maximum oxygen uptake of the individual. In general, the more intense the work, the longer will be the recovery time, but the relationship is nonlinear. A task that can be performed for an hour requires at least a 10 min rest period. More intense tasks (with shorter performance times) require longer rest times.

Conclusion of the Author

Physical exertion involves the entire body in a coordinated fashion. Adjustments made during work or exercise can be profound, but the limitations of exercise can be modified or overcome by training and proper selection of equipment. Familiarity with the physiological adjustments that occur can lead to enhanced effectiveness and larger return on investment for both manpower and equipment. As long as athletes are involved in performing physical or mental work, accommodation must be made for the adjustments that characterize their physical abilities. Training is important to improve the wearer’s ability to respond to work conditions, but does not eliminate the basic physiological and psychological limits to performance.

My Summary and Recommendations

This is a lot of information to assimilate, but the primary implications for fencing are easy to understand. The face mask, amount of protective equipment (especially the fencing mask), work intensity and time of exertion present both potential and real hazards to our athletes. However, educating our coaches and athletes about the importance of the frequency and duration of rest based on the duration and intensity of the workout can go a long way toward keeping our coaches and athletes safe from the exercise stresses that are increased by the wearing of a face mask, especially if the fencing mask is also worn over the face mask, even for short durations. In my opinion, the two most critical issues are identifying athletes with preconditions that would put them at risk and monitoring both respiration and heat problems. Wearing the face mask, and adequate sanitizing of shared equipment (Lysol or equivalent for hard equipment and washing with soap and water for soft equipment) is essential as long as we remain in the Covid 19 pandemic.

At a minimum, athletes and coaches need to have several clean and dry face masks at the beginning of each workout so they may be changed when wet. Open and/or remove protective gear to allow for evaporative cooling with availability of hydration drinks when at rest. Have detailed medical information including medical contact information for every athlete and coach that is easily available. Recently (late May, 2020), USA Fencing posted guidelines for returning to fencing. The recommendations presented for individuals, clubs and coaches are comprehensive and reaffirm the importance of facemasks for Covid 19 safety.

I recognize that our entire fencing community has diverse personal and political opinions as well as differing financial, health and safety needs. We all want to be able to enjoy the sport we love. My personal family health safety needs as well as concern that my own club cannot re-open safely (even under the new USA Fencing Guidelines) is difficult, but we will continue to find alternative ways to train. Let’s just be sure we do all we can to return to normalcy in a safe and responsible manner.