University of Alberta

Impact of music on cerebral and muscle oxygenation during wheelchair exercise

by

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Dedication

To my parents "Mr. NK Malik", "Mrs. Indra Malik"; my brother "Ritesh Malik" and my sister-in-law "Neeta Malik" who are the wheels of my life. Also to the most lovable person, my nephew "Tushar Malik".

Abstract

This study evaluated the effects of music on cardiro-respiratory and cerebral and muscle blood volume/oxygenation responses during wheelchair exercise. Twenty-one healthy males completed three testing sessions in which they rested while listening to self-selected music, exercised without music (E), and exercised with music (E + M). Physiological responses were measured by a wireless metabolic cart and the tissue oxygenation was monitored non-invasively by three dual wave NIRS units. Sub-maximal and maximal wheelchair performance increased significantly ($p<.10$) during (E + M) compared to E. These improvements were accompanied by significant increases ($p<.10$) in oxygen uptake, ventilation rate and oxygen pulse. However, there were no significant changes ($p>.10$) in sub-maximal and maximal cerebral and muscle blood volume/oxygenation responses. The change in sub-maximal wheelchair distance was significantly correlated ($r=0.42$, $p<.10$) with the change in cerebral oxygenation. It was concluded that listening to music improved wheelchair exercise performance by enhancing cerebral activation.

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Definition of Terms

Physiological variables

Absolute oxygen uptake	Volume of oxygen consumed by the whole body per unit of time; Unit: L/min
Relative oxygen Uptake	Volume of oxygen consumed by the whole body per unit of time, per unit of body mass; Unit: ml/kg/min
Heart rate	Frequency of heart beats; Unit: bpm
Ventilation rate	Volume of air taken into the lungs per unit of time; Unit: L/min
Respiratory exchange ratio	Ratio of carbon dioxide produced divided by the amount of oxygen consumed
Oxygen pulse	Ratio between absolute oxygen uptake and heart rate; Unit: ml/beat
Ventilatory equivalent of oxygen	Ratio between volume of air ventilated and the amount of oxygen consumed
Ventilatory equivalent of carbon dioxide	Ratio between volume of air ventilated and the amount of carbon dioxide produced
Maximum oxygen uptake	Maximum amount of oxygen consumed per unit of time; Unit: L/min or ml/kg/min

NIRS variables

Oxygenation	Difference in tissue (cerebral or muscle) absorbency between the oxyhemoglobin (850nm) and deoxyhemoglobin (760nm) signals
Blood volume	Sum of tissue (cerebral or muscle) absorbency between the oxyhemoglobin (850nm) and deoxyhemoglobin (760nm) signals

List of Abbreviations

AVO_2	Absolute oxygen uptake	(L/min)
E	Exercise without music	
E + M	Exercise with music	
HR	Heart rate	(bpm)
HRR	Heart rate reserve	
M	Music only	
NIRS	Near infrared spectroscopy	
O_2 pulse	Oxygen pulse	(ml/beat)
RER	Respiratory exchange ratio	
RVO_2	Relative oxygen uptake	(ml/kg/min)
V_E	Ventilation rate	(L/min)
V_E/VO_2	Ventilatory equivalent of oxygen	
V_E/VCO_2	Ventilatory equivalent of carbon dioxide	
VO_{2max}	Maximum oxygen uptake	

Chapter I: Statement of the Problem

Cerebral function during exercise

The brain is, as the controlling center of the body, the organ which controls the motor and sensory processes. It has the capability to monitor its own activity, as well as store and apply the knowledge generated during the processes (Parent, 1996). Brain function underlying the motor cortex is divided into multiple processing levels, including the spinal cord, brain stem, the cerebellum, the dienecephelon and cerebral hemisphere comprising the cerebral cortex and basal ganglia (Vander et al., 1994). The motor cortex, which is in the frontal lobe, consists of a number of processing areas which are responsible for execution of motor activity. Stimulation of neurons in the motor cortex activates multiple muscles at multiple joints, resulting in coordinated movements (Sherwood et al., 1989). The pyramidal or corticospinal system refers to those fibers that originate in the cerebral cortex and descend to the spinal cord through medullary pyramids. These fibers decuscates in the lower medulla and enter the spinal cord as the lateral corticospinal and anterior corticospinal tracts (Suszkiw et al., 1996).

The function of these corticospinal tracts is to maintain the tone of the muscles. There are two excitatory centers and two inhibitory centers in the brain (medial reticulospinal tract and lateral vestibulospinal tract) from where the impulses originate for extensor and flexor tone respectively. There is a fine balance between the excitation and inhibition signals. If this balance gets disturbed, it may cause more forceful contraction of one group of muscles, which may lead to sustained contraction of the muscle and even injury to the joint. In other words, hyper tonicity in one group of muscle (agonist) and hypo tonicity in the other group (antagonist).

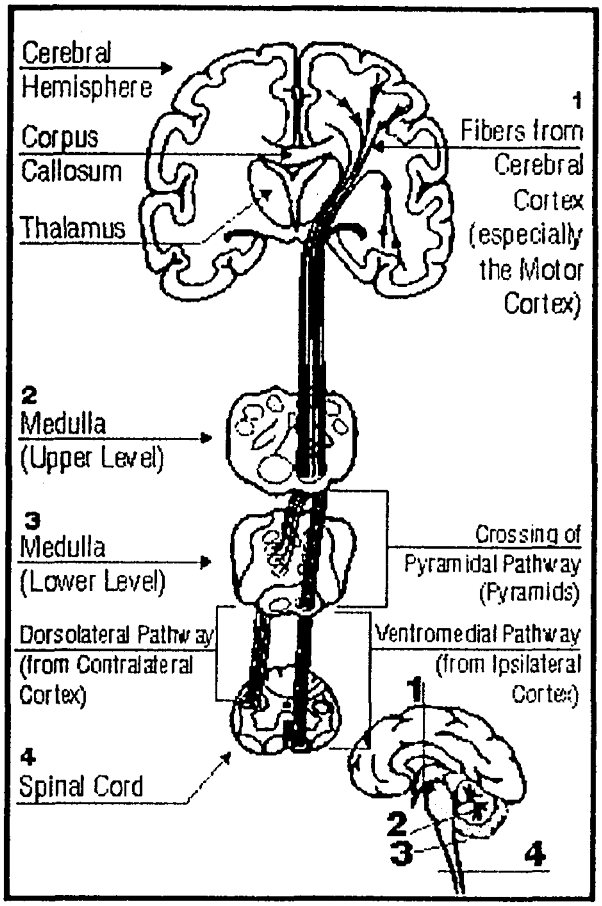


Figure 1: Corticospinal Tracts originating from cerebral cortex. Reproduced with permission. ©Athabasca University. www.athabascau.ca

The stimulus for muscle contraction originates in the motor cortex located in the frontal lobe of the brain (Kayser, 2003). This impulse is then relayed to the cerebellum via the thalamus. The cerebellum is responsible for posture, balance and smooth coordinated movements of the body. From the cerebellum, the impulse is transmitted to the medulla oblongata via the Pons and then synapses at the spinal cord. At this point, the stimulus is relayed to the motor unit (alpha motor neuron, associated axon, neuromuscular junction and the muscle fibers). Once the action potential generated is above the activation threshold, all the muscle fibers in the motor unit contract (all or none principle). Under normal conditions, the central nervous system (brain and spinal cord) exerts a certain degree of inhibition over the muscle contraction (Punkt, 2002). This is considered to be essential in order to minimize damage to the muscle and joints. However, under certain conditions such as motivation and music, some of this central inhibition can be released and muscle performance can be improved. It is postulated that the balance between the excitatory and inhibitory impulses in the reticular formation (the highest brain center) is altered in a manner that increases neuronal activation, thereby improving performance under these conditions.

Effects of music on exercise performance

During the last two decades, researchers have examined the effects of music on exercise performance. There is general consensus that listening to excitatory music (>124 beats per minute) during dynamic exercise significantly improves exercise capacity as measured by changes in the exercise time, distance traveled and alterations in the cardio-respiratory responses.(Copeland et al., 1991; Szabo et al., 1999; Hagen et al., 2003). Sub-maximal/maximal exercise responses such as HR, blood lactate, and catecholamine are significantly attenuated when exercising with music (i.e. the overall stress is lower). As well, the perception of effort is significantly reduced under these conditions. Recently, music has been used to encourage and stimulate exercise training in older persons in long term care settings (Hagen et al., 2003). The findings of this study indicated a significant improvement in balance and generalized functional movements in the upper and lower limbs when training was incorporated with music. As a result of these findings, several hypotheses have been developed to explain the improvement in exercise performance when individuals listen to music. These include: (1) increased arousal in the brain, which facilitates the transmission of motor impulses to the exercising muscle, (2) an attenuation in the afferent sensory feedback to the brain, (3) improvements in central autonomic control that can influence: (a) heart rate (HR) and cardiac output, and (b) localized muscle perfusion at the level of the arterioles, capillaries and venules. To date, all the studies pertaining to the effects of music on exercise performance have focused on the changes in the acute cardio-respiratory and perceptual responses. None of these studies have examined the effects of music on maximal aerobic power, VO_{2max}, which is one of the best indicators of cardio-respiratory fitness and alterations in the neuronal activation during exercise.

Application of Near Infrared Spectroscopy to evaluate cerebral and muscle oxygenation during exercise

Near infrared spectroscopy (NIRS) is a non-invasive optical technique that is used to evaluate cerebral and muscle oxygenation/blood volume during exercise in humans. NIRS is based on the differential absorption properties of chromophores in the near infrared region; i.e. between 700nm and 1000nm (Boushel et al., 2000; Simonson et al., 1996). The known chromophores that absorb infrared light in the tissues are hemoglobin (Hb), myoglobin (Mb, present only in muscle) and cytochrome oxidase. At a wave length of 760 nm Hb is in the deoxygenated form (deoxyHb), whereas at 850nm Hb is in the oxygenated state (oxyHb). The difference in absorbency between these two wavelengths indicates the relative change in oxyHb saturation in the small blood vessels (arterioles, capillaries, venules), whereas the sum of the absorbencies at these two wavelengths indicates the relative change in localized blood volume.

Recently, several studies have used NIRS to examine the changes in cerebral oxygenation and blood volume during dynamic exercise in humans. These studies have indicated that during dynamic exercise, cerebral oxygenation and blood volume increase systematically with work intensity up to the respiratory compensation threshold, followed by a decline until the maximal exercise capacity is attained (Bhambhani et al., in press; Koike et al., 2004; Nielsen et al., 2001). The increase in cerebral oxygenation has been attributed to greater neuronal activity necessary to initiate muscle contraction at the motor cortex (Obrig et al., 1996; Obrig et al., 1997). During maximal exercise in well- trained individuals, cerebral oxygenation may decline as a result of the arterial hypoxemia (decreased levels of oxygen in the arterial blood), thereby inducing fatigue.

During the last decade, numerous investigations have used NIRS to study the acute changes in muscle oxygenation and blood volume during a variety of dynamic exercise modes using different muscle groups (Bhambhani, In Press). Individuals with disabilities who are wheelchair dependent are forced to use their upper extremities for ambulation. Electromyographic evidence has indicated that during wheelchair exercise, both the biceps and triceps are recruited at various stages of the propulsion cycle (Veeger et al., 1991). Therefore, it is important to examine the changes in muscle oxygenation in both these muscles. Currently there is limited research that has examined the alterations in muscle oxygenation and blood volume during upper body (arm) exercise. Bhambhani et al. (1998) reported that the magnitude of deoxygenation in the biceps brachii was lower during arm cranking compared to that attained in the vastus lateralis during leg cycling. Their results, however, indicated no significant differences in the rate of deoxygenation per unit oxygen uptake between the two exercise modes. Muraki et al. (2003) investigated the difference in oxygenation trends in the triceps and vastus lateralis muscle in 27 women. Their findings in the triceps muscle were fairly consistent with the trend reported by Bhambhani et al. (1998) in the biceps muscle during arm cranking. Jensen-Urstad et al. (1995) evaluated the changes in biceps brachii oxygenation during arm cranking exercise performed at a constant work rate for 15 mins during normoxia and hypoxia (12% inspired oxygen). Their results indicated a rapid initial decrease in oxygenation during the first few minutes of exercise with a steady reversal during the latter phases of the test. The reversal was slower in all subjects under hypoxic conditions compared to normoxic conditions.

In a recent article entitled: “Exercise Starts and Ends in the Brain” (Kayser, 2003), it has been suggested that motor function, which is initiated in the motor cortex, is also terminated in the brain by a voluntary effort. However, the mechanisms by which this decision to terminate exercise are mediated are unknown. Since NIRS can evaluate both cerebral and muscle oxygenation during dynamic exercise simultaneously, it could be a useful technique to examine this phenomenon. Further, by examining how music affects the relationship between the changes in exercise performance and cerebral and muscle oxygenation/blood volume, our understanding of this area will be enhanced.

Objectives of the study

The *objectives* of this study were to:

1. examine the effects of music on the distance traveled and cardio-respiratory responses during 10 minutes of wheelchair exercise when compared to a controlled (no music) condition in healthy males,
2. evaluate the changes in cerebral and muscle oxygenation/blood volume under these conditions,
3. document the relationship between the changes in exercise performance and cerebral and muscle oxygenation/blood volume under these conditions.

Hypotheses

1. It was *hypothesized* that in comparison with the control condition, 10 minutes of wheelchair exercise under the influence of music will significantly:
    a) increase the distance traveled and average velocity,
    b) improve the cardio-respiratory and perceptual responses,
    c) enhance the changes in cerebral and muscle blood volume/oxygenation,
2. The changes in cerebral and muscle blood volume/oxygenation will be significantly higher when exercise is performed with music.
3. The improvements in the wheelchair exercise performance will be more closely related to changes in cerebral oxygenation/blood volume compared to muscle oxygenation/blood volume.

Chapter II: Review of Literature

The literature review has been grouped into the following topic areas:

1. Music: application of music in various fields.
2. Near Infrared Spectroscopy: principle, validity and reliability; and changes in cerebral and muscle haemodynamics.

Music and exercise

Studies in healthy individuals have found music to be helpful aid in decreasing pain and perceived exertion (Hayakawa et al., 2000). The music has the capability to evoke pleasant associations by masking unpleasant stimuli and serve as a distracter to internal feelings associated with discomfort (Becker et al., 1994). Szabo et al. (1999) investigated the effect of slow and fast rhythmic classical music on the cardio-respiratory changes during incremental leg cycling. Twenty four subjects (12 male 12 female), mean age 21, pedaled a stationary bike under five different conditions of 1) no music, 2) slow music, 3) fast music, 4) slow to fast music and 5) fast to slow music. The test protocol consisted of 10 min of initial rest followed by pedaling at the work rate of 50 W and it was increase 25 W per min until voluntary exhaustion. The music was switched from slow to fast (fourth condition), and fast to slow (fifth condition) when the subject had reached 70% of his/her maximal heart rate reserve (HRR). They found no significant difference in the percent maximum HRR in all five test sessions but the subjects attained a significantly higher power output in the slow to fast music condition. The researchers suggested that music reduced the perception of exercise thereby leading to accomplishment of more work.

In a similar study. Becker et al. (1994) examined the influence of music, played before the exercise. Three groups of subjects (children. adults and seniors) performed three 2 minute bicycle exercise trials preceded by 1 minute exposure to mellow music, frenetic music and white noise. The researchers found, the mileage in both music conditions was significantly high except among senior subjects. The authors suggested that disliking of that particular music by seniors attributed for the low mileage in their age group. Potteiger et al. (2000) examined the effect of music on ratings of perceived exertion during 20 min of moderate intensity on 27 healthy subjects. The subjects performed a graded VO_2 max test till voluntary exhaustion and 4 sub maximal tests equal to 70% of their VO_{2max}. The subjects listened to fast jazz, classical music, self selected music and "no music" in random order. The tempos for the fast jazz and classical music were set at 140-145 and 60-65 beats per min respectively. The subject listened to the music at a volume of 85-90 decibel. The authors found no significant differences in the HR among the four conditions. However there was a significant reduction in peripheral, central and overall RPE at 10 min, 15 min and 20 min of exercise during the music conditions. They suggested that different types of music may suppress the internal sensations and act as a passive distracter which may influence peripheral, central and overall ratings of perceived exertions during sub maximal exercise. Their findings were different from an earlier study by Copeland et al. (1991) who found that fast and upbeat music does not influence RPE during sub maximal and maximal exercise. Copeland and colleagues compaired the effects of fast, exciting music with slow, easy listening popular music on 24 subjects in an incremental treadmill exercise test. In three separate maximal tests, the subjects listened to high intensity (75- 85 db), fast music (140 beats/min) and low intensity (60-70 db), slow (100 beats/ min) and no music respectively. In the music groups, all the subjects listened to same music. They found that HR was significantly lower and the time to exhaustion was significantly higher in slow and soft music compared to the fast music and control group.

Szmedra et al. (1998) examined the effect of music on perceived exertion, plasma lactate concentration, norepinephrine, HR and blood pressure in 10 healthy well trained men ranging in age from 19 to 32 years. At first, the VO_{2max} of the subjects was determined by incremental treadmill exercise. This was followed by two sub-maximal work bouts, each at 70% of their VO_{2max} for 15 min, three days after the initial testing. During one of the sub-maximal exercises the subjects listened to popular classical music. Blood samples were collected before the test and during 3 minute recovery period. They found significant decreases of 4.6% in HR, 4% in Systolic blood pressure, 10% in RPE, 22.5% in blood lactate and 17.5% in norepinephrine during music condition. However there was no significant difference in the relative oxygen consumption during the music trial when compared to no music. The authors suggested that this could be the result of blockage of unpleasant signals from either local or central factors to the central nervous system. Music could have caused the lowering of sympathetic signals leading to some arteriole vasodilatation, hence allowing greater perfusion of blood to the working muscle.

These findings were supported by study by Hayakawa et al. (2000) in which 16 middle aged subjects listened to Japanese traditional folk songs, aerobic dance music (120 beats per min) and no music during bench stepping exercise for 60 min. They measured the vigor, fatigue, confusion, depression, anger and tension in the subjects by administering the Profile of Mood Scale. They found that subjects perceived more vigor and less fatigue after exercise with aerobic dance music and Japanese folk songs than non music suggesting that asynchronous and synchronous music were strong enough to distract the subjects from the afferent signals associated with physical exertion. The physiological responses of the body were not measured in this study.

In contrast Pfister et al. (1998) did not find any significant differences in the RPE, perceive dyspnea or walking distance in 19 subjects with chronic obstructive pulmonary disease (COPD). These subjects performed two 6 min walks on two different days, one with music and the other without music. They listened to the music from the categories: big band, 1960's, country, tropical and broadway themes and the music tempos were set between 119 and 126 beats per min. The subjects walked as fast as they could in the 6 min test. They used modified Borg's scale to measure the RPE and found no significant difference between the two conditions. They also didn't find any significant difference in the distance traveled: 331m for music group and 321 for control group suggesting that external environment wasn't sufficient to distract them from the exertion. Their findings must be interpreted with caution because their sample size was small, and therefore, cannot be generalized to this patient group. In another study, Yamamoto et al. (2003) examined the effects of slow and fast rhythmic music on supra-maximal exercise in 6 healthy male subjects. Prior to the tests, the subjects listened to slow and fast music respectively for 20 minutes in the supine position. The tests were separated by 7 days. During the supra-maximal exercise, the subjects pedaled the cycle at their maximum for 45 seconds. They observed no significant differences in the power output, HR, blood lactate and ammonia concentrations. They found an increase in plasma epinephrine concentration during fast rhythmic music and a decrease in plasma norepinephrine concentration during slow rhythmic music. They suggested that slow rhythmic music depresses sympathetic activation and the fast rhythmic music increases adrenergic activation. The authors concluded that music has no impact on power output during supra-maximal exercise. But their finding should be interpreted with caution because the blood samples were taken only after the completion of the tests and not during the tests. Moreover the subjects didn't listen to the music during the 45 second supra-maximal tests.

More recently Hagen et al. (2003) examined the effect of music and exercise on the physical, emotional, behavioral and cognitive changes in older persons living in a long term care facility. Sixty participants (19 male, 41 females) having mean age of 78 yr were randomly assigned into three groups: 1) control group, 2) Occupational Therapy (OT) group, 3) musical movement exercise group. The control group received only the routine nursing care. The occupational therapy group received 1 hr OT program 3 times a week for total of 10 weeks. The music group received a program developed by YMCA for seniors which consisted of 40 min session of movements to music from 1920's, 30's and 40's, three times a week for a total of 10 weeks. The impact of the program on subjects was then assessed by measuring the cognitive status, behavioral difficulties, life satisfaction, balance and joint functioning. They reported a significant decrease in behavioral problems, an improvement in balance and generalized functional movements in upper and lower limbs in both OT and music group, but more predominantly in music group. The authors conducted a second assessment 10 weeks after the program had ended and found that there was a marked decline in the functional movements. They concluded that music acts as an external distracter which attenuates the internal sensation of exertion and can produce significant physical and cognitive benefits.

It is evident from the above studies that music significantly affects athletic performance. It may enhance exercise performance in by: a) increasing relaxation, b) enhancing motor co-ordination, c) increasing arousal and, d) reducing the perception of fatigue and pain. With this study, our understanding of effects of music on cerebral and muscle oxygenation/blood volume, and exercise performance will be enhanced.

Principle of Near Infrared Spectroscopy

Near infrared spectroscopy (NIRS) is a non-invasive optical technique that is used to evaluate cerebral and muscle oxygenation/blood volume during exercise in humans. NIRS is based on the differential absorption properties of chromophores in the near infrared region; i.e. between 700nm and 1000nm (Boushel et al., 2000; Simonson et al., 1996). The known chromophores that absorb infrared light in the tissues are hemoglobin (Hb), myoglobin (Mb, present only in muscle) and cytochrome oxidase. At a wave length of 760 nm Hb is in the deoxygenated form (deoxyHb), whereas at 850nm Hb is in the oxygenated state (oxyHb). The difference in absorbency between these two wavelengths indicates the relative change in oxyHb saturation in the small blood vessels (i.e. arterioles, capillaries, venules), whereas the sum of the absorbencies at these two wavelengths indicates the relative change in localized blood volume.

When the light falls on a medium, the photons (light particles) get absorbed, scattered, take a longer path length, pass through without scattering or gets reflected back. Considering negligible light scattering, the concentration can be determined with Beer-Lambart Law. $A = E \times C \times D$ where:

A: Lg (I_0/I): Light extinction,

E: Specific extinction coefficient,

C: Substance concentration,

D: Distance (width of cuvette).

This law holds good only if the light is absorbed or directly reflected back to the detector without any scattering. Because there is considerable scattering in biological tissue, a term B which accounts for longer path length and factor G which accounts for the signal loss due to light scattering is included in the equation (Villringer et al., 1997). This has resulted in the development of the Modified Beer Lambert law:

$A = E \times C \times D \times B + G$ where:

B: Differential path length factor,

G: Signal loss due to light scattering.

Validity of NIRS for measuring cerebral oxygenation

NIRS has been validated by comparing it with fMRI (Kleinschmidt et al., 1996) and Positron Emission Tomography (PET) (Rostrup et al., 2002) in some of the studies. In one such study, Schipper et al. (2002) compared the results of NIRS and fMRI in elderly and young subjects who performed repetitive contra lateral finger tapping for 20 sec period, seven times with a rest of 40 sec after every tapping session. They found a significant correlation of $r = -.70$, $r^2 = .48$, $P<0.001$ for young and $r = -0.82$, $r^2 =.67$, $P< 0.001$ for elderly subjects when comparing the deoxygenated Hb level. They observed that NIRS and fMRI similarly assess blood oxygenation changes in brain and suggested that NIRS is a valid source for measuring the blood oxygenation trends.

Rostrup et al. (2002) investigated the cerebral blood volume changes during hypercapnia (increase in CO_2 in blood), normal ventilation, and hyperventilation with Positron Emission Tomography (PET) and NIRS simultaneously in 5 healthy subjects. They observed significant correlation for the changes in cerebral blood volume measured by NIRS and PET. During hypercapnia, hyperventilation and normoventilation both PET and NIRS showed similar results. They observed an increase in cerebral oxygenation during hypercapnia, and a decrease during hyperventilation.

Reliability of NIRS for measuring cerebral oxygenation

Many studies have demonstrated that NIRS is reliable for measuring cerebral oxygenation. The studies in which the probe was placed on the left frontal lobe have shown to have higher correlation than the studies in which probes were placed bilaterally or on the right frontal lobe. The reliability results ranged from r = 0.88 to 0.14. In one of the rigorous studies (Kioke et al., 2004) examined the reproducibility of left frontal cerebral oxygenation in twelve subjects with heart disease during incremental exercise. The subjects performed two symptom limited incremental cycle ergometer test at an interval of 11.3± 4.6 days. The authors observed a significant correlation in the oxyhemoglobin measurements during exercise (r = 0.88, p< 0.0001) and found no outliers in the Bland Altaman analysis.

Houtman et al. (1999) investigated the reproducibility of cerebral oxygenation from supine rest to head-up tilt at 70 degree angel. Ten healthy subjects performed two consecutive maneuvers consisting of 10 min supine and 10 min 70 degree head up tilt and repeated it on the second day. Their results indicated a small reproducibility error for deoxyhemoglobin and larger errors for oxyhemoglobin and total hemoglobin. They suggested that HHb (difference between oxygen consumption and delivery) measured by NIRS is reproducible. In a similar study, Totaro et al. (1998) investigated the changes in the measurement of cerebrovascular oxygenation reactivity in 27 healthy subjects with NIRS and Transcranial Doppler sonography simultaneously at different body positions (supine, 35 degree Trendelenburg and 35 degree reverse Trendelenburg). The subjects were exposed to 5% carbon dioxide for 3 min and the test was repeated after one hour. The NIRS probes were placed on the right frontal lobe and the probes were placed at the same position in the second trial. The authors reported significant correlations of r = 0.68, 0.76, 0.21 for oxyhemoglobin, deoxyhemoglobin and total hemoglobin respectively. They also found that NIRS values are not affected with different head positions. Their results suggested that NIRS is a reliable and reproducible method for measuring cerebro-vascular reactivity.

In a recent study, Watanabe et al. (2003) examined the cerebral blood volume response to cognitive tasks and hyperventilation with multi-channel NIRS. Ten healthy subjects performed four cognitive and one physiological test (hyperventilation). These tests were repeated by the by five subjects to evaluate the test- retest reliability. The 24 channel NIRS probes with five emitters and four detectors were placed on both, right and left frontal lobes. The authors observed an increase in the Oxyhemoglobin and total hemoglobin during verbal fluency and design fluency tasks but a decrease during hyperventilation. They didn't find any change in the deoxyhemoglobin. They also found the decrease of oxyhemoglobin and total hemoglobin was mainly from the medial part of the frontal lobe. Their results showed that test retest reliability of NIRS was high (ICC = 0.87, 0.76) and suggested NIRS is suitable for measuring the cerebral vascular responses.

Cerebral oxygenation during exercise

Several studies have used NIRS to examine the changes in cerebral oxygenation and blood volume during dynamic exercise in humans. These studies have indicated that during dynamic exercise, cerebral oxygenation and blood volume increase systematically with work intensity up to the respiratory compensation threshold, followed by a decline until the maximal exercise capacity is attained (Bhambhani et al., In press; Koike et al., 2004; Nielsen et al., 2001).

Ide et al. (1999) studied the cerebral metabolic responses during sub-maximal exercise in 12 subjects. The total cerebral oxygenation, deoxyhemoglobin, as well as oxyhemoglobin increased significantly as the exercise progressed from 30% to 60% of VO_2 max. They also used Positron Emission Tomography and fMRI to measure the metabolic activity of the brain. They found that oxyhemoglobin increased by 10 and 25 μmol/l ($P < 0.01$) in 30% and 60% of submaximal exercises respectively suggesting that, cerebral blood flow increases in excess of the O_2 demand during exercise. The increase in cerebral oxygenation has been attributed to greater neuronal activity necessary to initiate muscle contraction at the motor cortex (Obrig et al., 1996; Obrig et al., 1997). During maximal exercise in well-trained individuals, cerebral oxygenation may decline as a result of the arterial hypoxemia (decreased levels of oxygen in the arterial blood), thereby inducing fatigue.

Saito et al. (1999) studied the effects of workload on cardiovascular and cerebral oxygenation in the untrained trekkers at the altitude of 3700, 2700 and at sea level. They used INVOS 3100 (Somanetics, Michigan, USA) to measure regional cerebral oxygenation saturation. Ten subjects (6 male, 4 female) with average age of 31 participated in the study. Stable cerebral oxygenation measurements of the subjects were taken during the 5 min rest followed by Master's double two-step test, which required the subjects to step onto and off of two 23 cm steps for 3 min. at resting level. The researcher found no significant difference in the cerebral oxygenation saturation in all the three altitudes viz 3700, 2700 and at sea level, suggesting that the reduction of oxygen supply resulting from decrease in arterial oxygen saturation was compensated by the increase in blood flow. But the cerebral oxygenation decreased significantly in 3700m and 2700m after exercise as further reduction could not be supplemented by cerebrovascular reflex in timely manner. Other significant finding was increase in oxygenation values after recovery were higher than the pre-exercise value, due to simultaneous increase in arterial oxygenation saturation and cerebral blood flow. Here the cerebral oxygenation did not rise as typically shown during the graded exercise. They observed that the cardiovascular changes during the exercise occurred only beyond 3000 m altitude and above.

Validity of NIRS for measuring muscle oxygenation

Sako et al. (2001) examined the validity of near-infrared continuous wave spectroscopy by measuring the muscle oxidative metabolism during exercise. They compared the post exercise muscle metabolic rate in Phosphorus magnetic resonance spectroscopy, which is considered the gold standard for quantifying the rate human skeletal muscle metabolism (Cresshull et al., 1981), and NIRS. Twelve male subjects, taken in the study were required to be seated with the exercising arm extended, gripping the ergometer positioned inside the 31P- magnetic resonance spectroscopy magnet. The impulses were recorded by the NIRS light probes and 31P-MRS surface coils positioned beneath the forearm over the finger flexor muscles. Each subject underwent three sessions, one for RMRmus (resting metabolic rate) measured by 31P-MRS and NIRS respectively during 15 min of arterial occlusion, followed by two separate exercise sessions. Both the tests were initiated by 2 min rest followed by 1 min arterial occlusion, followed by 2 min of rest and exercise for 3 min. subjects again underwent arterial occlusion during NIRS measurement 30sec post exercise. During the handgrip exercise, the frequency of one contraction being set one per every two sec for 3 min. Six subjects performed the contraction at 24%, three subjects at 18% and remaining three at 12% of the maximum voluntary isometric contraction. A very high correlation was found between muscle oxidative metabolic rate of NIRS ($r = 0.965$, $P < 0.001$).

Mancini et al. (1994) investigated the validity of NIRS measurements in the muscles. They performed 4 different protocols. In the first protocol, they examined the contribution of skin blood flow to the changes in 760-800 nm in three subjects. These changes were measured by laser flow Doppler and NIRS simultaneously. They observed changes in the skin blood flow during the immersion of the forearm in hot water, but there were no alterations in 760-800 nm absorption. They concluded that NIRS signal measures primarily muscle and not skin oxygenation. The second protocol was tended to find the correlation of changes of 760-800nm absorption with venous saturation. They observed a statistically significant linear correlation of 0.82 to 0.97. In the third protocol 4 subjects were assessed for the changes in 760-800 nm absorption when their forearm blood flow was altered by small doses of nitropruside and norepinephrine. The subjects performed the wrist flexion exercise for 4 minutes and their forearm blood flow was measured by plethysmography. The authors observed a decrease in limb perfusion induced by norepinephrine resulting in an increase in deoxygenation and an increase in limb perfusion induced by nitroprusside resulting in less deoxygenation. They concluded that NIRS can detect significant differences in the tissue oxygenation.

In the final protocol, they performed H1- Magnetic resonance spectroscopy (MRS) in 4 subjects to evaluate the role of deoxygenated myoglobin during NIRS absorption. The subjects performed planter flexion of foot, which was placed on a pneumatic device. In three of the 4 subjects, there wasn't any deoxymyoglobin detected despite a higher value for the deoxygenated hemoglobin. They concluded that deoxygenation measured by NIRS was exclusively derived from deoxygenated hemoglobin and not from myoglobin. All these results indicate that NIRS is a valid tool for measuring muscle oxygenation trends.

The studies by MacDonald et al. (1999); Costes et al. (1996) and Hicks et al. (1999) are in contrast to validation studies of NIRS. MacDonald et al. (1999) examined the oxyhemoglobin saturation of the muscle and femoral venous oxygen saturation during leg kicking exercise while the subjects breathed 14, 21 and 70% oxygen. The NIRS probe was placed 10-12 cm above the base of patella on the right vastus lateralis muscle in five subjects and on the left vastus lateralis in one subject. The venous oxygen saturation was measured by taking blood samples from radial artery and femoral vein. They found that oxyhemoglobin of the muscle measured by NIRS was significantly related to femoral venous oxygenation in all the three conditions (normoxia, hyperoxia and hypoxia) only during the first 40 sec after the onset of exercise. When total exercise time was considered they found a correlation r = 0.42 in hypoxia but didn't find any significant correlation in hyperoxia (r = 0.05) and normoxia (r = 0.02).

Earlier, Costes et al. (1996) measured infrared muscle oxygenation (IRO2) and femoral venous oxygen saturation (SfO2) during hypoxia and normoxia. Six healthy subjects performed 30 minute steady state exercise at 80% of their $VO_{2\ max}$ The NIRS probe was placed on the right vastus lateralis muscle. They observed a gradual drop in both IRO2 and SfO2 in hypoxia. but SfO2 showed a faster decrease than IRO2 in normoxia. Hicks et al. (1999) also found the discrepancy in tissue oxygenation measured by NIRS and forearm blood flow measured by Dopper ultrasound. Similar to the study above, the subjects performed the exercise in the conditions of hypoxia and normoxia. But in all the above studies, the blood samples were taken from the veins. Therefore their findings must be interpreted with caution because the veins drain the venous blood not only from a single muscle but also from other adjacent muscles. Hence the sampled blood was not the true venous drainage of the muscle, but the mixed venous blood from the whole muscle group. (Bhambhani et al., in press)

Reliability of NIRS for measuring muscle oxygenation

There is only one reliability study for the use of NIRS in the muscle. Kell et al. (2004) examined the reproducibility of measuring muscle oxygenation on the erector spinae muscle in 17 subjects. The NIRS probe was placed at the L3 level on both sides of the vertebrae. The subjects performed Biering Sorensen Muscle Endurance test twice, with in a weeks time, in which they extended their back from prone position till volitional fatigue. They observed an initial increase in the Oxyhemoglobin and blood volume followed by a decrease or leveling off in some subjects. They observed similar trends in the second trail. They found a significantly high ICC between 0.69 to 0.84 for the two trails and two sides. They also found ICC of 0.98 for the endurance time, indicating strong test-retest reliability. They suggested that NIRS can be used as a non- invasive tool to measure the oxygenation and blood volume responses of paravertebral muscles during static contraction.

Muscle oxygenation during upper body exercise

During the last decade, numerous investigations have used NIRS to study the acute changes in muscle oxygenation and blood volume during a variety of dynamic exercise modes using different muscle groups (Bhambhani., In Press). But there is limited research that has examined the alterations in muscle oxygenation and blood volume during upper body (arm) exercise.

Bhambhani et al. (1998) reported that the magnitude of de-oxygenation in the biceps brachii was lower during arm cranking compared to that attained in the vastus lateralis during leg cycling not only in constant but incremental work load exercise as well. They monitored the changes in the muscle oxygenation during incremental arm and leg exercise in men and women respectively. They used dual wavelength NIRS unit (Runman, NIM, Philedelphia, Pa, USA) for their study. Fifteen men and nine women performed incremental arm cranking and leg cycling separately. One of the NIRS probes were placed at the right vastus lateralis (14-18 cm from the knee) during the leg exercise and other over the motor point of the medial aspect of the biceps brachii (6-8cm from the elbow crease) during arm cranking. The muscle oxygenation was calculated for 30%, 45%, 60%, 75%, and 90% of the VO_{2max}. They reported an inverse relation between VO_2 and muscle oxygenation % and found the multiple r value of -0.96 and -0.99 in men and corresponding values in women were -0.94 and -

0.99. They found that there was an increase in the tissue absorbency during first 2 min of pedaling (zero load) in both exercises but it was of shorter duration in arm cranking exercise. They suggested, this was due to the smaller muscle mass of the upper extremity, hence, there wasn't sufficient amount of blood available for redistribution within the muscle. With the increase of power output the tissue absorbency declined in both exercises. Tissue absorbency leveled off just before the end of the exercise in leg cycling but in arm cranking the leveling off occurred almost at the half stage of the exercise. The researchers suggested that 25 W increase in the power output in the arm cranking was too high for some subjects which led to rapid decrease in the muscle de-oxygenation. Their results, however, indicated no significant differences in the rate of de-oxygenation per unit oxygen uptake between the two exercise modes.

In another incremental exercise test. Muraki et al (2004) investigated the difference in oxygenation trends in the triceps and vastus lateralis muscle in 27 women. Their findings in the triceps muscle were fairly consistent with the trend reported by Bhambhani et al. (1998) in the biceps muscle during arm cranking. They used spatially resolved spectroscopy based photometer (OM-200, Shimadzu, Kyoto, Japan) to assess the oxygenation of the triceps and vastus lateralis muscle respectively. The subjects (age 18-21 yr) performed two VO_2 tests; arm cranking and leg cycling respectively, which were separated by at least 24 hr rest. They maintained the crank rate of 60rpm and the power output was raised from 5.0 to 7.0 W and from 7.5 to 15.0 W every min beginning at zero load period during the arm cranking and leg cycling respectively till the voluntary exhaustion of the subject. They observed two patterns in the tissue oxygen saturation in vastus lateralis. After the initial accelerated decrease in tissue oxygenation. 14 subjects showed a continuous decrease till exhaustion while other 13 subjects showed a leveling off of the tissue oxygenation 1 min prior to reaching VO_{2max}. However, the total Hb/Mb (index of blood volume) remained below the resting level. These results were in accordance with the study by Bhambhani et al. (1998). Arm cranking showed different patterns of tissue oxygen saturation then the leg cycling. During the first half of the exercise the tissue oxygen saturation decreased due to decrease in Oxy-Hb/Mb and increase in de-oxyhemoglobin. Then it leveled off until it reached $VO_{2\ max}$ in 25 out of 27 subjects which corresponded to increase in muscle blood flow at the onset of exercise and decrease in the utilization of oxygen by the muscle as the exercise progressed. In 25 subjects three types of patterns were observed after reaching 51.4 % (12.3) of their VO_{2max}. Firstly tissue oxygenation remained at a plateau in 10 subjects, remained at plateau and then increased in 3 subjects and began to increase in remaining 12 subjects. The Oxy- Hb/Mb and total Hb/Mb showed gradual increase after the first half of the exercise but deoxy-Hb/Mb remained stable. This suggested that the ability of the triceps muscle to take up oxygen became limited at the middle of VO_{2max}, despite adequate oxygen supply. They argued that the triceps had a lower ratio of slow twitch oxidative motor units (type I) compared to the vastus lateralis causing it to reach its limit for oxygen extraction earlier during the incremental exercise test.

In another study, Jensen-Urstad et al. (1995) evaluated the changes in biceps brachii oxygenation during arm cranking exercise performed at a constant work rate for 15 minutes during normoxia and hypoxia (12% inspired oxygen). Their results indicated a rapid initial decrease in oxygenation during the first few minutes of exercise with a steady reversal during the latter phases of the test. The reversal was slower in all subjects under hypoxic conditions compared to normoxic conditions.

It is evident from the above studies that NIRS is a valid, reliable and effective method for measuring cerebral and muscle oxygenation/blood volume. It assesses concentration changes of oxyhemoglobin (HbO_2) and deoxyhemoglobin (HHb) by measuring changes of absorption at different wavelengths, non-invasively, without any discomfort to the subject. To date, none of the studies have looked at cerebral and muscle oxygenation/blood volume simultaneously, with music acting as an external stimulus, during exercise.

Chapter III: Methods and Procedures

Subjects

Written informed consent was obtained from 21 healthy male volunteers from the University of Alberta to participate in this study (Appendix A). Subjects were recruited by means of advertisements placed across campus (Appendix B). The inclusion criteria were: (1) age between 18 to 40 years, (2) absence of cardio-respiratory, metabolic, and neuromuscular disorders as indicated in the Physical Activity Readiness Questionnaire (CSEP, 1982) (Appendix C), (3) absence of any auditory condition, and (4) no previous experience in using a wheelchair. The subjects had similar exercise habits in that majority of them were not endurance trained. Each subject was asked to complete the following four testing sessions, the procedures of which had been approved by the Health Research Ethics Board of this institution (Appendix D). The results of one subject were eliminated from the study due to technical problems. The physical characteristics of the remaining 20 subjects are presented in Table 1.

Roller system

The experimental set up for this study is illustrated in Figures 2 and 3. A standard wheelchair (Quickie, MediChair Inc., Edmonton) was mounted on a frictionless roller system that was interfaced with a computer using a Dash 8 computer board (Bhambhani et al., 1991). A 1 cm strip of reflective tape was fastened on the rim of the flywheel, which was then detected by the web camera mounted on the roller frame. This roller system was connected to the computer which recorded the number of revolutions per minute (rpm) from the signals generated each time the reflective tape crossed the path of the web camera. The computer program also calculated the wheeling speed in kilometers per hour (kmh) and distance traveled (meters) from the flywheel circumference and rpm data. The velocity was displayed as a digital speedometer on the computer. To ensure reliability of this measurement, a cat eye recorder (Velo 5, cc-vl500, OS, Japan) was also used to monitor the speed of the wheelchair. The distance traveled and speed during the test was printed upon the completion of test. The tire pressure in the wheelchair was maintained at 65 psi and checked before every test.

Table 1: Physical characteristics of subjects (N = 20)

Variable	Mean	Standard Deviation	Minimum	Maximum
Age (yrs)	26.45	3.72	18	35
Ht (m)	1.75	0.08	1.63	1.94
Wt (kg)	79.1	11.8	61.5	100.6
BMI (kgm^{-2})	25.7	2.9	21.0	32.2
% Body Fat	18.3	5.0	8.7	28.1

Session one

In this session the subject first completed the written informed consent form and then was familiarized with wheelchair exercise and the cardio-respiratory and NIRS testing procedures. This exercise mode was selected because many older individuals as well as people with disabilities use wheelchairs for ambulation. The subject was asked to identify four pieces of excitatory music (lasting at least 10 minutes) from a personal selection of CDs. These pieces were downloaded from the CD to the computer so that they could be easily retrieved during the testing session. The subjects were asked to select their own music because this is typically what happens in a practical setting. After the subject completed all the testing sessions, these pieces of music were deleted from the computer. This test session lasted approximately 30 minutes.

Session two, three and four

These three sessions were administered in random order. In one of these sessions, the subject did not perform any exercise, but listened to his favorite music identified in session one for 10 min. The subject listened to the music for the entire test duration using head phones (Labtec Elite 840) connected to the computer at a self-selected volume. This test session lasted approximately 30 minutes. In the remaining two sessions, the subject was asked to exercise for 10 minutes on the wheelchair-roller system at a self-selected velocity under the two conditions: control (E) and music ((E + M)) of their own choice selected in session one. The subject was not provided any feedback pertaining to wheelchair velocity or distance traveled during either test condition. This was ensured by placing the computer monitor behind the subject during the test protocol. At the end of 10 minutes, the subject was signaled to propel the wheelchair at maximum velocity and continue exercising until voluntary fatigue, or the following criteria for VO_{2max} were attained (ACSM, 1991): (1) no further increase in the oxygen uptake with increasing velocity, (2) age predicted maximum HR (220 – age, yrs), and (3) a respiratory exchange ratio >1.10. Each exercise test session lasted approximately 1 hour.

Cardio-respiratory measurements

Cardio-respiratory responses were monitored continuously using a wireless automated metabolic cart (VmaxST, Sensormedics, Yorba Linda, CA). The mass flow sensor was calibrated for volume using a 3L syringe. The oxygen and carbon dioxide analyzers were calibrated using commercially available precision gases (16% oxygen, 4% carbon dioxide, balance nitrogen). This wireless metabolic cart has a fast response oxygen analyzer that uses high sensitivity paramagnetic technology to measure the percentage of expired oxygen, an infrared absorption analyzer for the determination of fractional percentage of expired carbon dioxide, and a mass flow sensor to measure expired volume of air. The subject wore the face mask and the flow sensor was attached to it. Heart rate (HR) was recorded using a wireless monitor attached to the chest. The data were gathered in the breath-by-breath mode and averaged over 20 sec intervals at the end of the test. In order to minimize interference, the central (heart and lungs) and peripheral (localized muscles) RPE (Borg, 1982) was recorded after completion of the test.

Near Infrared Spectroscopy (NIRS) measurements

Cerebral and muscle oxygenation during the exercise tests were recorded continuously using three dual wave NIRS units (MicroRunman, NIM Inc., Philadelphia, PA). The NIRS probe consisted of one light source and two silicone detectors. The distance between the light source and detectors was 3-cm. The light source emitted white light from a tungsten source and the intensity of the reflected light was detected at 760 and 850 nm. The software calculated the absorbency at each wave length and expressed the values in OD units. Real time values for difference between oxyhemoglobin and deoxyhemoglobin (850nm - 760nm) and the sum of oxyhemoglobin and deoxyhemoglobin (850nm + 760nm) was obtained during rest and exercise. The difference in OD between the two wavelengths was used as an index of oxygenation, while the sum of the OD was used as an index of blood volume.

For the cerebral oxygenation measurements, the probe was placed on the left frontal lobe approximately 3 cms from the midline, just above the supra-orbital ridge so as to avoid contamination of the signal by the temporalis muscle (Kleinschmidt et al., 1996; Obrig et al., 1996). The reproducibility of the oxyhemoglobin and deoxyhemoglobin measurements during dynamic cycling exercise in cardiac patients has been demonstrated (Koike et al., 2004). For the muscle oxygenation measurements, the probe was secured over the belly of the biceps brachii (5 to 7 cms from the elbow joint) and the long head of the triceps muscles (approximately 7 to 10 cms from the elbow joint) of the dominant arm. These points were identified with an indelible marker so that the probe could be placed at the same point for the subsequent test. Inter-session test reliability of the minimum oxygenation obtained during incremental lifting is 0.95 (Kell et al., 2004). The NIRS probe was calibrated individually for each subject with the same light intensity and penetration depth for each condition. Data were collected on line using NIRCOM software (NIM Inc., Philadelphia) available with the instrument. A clear plastic sheet was placed between the probes and skin to prevent distortion of signal due to perspiration. The signals from the three NIRS units were monitored on the computer screen continuously.

The cardio-respiratory and NIRS values during sub-maximal exercise were calculated by taking the average of the 10 minutes of exercise period. For sub-maximal NIRS responses, the averaged values of last 20 seconds, just prior to the start of sub-maximal exercise, were deducted from the values obtained during the exercise. The cardio-respiratory measurements during maximal exercise were averaged over 20 seconds intervals. For maximal NIRS responses, the average values of the last 20 seconds, just prior to the start of maximal exercise were deducted from the values obtained during exercise period. Body fat measurements were measured by hand held electrical impedance monitor (Omron BF 300, Wegalaan, Germany).

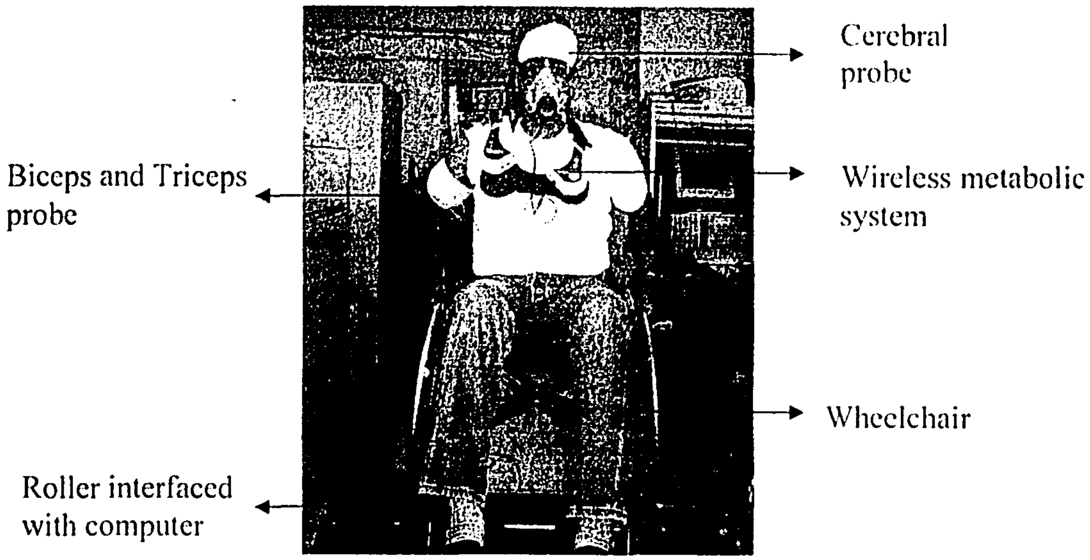


Figure 2: Front view of subject seated in the wheelchair mounted on the roller system

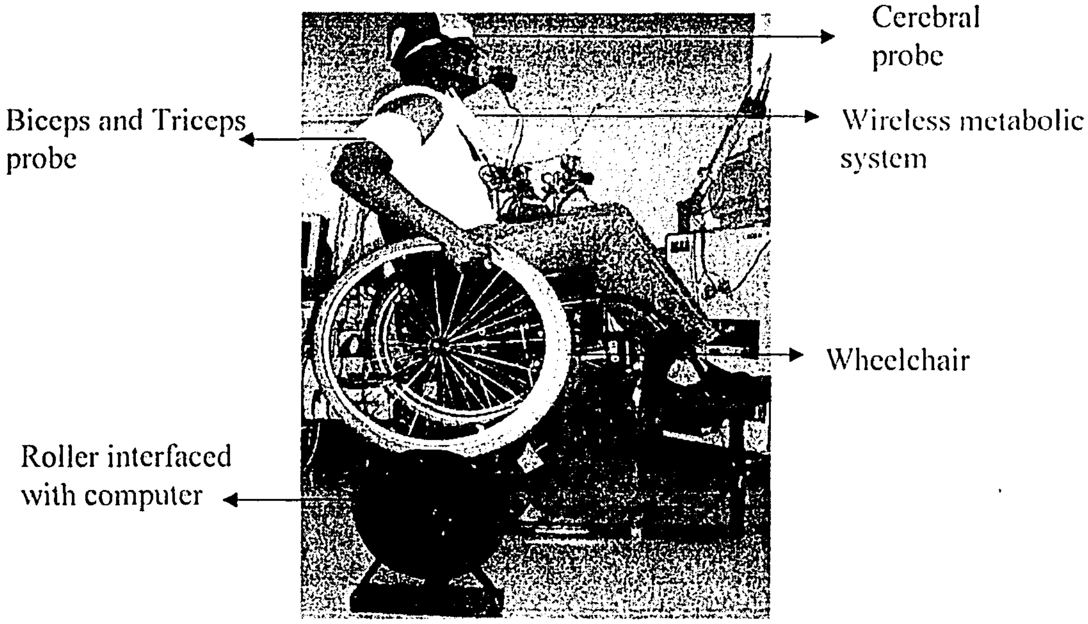


Figure 3: Side view of subject seated in the wheelchair mounted on the roller system

Statistical analysis

Differences between the means of the pertinent cardio-respiratory and NIRS variables were compared using a repeated measures analysis of variance. The Pearson correlations were used to examine the inter-relationships among the delta values [i.e. (E + M) – E] of wheelchair distance, velocity, cerebral and muscle oxygenation/blood volume changes during the two conditions. Hierarchical analysis was performed to identify the variables (cardio-respiratory, cerebral and muscle NIRS) that would best predict the changes in wheelchair distance and speed between two conditions. Hierarchical analysis was performed with delta distance and speed as the dependent variables. The changes in cardio-respiratory and NIRS responses were considered the independent variables. Because of the large standard deviation of the NIRS measurement, the level of significance was set at 0.10. The statistical analysis was performed using SPSS computer programs. (version 12.0, Chicago, IL).

Limitations of the study

1. The same wheelchair was used for all the subjects.
2. The resistance of the rollers was not been taken into consideration. It was presumed that wheelchair users experience a similar kind of resistance when propelling the wheelchair on the ground.
3. To minimize the effects of learning, the subjects were familiarized with the equipment and wheelchair in the first session.

Delimitations

Only male volunteers between the ages of 18 and 35 years were allowed to participate in the study to minimize the effect of subcutaneous fat on NIRS responses. Therefore these results can be generalized only to this sub-population.

Chapter IV: Results

Part I: Responses during rest

Effects of music on metabolic and cardio-respiratory responses during rest

The means and standard deviations of the physiological variables at one minute and ten minutes while listening to the self selected music in the wheelchair are summarized in Table 2. The mean values for AVO_2, RVO_2, HR, V_E, RER and V_E/VO_2 at 10 minutes were significantly higher when compared with first minute of listening to music. However no significant differences were observed for O_2 pulse and V_E/VCO_2 ratio.

Effects of music on cerebral and muscle blood volume/oxygenation responses during rest

(i) *General trends*

The cerebral, biceps and triceps muscle oxygenation and blood volume trends during rest (M condition) in a representative subject are illustrated in Figures 5, 6 and 7 respectively.

Cerebral tissue

During the M condition, there were small changes in cerebral oxygenation and blood volume during the 10 minute interval. Fourteen subjects showed a slight increase in the blood volume whereas others showed a slight decrease. Similarly, an increase in oxygenation was observed in 12 subjects while the remainder showed a small decrease.

Biceps muscle

During the M condition, an increase in blood volume was observed in all but four subjects. As a result, the muscle oxygenation also increased in these subjects. These values were fairly stable throughout the music listening period, rising slightly above the baseline.

Triceps muscle

Similar to the pattern observed in biceps during the M condition, the blood volume and oxygenation increased in almost all the subjects. These values showed an increase throughout the music listening period.

(ii) *Comparison of NIRS responses at rest*

The means and standard deviations of NIRS variables at one minute and ten minutes are summarized in Table 3. The mean values of cerebral blood volume, biceps blood volume/oxygenation, triceps blood volume/oxygenation at 10 minutes were significantly higher when compared with first minute of listening to music. However no significant difference was found for cerebral oxygenation.

Table 2: Physiological responses during rest (Mean ± SD)

Variable	Minute 1	Minute 10	% Difference
*AVO$_2$ L/min	0.28 ± 0.06	0.33 ± 0.15	↑ 15.92
*RVO$_2$ ml/kg/min	3.7 ± 0.87	4.4 ± 1.96	↑ 16.31
*HR bpm	68 ± 6.39	74 ± 10.35	↑ 7.93
*V$_E$ L/min	8.5 ± 2.44	11.5 ± 5.74	↑ 25.98
*RER	0.89 ± 0.06	0.96 ± 0.05	↑ 7.3
O$_2$ pulse ml/bt	4.16 ± 0.95	4.46 ± 1.24	↑ 6.65
*V$_E$/VO$_2$	28.2 ± 4.83	32 ± 5.27	↑ 11.82
V$_E$/VCO$_2$	30.7 ± 4.19	31.6 ± 4.35	↑ 2.74

* Significant difference ($p<.10$) between minute 10 and minute 1

Table 3: Effects of music on NIRS responses during rest (Mean ± SD)

Variable	Minute 1	Minute 10	% Difference
* Cerebral Blood Volume, OD units	0.0002 ± 0.0169	0.0063 ± 0.0156	↑ 3045.8
Cerebral Oxygenation, OD units	0.0031 ± 0.0086	0.0004 ± 0.0259	↓ 13.6
* Biceps Blood Volume, OD units	0.0133 ± 0.0130	0.0276 ± 0.0330	↑ 107.9
* Biceps Oxygenation, OD units	0.0160 ± 0.0123	0.0278 ± 0.0197	↑ 73.5
* Triceps Blood Volume, OD units	0.0111 ± 0.0104	0.0400 ± 0.0724	↑ 259.5
* Triceps Oxygenation, OD units	0.0078 ± 0.0090	0.0163 ± 0.0136	↑ 108.0

* Significant difference (p<.10) between minute 10 and minute 1

Part II: Responses during sub-maximal exercise

Effects of music on wheelchair distance and velocity

The means and standard deviations of the wheeling distance and velocity under the two conditions are summarized in Table 4. It is evident that there were significant increases in both these variables during the 10 minutes of exercise when the subjects were listening to music. The mean increase was 12.3% during this 10 minute interval.

Effects of music on metabolic, cardio respiratory and perceptual responses during wheelchair exercise

The means and standard deviations of the physiological variables are summarized in Table 5 and illustrated in Figure 4. The mean values for AVO_2. RVO_2, V_{E}, RER and O_2 pulse during (E + M) were significantly higher when compared to E only. Although HR and V_E/VO_2 values increased by 2.5% and 1.97% respectively during (E + M), they were not statistically significant (P>.10). Despite the increase in the AVO_2 and V_{E}, both the central and peripheral RPE were significantly lower during the (E + M) condition.

Table 4: Effects of music on wheelchair distance and velocity (Mean ± SD)

Variable	Exercise	Exercise Plus Music	%Difference
*Distance (m)	681.40 ± 117.42	759.19 ± 150.39	↑ 12.3 %
*Velocity (km/hr)	4.09 ± 0.70	4.56 ± 0.90	↑ 12.3 %

* Significant difference (p<.10)

Table 5: Physiological and perceptual responses during sub-maximal wheelchair exercise (Mean ± SD)

Variable	Exercise Only	Exercise Plus Music	% Difference
* AVO_2 L/min	0.72 ± 0.19	0.79 ± 0.23	↑ 9.3%
* RVO_2 ml/kg/min	9.19 ± 2.36	10.02 ± 2.86	↑ 9.5 %
HR bpm	96.69 ± 10.27	99.14 ± 10.89	↑ 2.5 %
* V_E L/min	22.89 ± 7.37	25.52 ± 9.53	↑ 11.7%
* RER	1.03 ± 0.07	1.05 ± 0.05	↑ 4.6 %
* O_2 Pulse ml/bt	7.57 ± 2.06	8.11 ± 2.22	↑ 6.5 %
V_E/VO_2	32.14 ± 5.83	32.77 ± 6.25	↑ 1.97 %
V_E/VCO_2	30.33 ± 3.04	30.22 ± 4.76	↓ 0.62 %
* RPE central	11.65 ± 1.13	11.20 ± 0.76	-----
* RPE peripheral	12.55 ± 0.75	12.1 ± 0.64	-----

* Significant difference ($p<.10$)

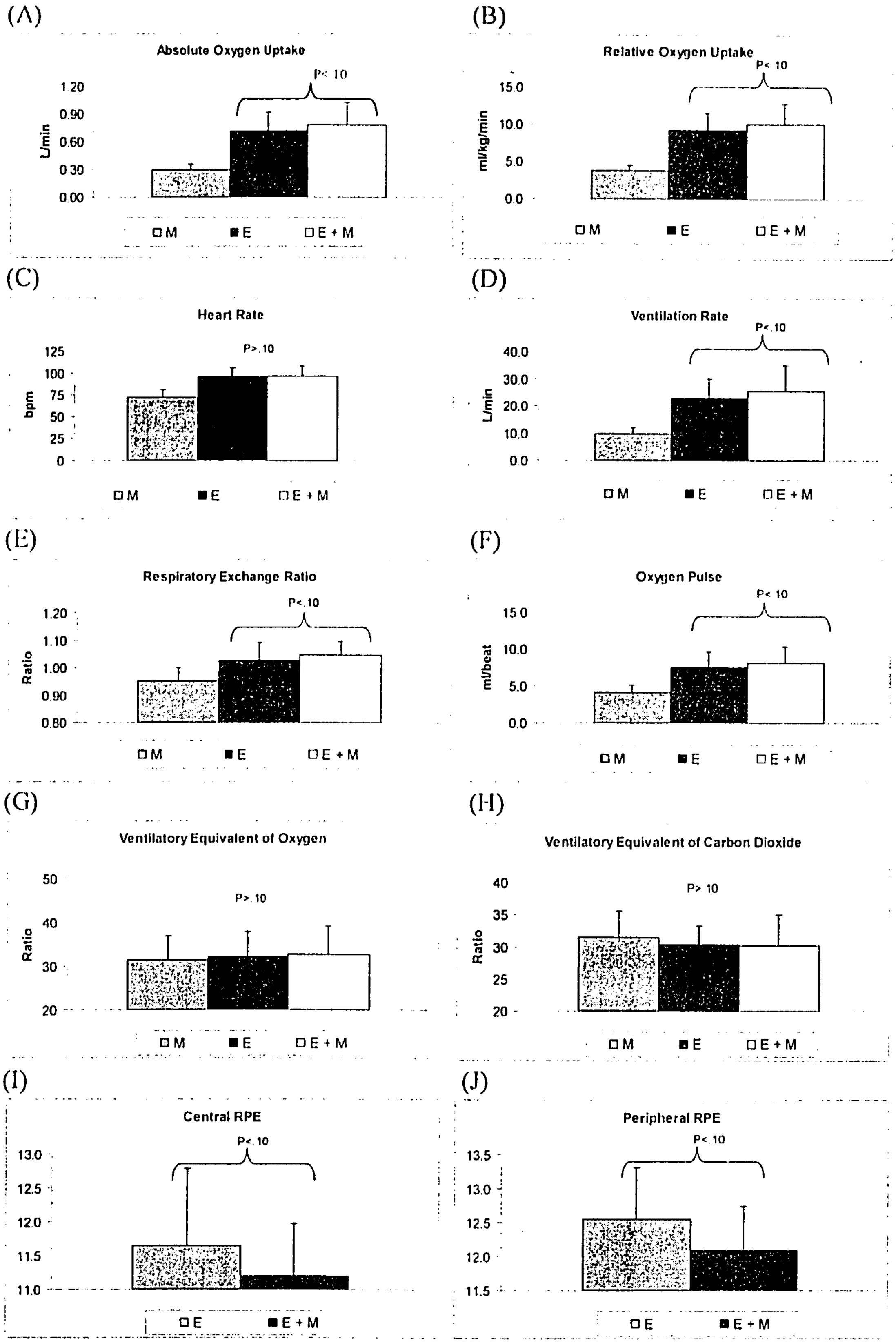


Figure 4: Mean values of physiological and perceptual responses during sub-maximal wheelchair exercise

Effects of music on cerebral and muscle blood volume/oxygenation responses during sub-maximal wheelchair exercise

(i) *General trends*

The cerebral, biceps and triceps muscle oxygenation and blood volume trends during rest and the 10 minutes of sub-maximal wheelchair exercise in a representative subject under the three conditions (M, E and E +M) are illustrated in Figures 5, 6 and 7 respectively.

Cerebral tissue

When exercise was initiated, there was a systematic increase from the resting values in both these variables during the 10 minutes under both E and (E + M) conditions in majority of subjects. Fifteen subjects showed an increase, whereas the remainder showed a slight decrease in the blood volume and oxygenation. In some cases, a leveling off was observed during the latter stages of exercise, whereas in others, these values continued to rise throughout the 10 minutes of exercise. In general, the values during the (E + M) condition tended to be higher than those observed during E.

Biceps muscle

At the initiation of 10 minutes of sub-maximal exercise, a decrease in blood volume with a simultaneous increase in the blood oxygenation was observed in almost all subjects under both E and (E + M) conditions. The magnitude and duration of these changes varied among the subjects. Following these initial changes, the blood volume and oxygenation returned towards the baseline. With the progression of exercise, all the subjects showed an increase in the blood volume from the baseline until the end of the sub-maximal exercise period. This increase tended to be higher during the (E + M) condition. The muscle oxygenation remained slightly lower than the baseline and fairly constant throughout the exercise period. In five subjects the oxygenation declined continuously till the start of all out exercise. In some subjects the baseline was slightly lower, so the trends became positive even though the oxygenation didn't decrease or increase drastically. The oxygenation patterns were similar in both (E + M) and E conditions, with the decrease being more pronounced in the E condition.

Triceps muscle

During the 10 minutes of sub-maximal exercise triceps blood volume increased systematically in both (E + M) and E condition. Fourteen subjects demonstrated a slight decrease in blood volume at the start of exercise. Thereafter, it increased continuously in all the subjects till the end of the sub-maximal exercise period. The muscle oxygenation remained fairly stable throughout the exercise period and increased only marginally from the baseline. There was an increase in oxygenation in three subjects, but the magnitude of increase in blood volume was higher in these subjects. The trends were similar in both (E + M) and E conditions with the values being slightly higher in the E condition.

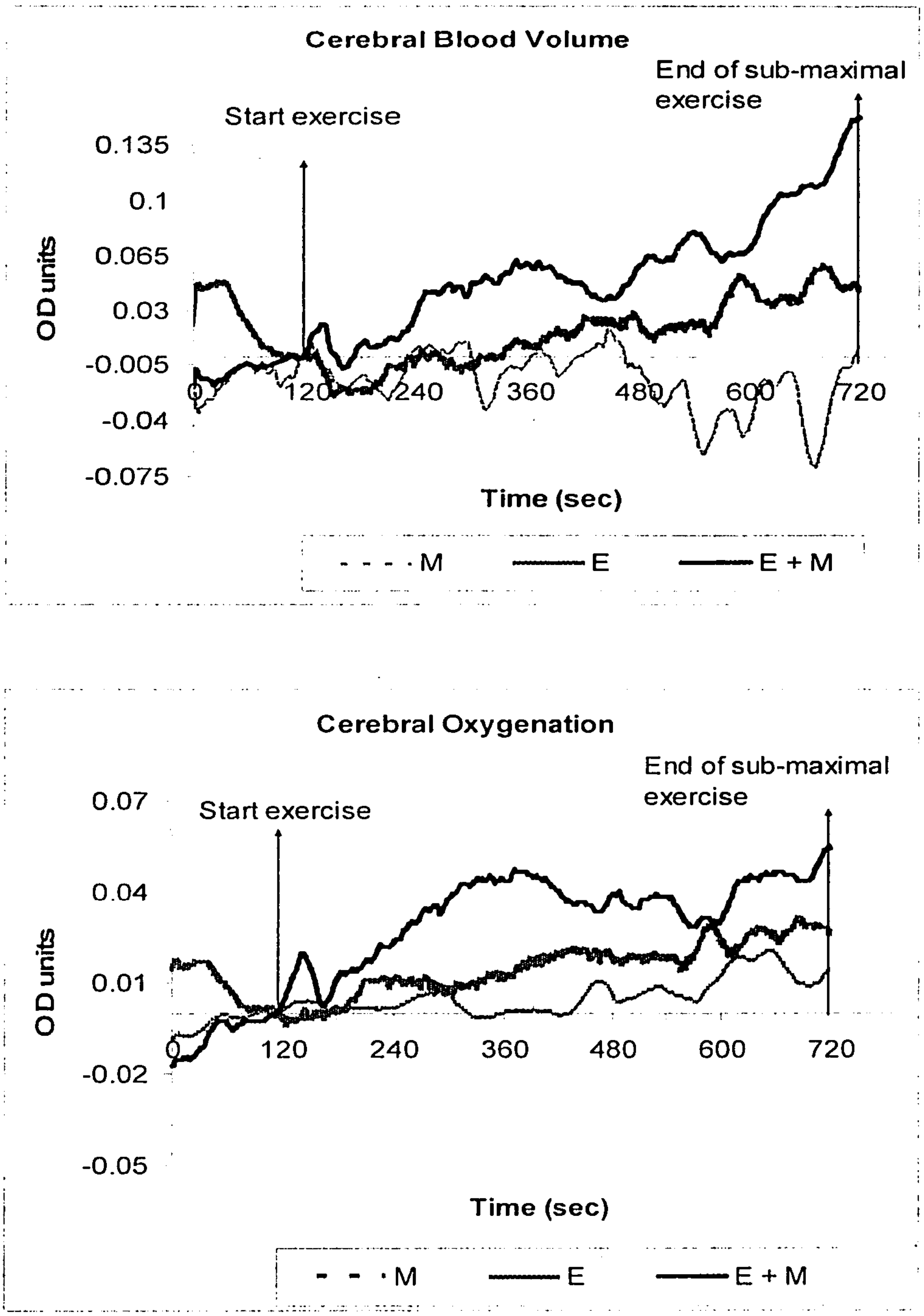
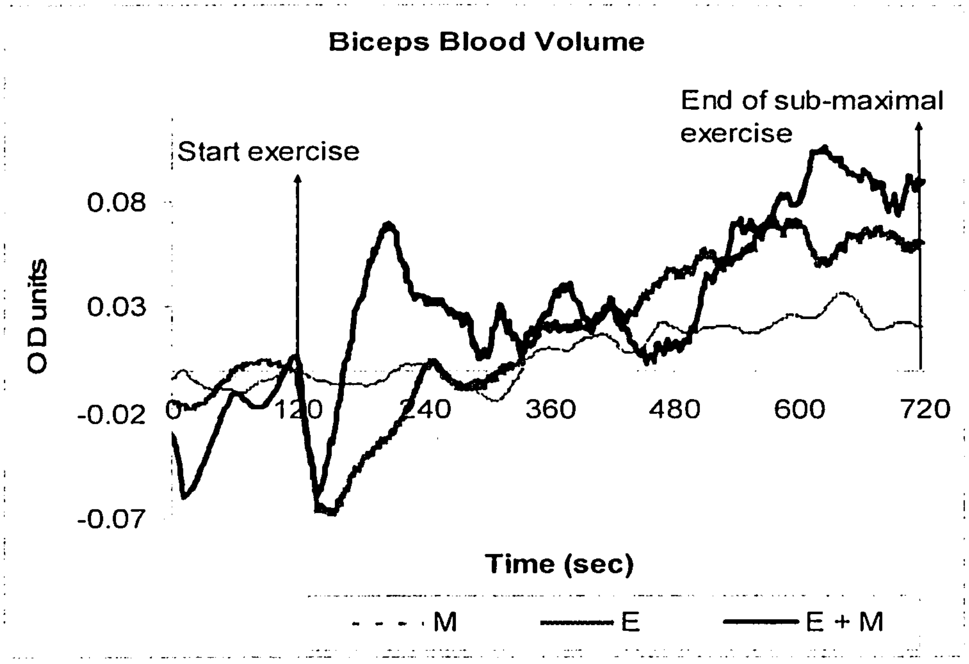


Figure 5: Cerebral blood volume and oxygenation trends during sub-maximal wheelchair exercise in a representative subject



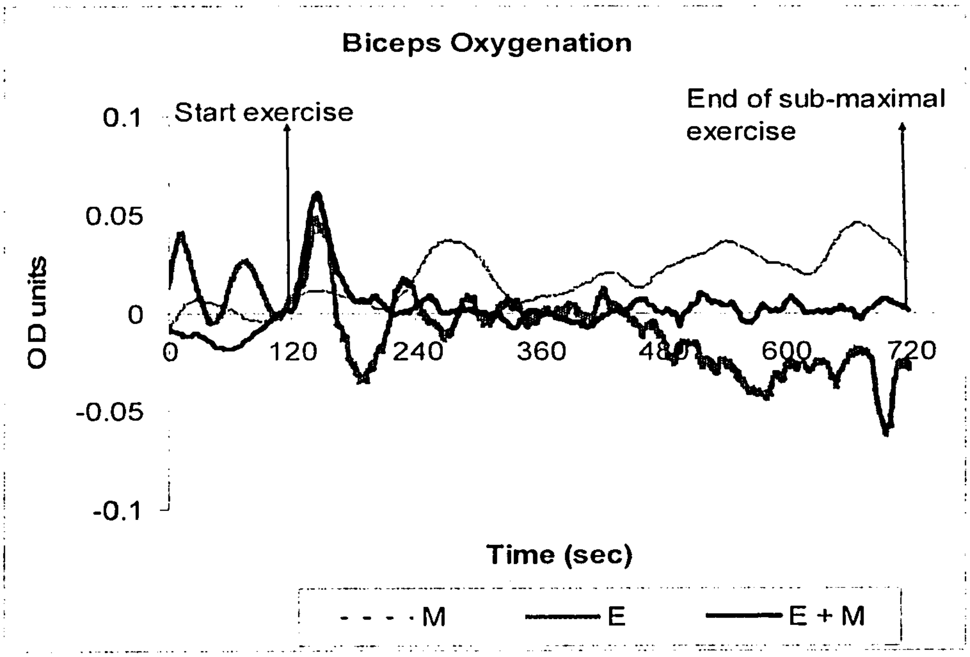
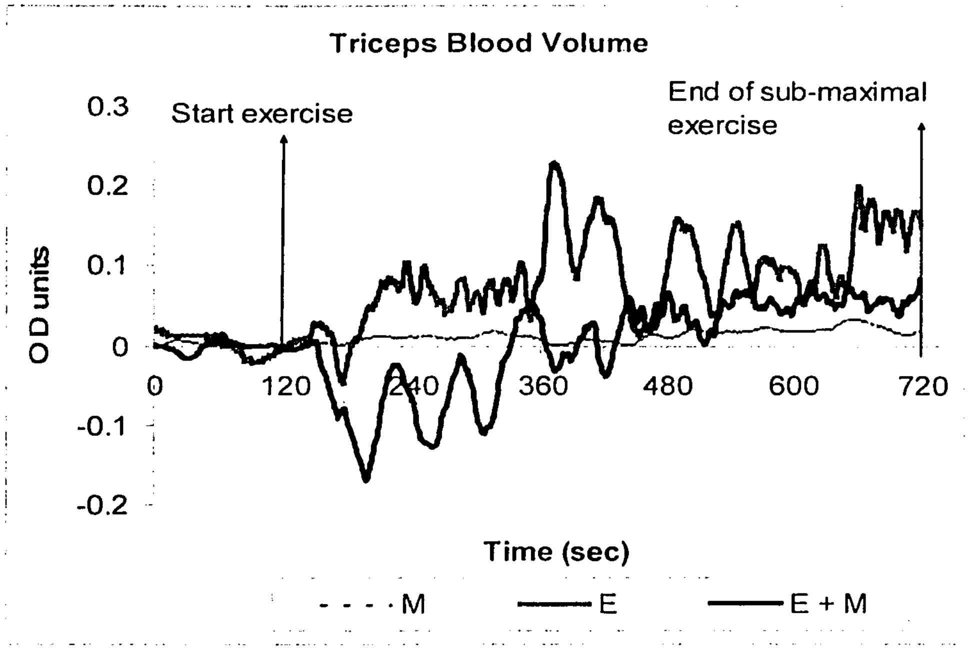


Figure 6: Biceps blood volume and oxygenation during sub-maximal wheelchair exercise in a representative subject



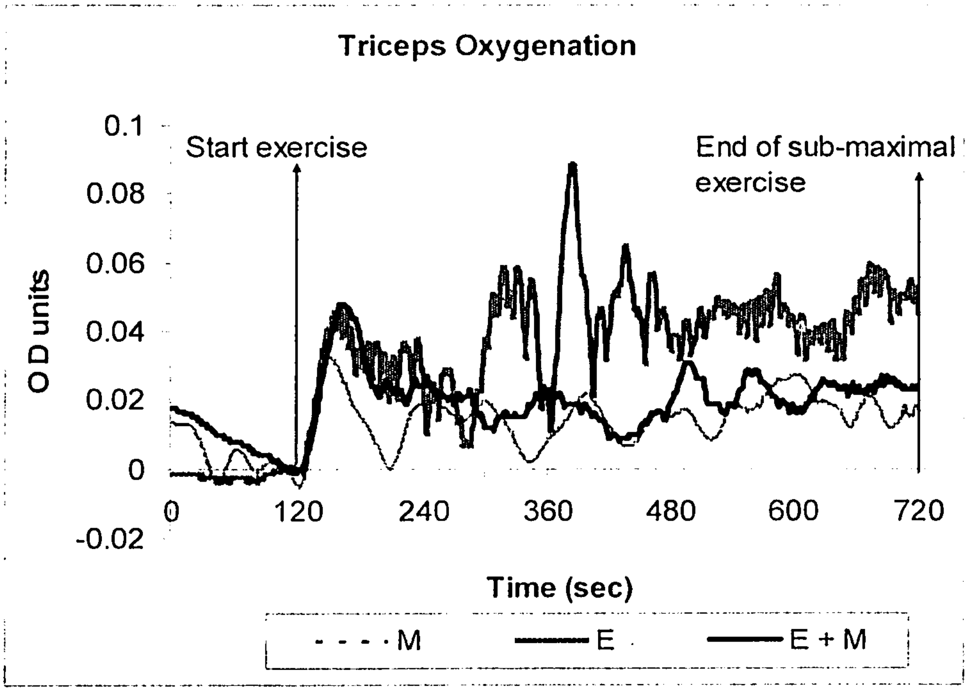


Figure 7: Triceps blood volume and oxygenation during sub-maximal wheelchair exercise in a representative subject

(ii) *Comparison of mean NIRS responses in cerebral and muscle tissue*

The average values of cerebral and muscle oxygenation/blood volume under the three conditions are summarized in Table 6 and illustrated in Figure 8. When comparing the values with E condition, an increase of 13.7% and 48.3% was observed in cerebral blood volume and cerebral oxygenation respectively during the (E + M) condition. The decrease in biceps oxygenation (i.e. deoxygenation) was lower by 53.8%, with a simultaneous increase in biceps blood volume by 117.7%. Marginal decreases of 2.79% and 0.68% were found in triceps blood volume and triceps oxygenation respectively. However, due to the high standard deviation of these measurements, none of these differences were statistically significant.

Table 6: Effects of music on NIRS responses during sub-maximal wheelchair exercise (Mean ± SD)

Variable	Music	Exercise	Exercise Plus Music	% Difference
Cerebral Blood Volume, OD units	0.0066 ± 0.0219	0.0212 ± 0.0276	0.0241 ± 0.0439	↑ 13.7%
Cerebral Oxygenation, OD units	0.0035 ± 0.0093	0.0099 ± 0.0218	0.0147 ± 0.0189	↑ 48.3%
Biceps Blood Volume, OD units	0.0160 ± 0.0148	0.0191 ± 0.0501	0.0417 ± 0.0486	↑ 117.5%
Biceps Oxygenation, OD units	0.0216 ± 0.0148	-0.0067 ± 0.0565	-0.0031 ± 0.0590	↑ 53.8%
Triceps Blood Volume, OD units	0.0201 ± 0.01260	0.0419 ± 0.0591	0.0408 ± 0.0329	↓ 2.79%
Triceps Oxygenation, OD units	0.0111 ± 0.0086	0.0130 ± 0.0191	0.0129 ± 0.0251	↓ 0.68%

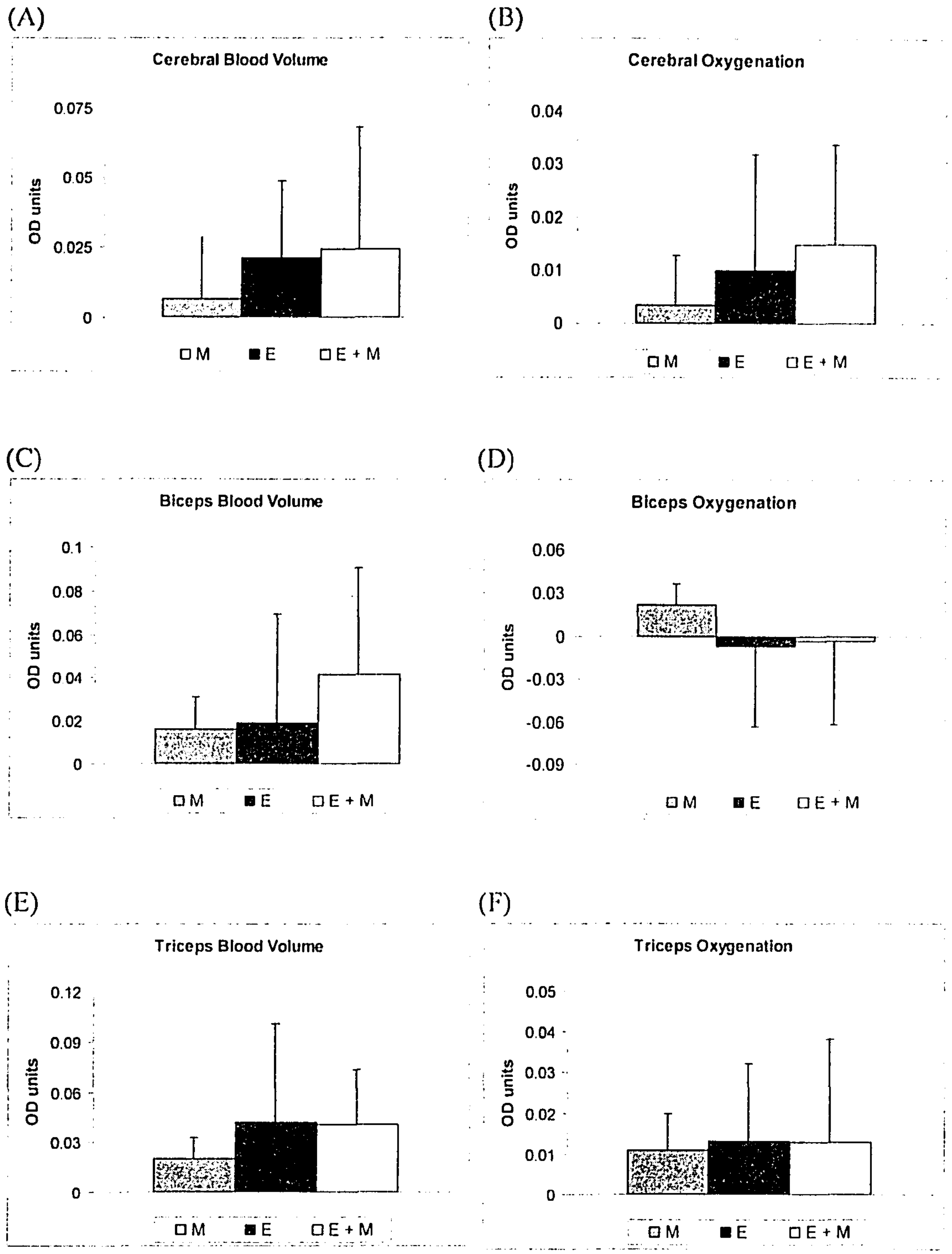


Figure 8: Mean values of NIRS responses during sub-maximal wheelchair exercise

Relationship between wheelchair exercise performance and cardio-respiratory responses during sub-maximal exercise

Significant correlations were observed between wheelchair speed and the absolute and relative values of VO_{2max} The correlations (r) were as follows: speed vs AVO_2 (E) = .74, speed vs RVO_2 (E) = .78, speed vs AVO_2 ((E + M)) = .56, speed vs RVO_2 ((E + M)) = .68. These correlations are illustrated in Figure 9. The correlations between the delta values of wheelchair speed versus the AVO_2, RVO_2, HR, V_E and O_2 pulse are illustrated in Figure 10. No significant correlations were observed for any of the relationships that were examined.

Relationship between wheelchair exercise performance and NIRS responses

The correlation between delta wheelchair speed versus delta cerebral and muscle blood volume/oxygenation are illustrated in Figure 11. Significant correlations were found between delta speed and delta cerebral oxygenation (r = .42, P<.10) and a slightly lower correlation between the delta speed and delta cerebral blood volume (r = .33, P>.10). The regression equation for predicting the change in delta speed and delta cerebral oxygenation was: $y = 0.0278x - 0.01$ (P =.07). This suggests that increased speed during (E + M) condition tended to be associated with enhanced cerebral oxygenation. Although none of the other correlations were significant, it is interesting to note that the correlations with the cerebral NIRS variables were positive while those with the muscle NIRS variables were negative (with the exception of the triceps oxygenation). The hierarchical analysis selected only delta cerebral oxygenation as a predictor of the delta speed. No other variable was selected due to low correlation values.

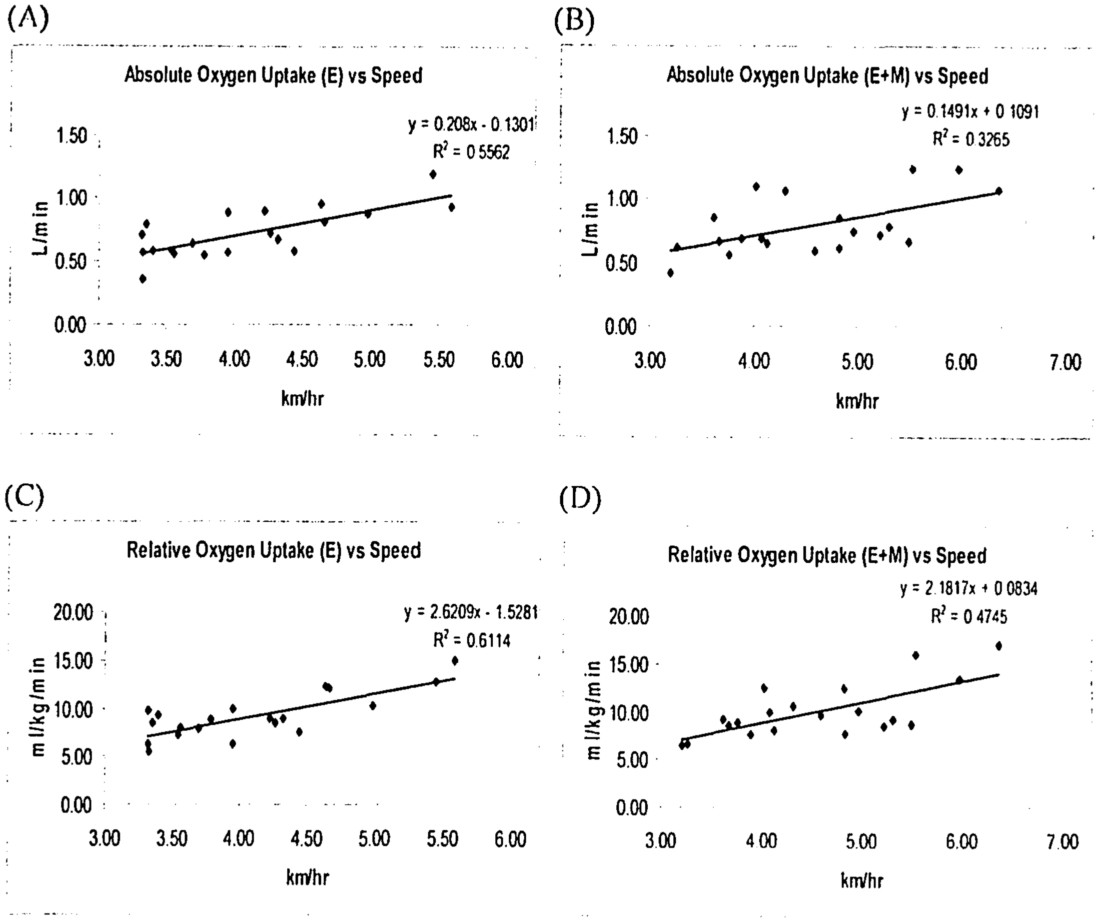


Figure 9: Relationship between speed and cardio-respiratory responses during sub-maximal wheelchair exercise

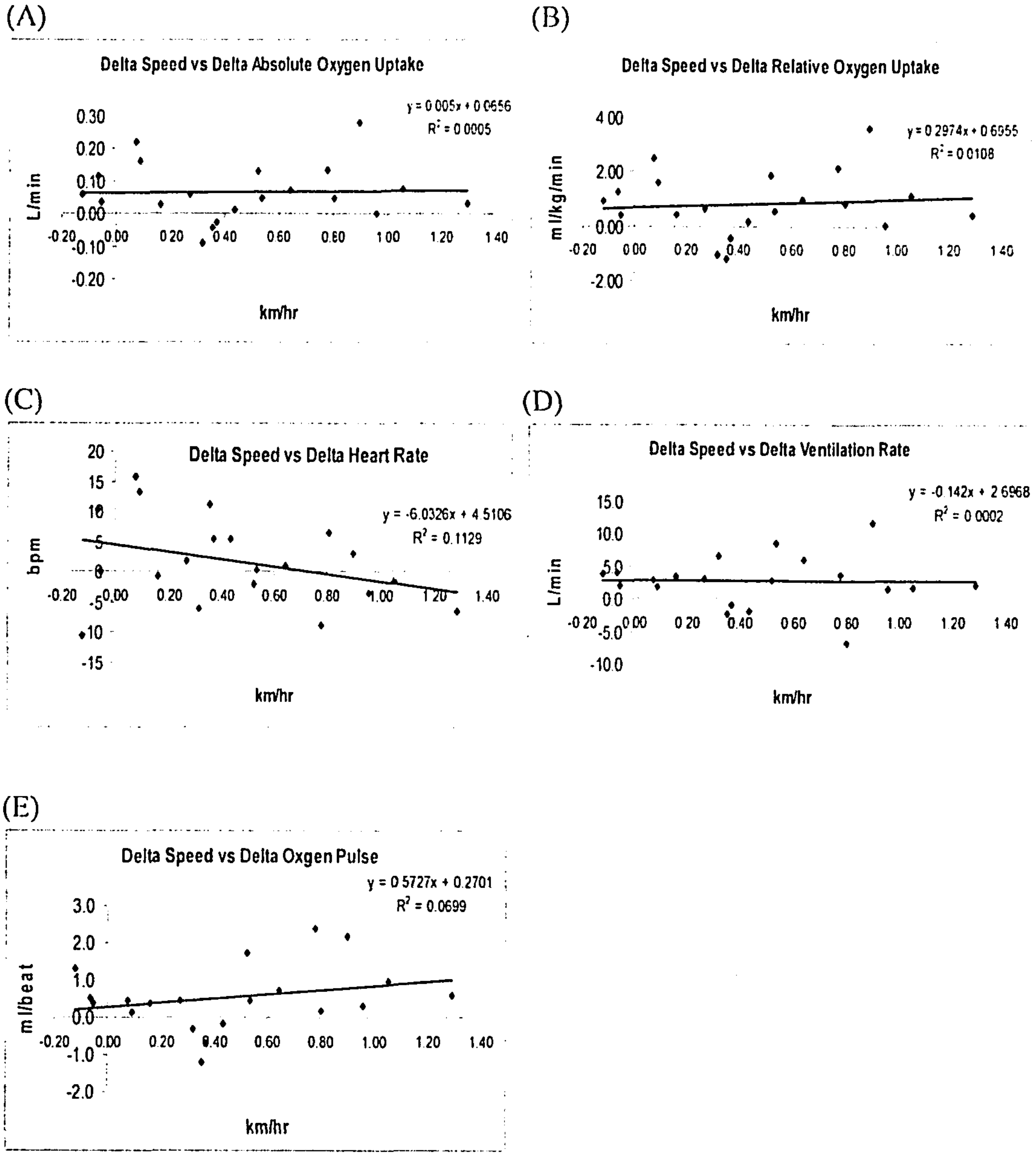


Figure 10: Relationship between delta speed and cardio-respiratory responses during sub-maximal wheelchair exercise

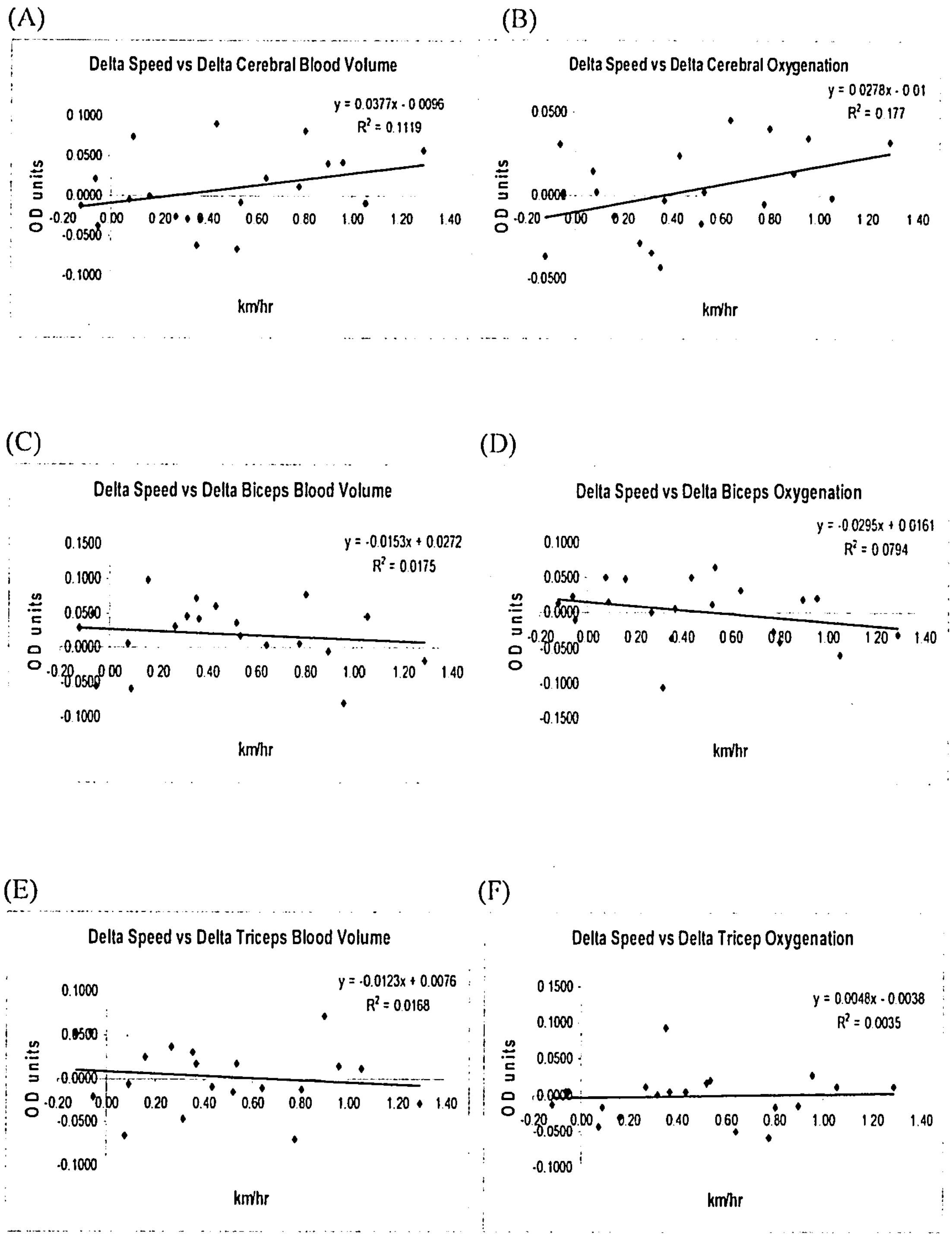


Figure 11: Relationship between delta speed and NIRS responses during sub-maximal wheelchair exercise

Part III: Responses during maximal exercise

Effects of music on cardio-respiratory and perceptual responses during wheelchair exercise

The physiological and perceptual responses during maximal wheelchair exercise are summarized in Table 7 and illustrated in Figure 12. Participants propelled the wheelchair faster at the start of the maximal exercise period after which the speed declined until they terminated the test due to fatigue. The time taken by the subjects to reach volitional fatigue increased by 11.27% and was significantly higher during the (E + M) condition. None of the subjects reached their age predicted maximal HR during the maximal tests under the two conditions. However, all the subjects were able to attain an RER value that exceeded 1.10, which was one of the criteria for maximal performance. The "t" test indicated significantly higher values for AVO_2, RVO_2, HR, V_E and O_2 pulse ($P<.10$) during (E + M) condition when compared with E only. The average central and peripheral RPE decreased marginally by 1.8 % and 0.55% respectively. Although these declines in RPE were very small, the central RPE was significantly different. It remained unchanged in most of the subjects and only six subjects showed this decline in the (E + M) condition.

Table 7: Physiological and perceptual responses during maximal wheelchair exercise (Mean ± SD)

Variable	Exercise Only	Exercise Plus Music	% Difference
*Time for all out exercise Sec	92.75 ± 32.4	103.15 ± 24.6	↑ 11.2%
*AVO_2 L/min	1.60 ± 0.38	1.75 ± 0.48	↑ 9.2%
*RVO_2 ml/kg/min	20.60 ± 4.98	22.50 ± 6.21	↑ 9.4 %
*HR bpm	148.6 ± 14.7	154.0 ± 12.9	↑ 3.8 %
*V_E L/min	67.59 ± 19.94	75.50 ± 26.18	↑ 12.2%
RER	1.37 ± 0.16	1.42 ± 0.18	↑ 3.9 %
*O_2 Pulse ml/bt	10.93 ± 2.87	11.49 ± 3.44	↑ 5.04 %
V_E/VO_2 ratio	43.84 ± 11.79	44.08 ± 11.84	↑ 1.08 %
V_E/VCO_2 ratio	32.20 ± 7.73	31.90 ± 8.95	↓ 0.9 %
*RPE central	16.35 ± 0.67	16.10 ± 0.72	--------
RPE peripheral	18.15 ± 0.37	18.10 ± 0.31	--------

* Significant difference ($p<.10$)

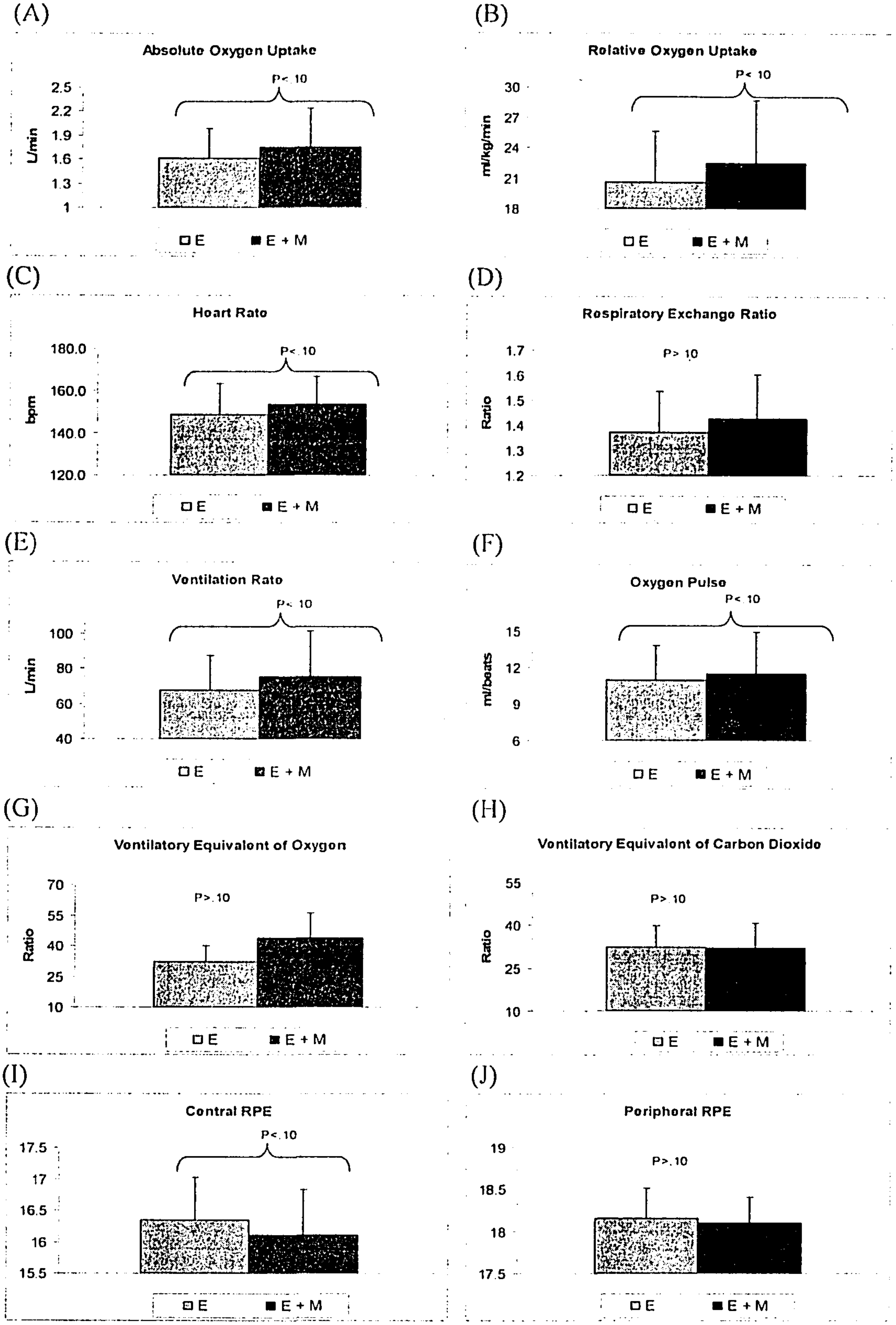


Figure 12: Mean values of physiological and perceptual responses during maximal wheelchair exercise

Effect of music on cerebral and muscle oxygenation/blood responses during maximal exercise

(i) *General Trends*

The trends in cerebral, biceps and triceps muscle oxygenation and blood volume during maximal exercise in a representative subject under the three conditions (M, E and E +M) are illustrated in Figures 13, 14 and 15 respectively.

Cerebral tissue

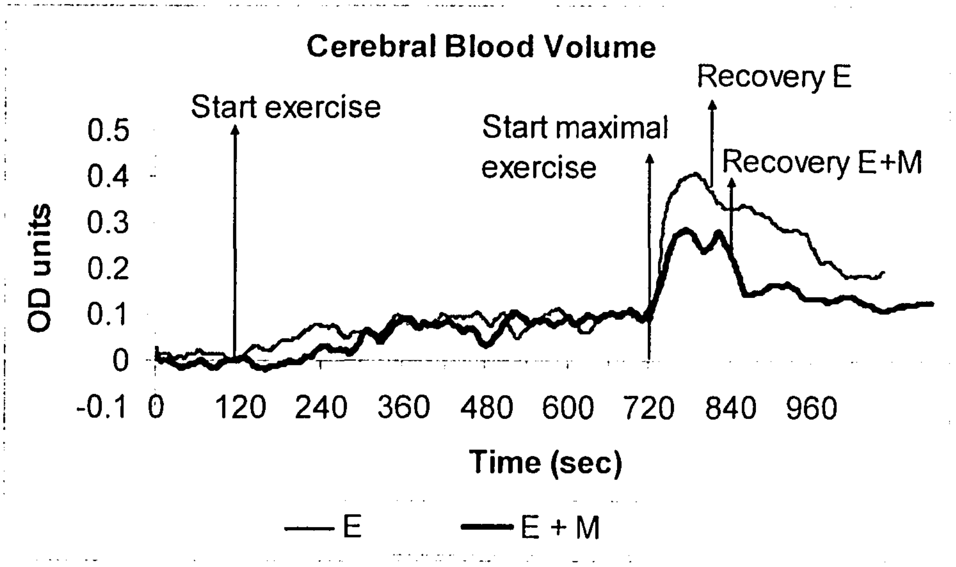
During maximal exercise, the cerebral blood volume and oxygenation started increasing at the onset of maximal exercise, and showed a decrease just before the end of exercise under both conditions. The magnitude of increase in blood volume was higher than that of oxygenation in almost all the subjects. The values for blood volume during (E + M) condition tended to be lower than that in E condition, whereas the values for blood oxygenation were higher for (E + M) condition. However, none of these differences were statistically significant.

Biceps muscle

Some interesting patterns were observed in the biceps muscle during the maximal exercise. In both the E and (E + M) conditions the blood volume increased initially, reached a peak and then started to decline towards the end of exercise, in almost all the subjects. There was a tendency for the mean blood volume during (E + M) condition to be higher than that in E condition. The biceps oxygenation showed a more complex response. In the (E + M) condition, 16 subjects showed an initial increase and then a decrease. This was followed by a plateau or increase towards the end. However, in the E condition, 11 subjects showed an initial increase in the oxygenation followed by a decrease. The rest of the subjects showed an initial decrease followed by an increase. There was a tendency for mean oxygenation in (E + M) to be lower than that in the E condition.

Triceps muscle

The blood volume in 15 subjects decreased initially and gradually increased till the end of exercise. In the remaining five subjects, the blood volume showed an increase followed by a decrease towards the end of exercise. The mean blood volume in the (E + M) condition tended to be higher than that in E condition. A similar pattern was observed in muscle oxygenation. The muscle oxygenation decreased initially and was followed by an increase towards the end of exercise in 14 subjects in both the (E + M) and E conditions. In one subject it showed a continuous decrease till the end of exercise in the E condition. In the remaining five subjects there was an initial increase followed by decrease in the oxygenation. The magnitude of decrease tended to be higher in the (E + M) condition.



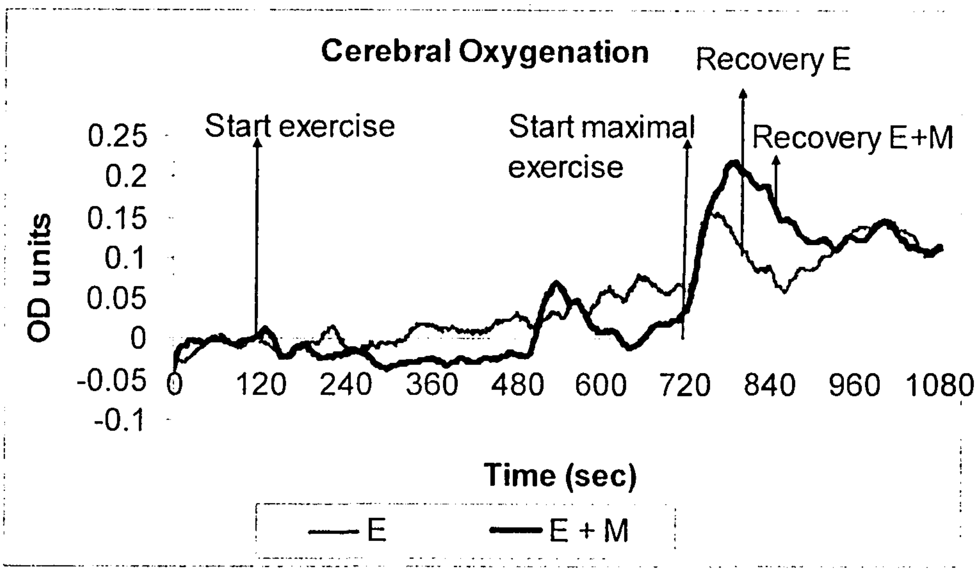
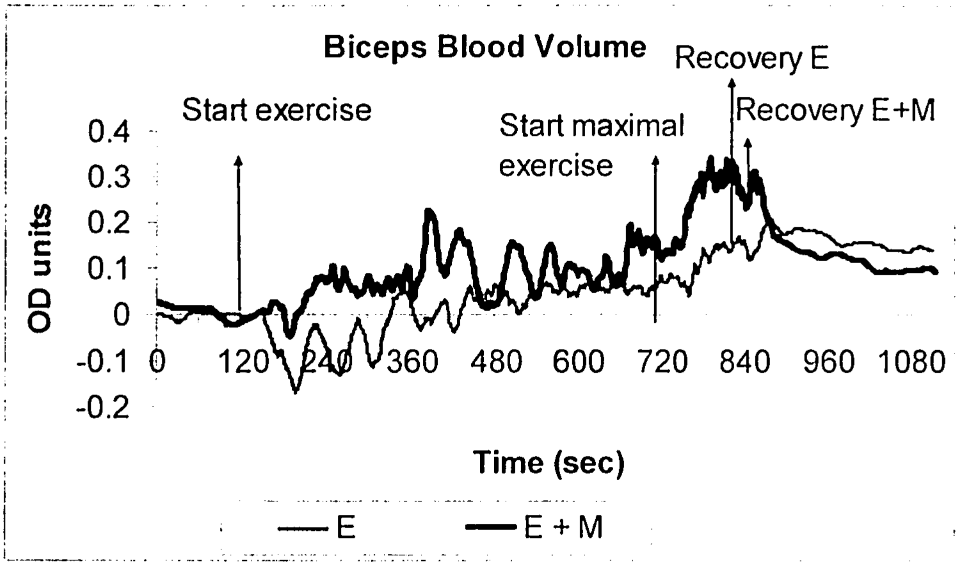


Figure 13: Cerebral blood volume and oxygenation trends during maximal wheelchair exercise in a representative subject



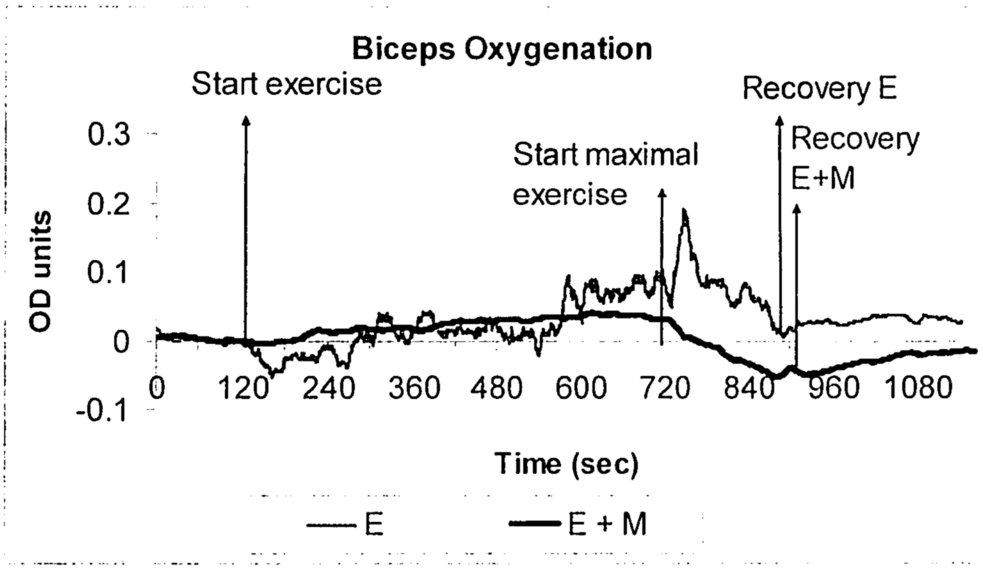


Figure 14: Biceps blood volume and oxygenation trend during maximal wheelchair exercise in a representative subject

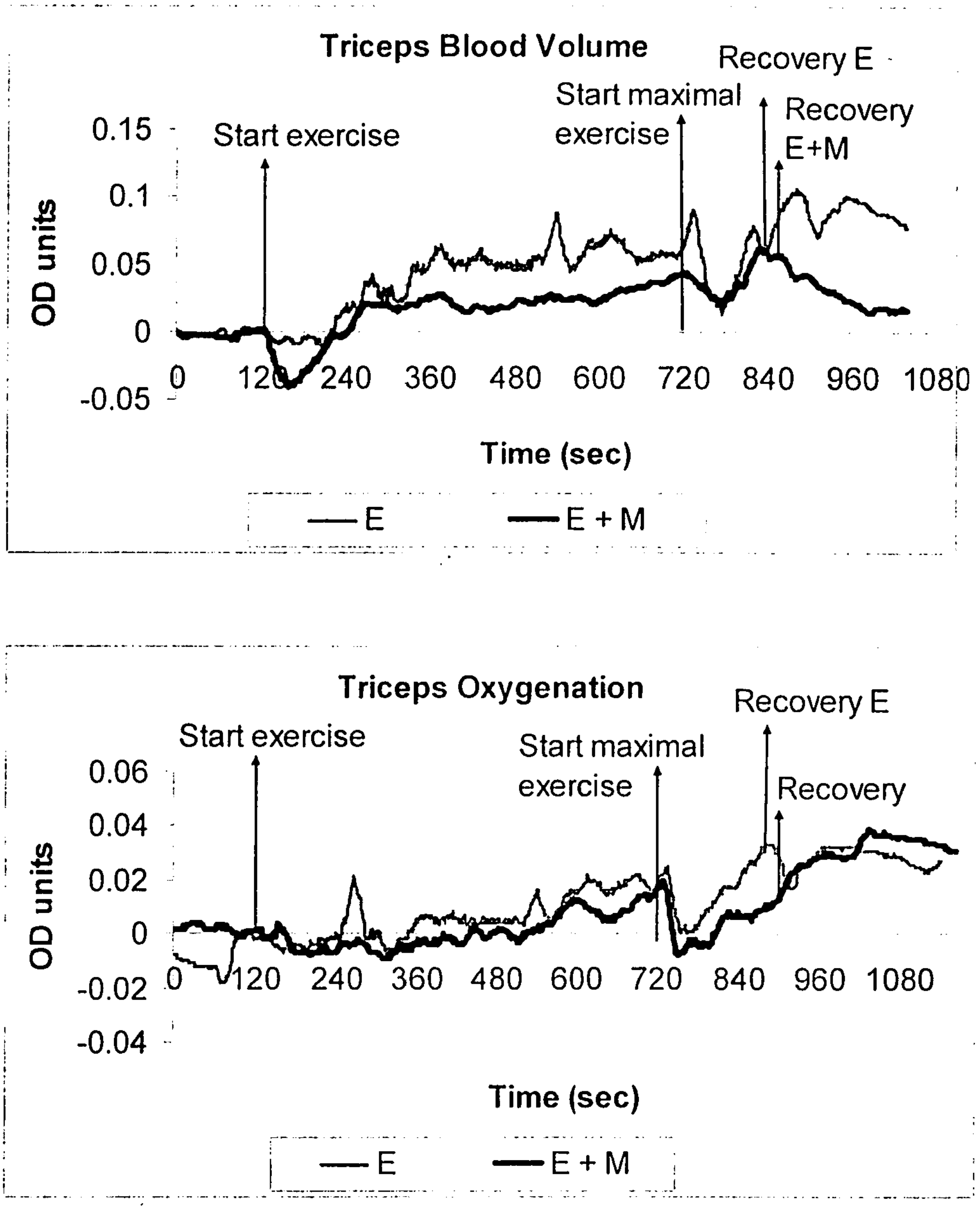


Figure 15: Triceps blood volume and oxygenation trend during maximal wheelchair exercise in representative subject

(ii) *Comparison of mean NIRS responses in cerebral and muscle tissue*

The mean values of the cerebral and muscle oxygenation and blood volume responses during the maximal wheelchair exercise are shown in Table 8 and illustrated in Figure 16. During the (E + M) condition, cerebral blood volume showed a decrease of 7.03% but the cerebral oxygenation increased by 53.97%. The biceps blood volume showed an increase of 9.92% with a corresponding decrease of 31.5% in biceps oxygenation. The triceps blood volume showed a large increase of 73.44% with a concomitant decrease of 45.37% in triceps oxygenation. Due to the high standard deviation of the measurements, none of these differences were statistically significant.

Table 8: Effects of music on NIRS responses during maximal wheelchair exercise (Mean ± SD)

Variable	Exercise	Exercise Plus Music	% Difference
Cerebral Blood Volume, OD units	0.112 ± 0.075	0.104 ± 0.0798	↓ 7.03%
Cerebral Oxygenation, OD units	0.009 ± 0.039	0.021 ± 0.023	↑ 53.97%
Biceps Blood Volume, OD units	0.060 ± 0.071	0.067 ± 0.083	↑ 9.92%
Biceps Oxygenation, OD units	-0.011 ± 0.047	-0.035 ± 0.067	↓ 31.5%
Triceps Blood Volume, OD units	0.004 ± 0.047	0.014 ± 0.061	↑ 73.44%
Triceps Oxygenation, OD units	-0.010 ± 0.018	-0.021 ± 0.070	↓ 45.37%

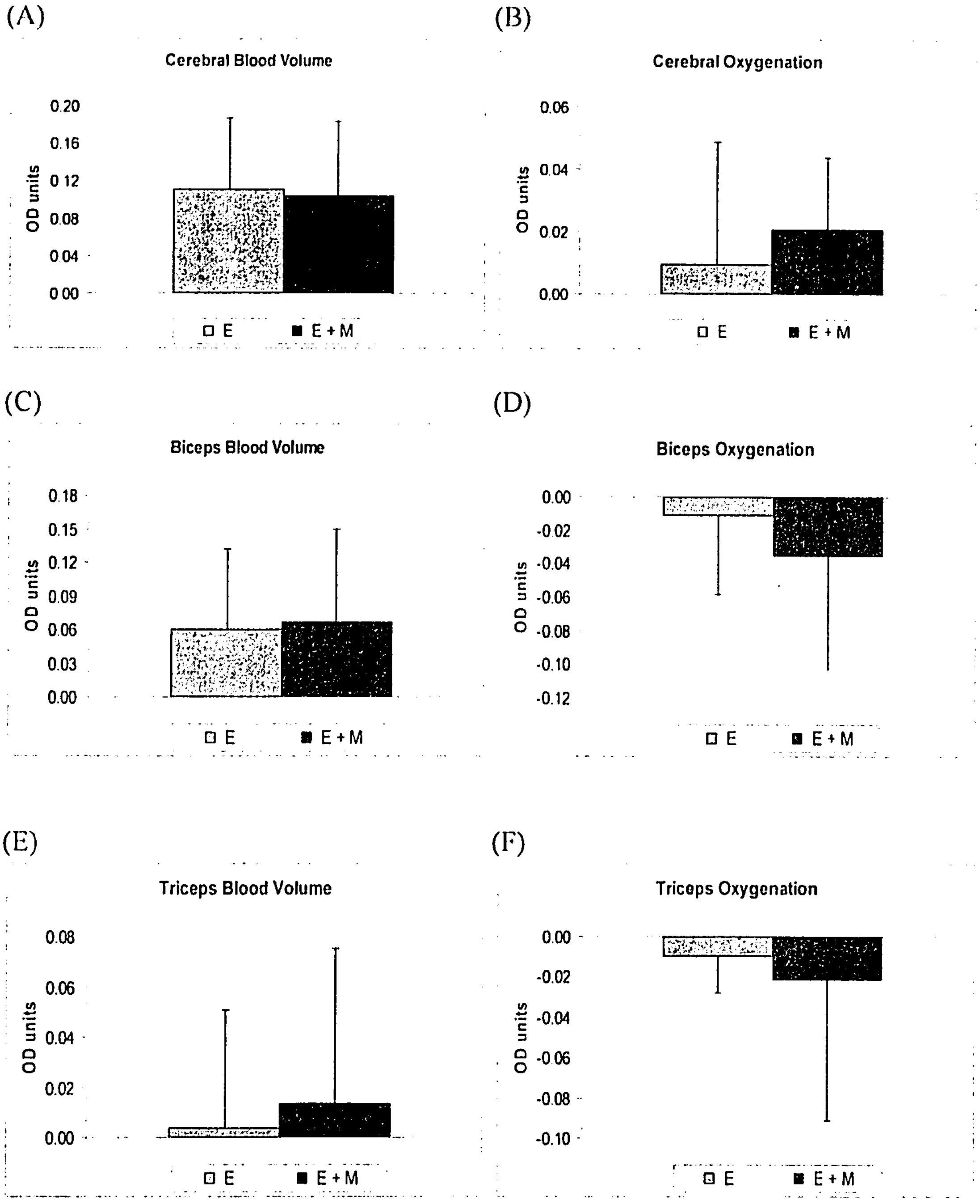


Figure 16: Mean values of the NIRS responses during maximal wheelchair exercise

Relationship between wheelchair exercise performance time and cardio-respiratory responses during maximal exercise

The correlations between the changes in wheelchair exercise time versus the changes in AVO_2, RVO_2, HR, V_E and O_2 pulse are illustrated in Figure 17. No significant correlations were found for any of these relationships. There was a tendency for the change in wheelchair exercise time to be positively correlated with the change in AVO_2 ($r = 0.22$), RVO_2 ($r = 0.22$), and O_2 pulse ($r = 0.32$). However, the change in wheelchair exercise time tended to be inversely related to the change in HR ($r = -0.24$).

Relationship between wheelchair exercise performance time and NIRS responses

The correlations between the changes in wheelchair exercise time versus the changes in cerebral and muscle blood volume/oxygenation are illustrated in Figure 18. No significant correlations were found between the wheelchair exercise time and any of the NIRS variables. The hierarchical analysis did not select any variable due to the low correlation values.

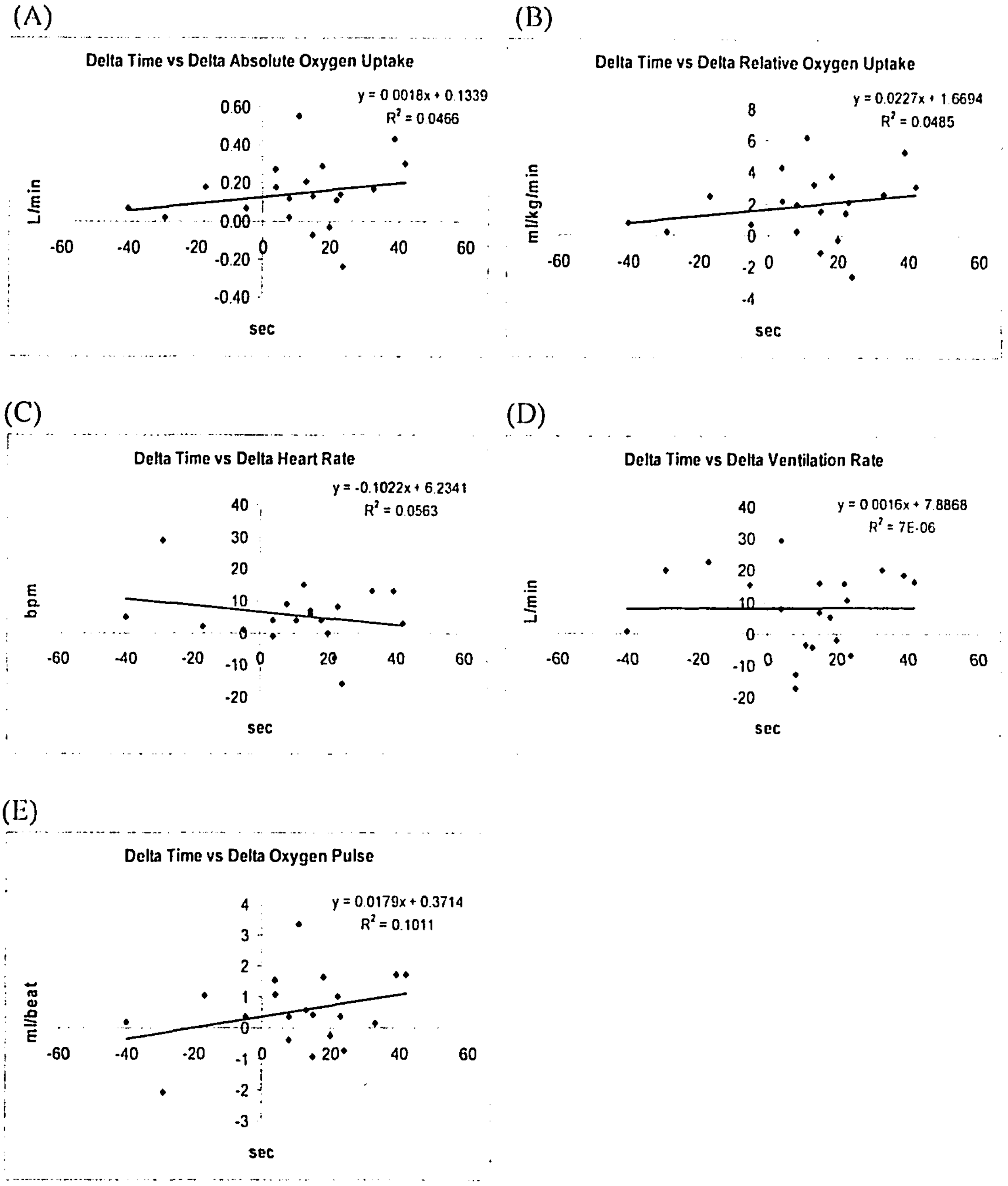


Figure 17: Relationship between delta time and cardio-respiratory responses during maximal wheelchair exercise

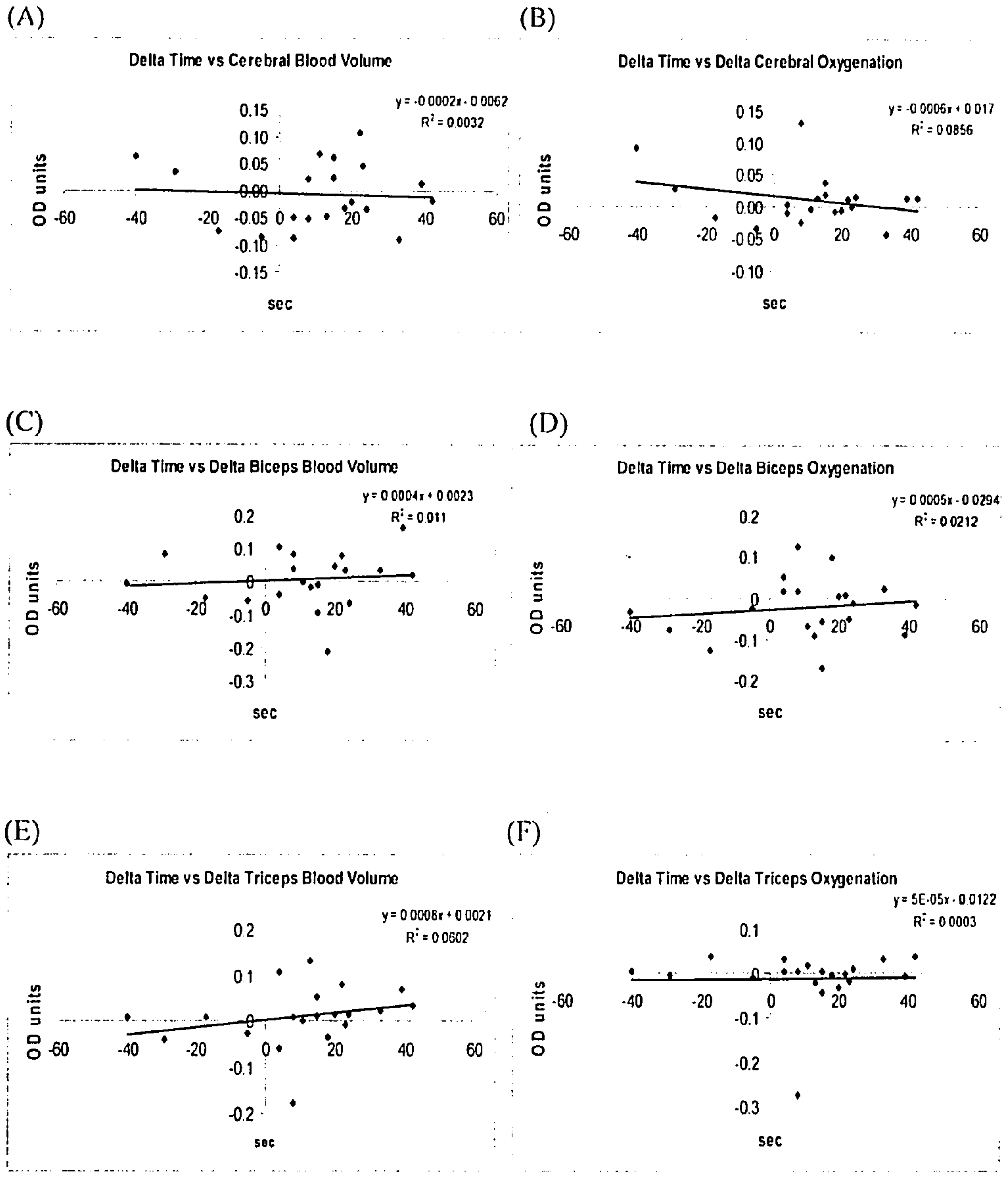


Figure 18: Relationship between delta time and NIRS responses during maximal exercise

Chapter V: Discussion

Part I: Responses during rest

Effects of music on metabolic and cardio-respiratory responses during rest

Significant increases were observed in AVO_2, RVO_2, HR, V_E, RER and V_E/VO_2 at 10 minutes when compared with first minute of rest (Table 2). However, no significant changes were observed in the O_2 pulse and V_E/VCO_2 ratio. A possible explanation is that the listening to music stimulated the medulla oblongata, which controls cardio-respiratory functions of the body (Suszkiw et al., 1996), thereby leading to increases in these physiological variables. The lack of a significant increase in the O_2 pulse suggests that the AVO_2 and HR increased in proportion while listening to music.

Effects of music on cerebral and muscle oxygenation/blood volume during rest

The current observation indicated that cerebral and muscle (biceps and triceps) blood volume increased significantly from the first to the tenth minute while listening to music under resting conditions (Table 3). Since the HR showed a significant increase, the evidence indirectly suggests that these increases n the blood volume were most likely due to enhanced central circulation. Future studies should confirm this by measuring the cardiac output under this condition. The fact that cerebral oxygenation had a tendency to decrease could be due to the significant enhancement of cerebral blood volume.

Part II: Responses during sub-maximal exercise

Effects of music on wheelchair distance and velocity

A significant increase of 12.3% occurred in the wheelchair distance traveled and the speed attained during 10 minutes of exercise in the (E + M) condition. These observations are consistent with those of Atkinson et al. (2004) who reported a significant increase in cycling velocity during a time trial in healthy subjects who listened to mixed music selected by the researcher at a music tempo of 142 beats/min. However, Emery et al. (2003) reported no significant change in exercise time in cardiac patients participating in a cardiac rehabilitation program. The subjects listened to rhythmic music of moderate tempo selected by the researchers (Vivaldi's Four Seasons). Whether this discrepancy is due to the clinical status of the patients is unclear.

Effect of music on metabolic and cardio respiratory responses during sub-maximal wheelchair exercise

We observed significant increases in AVO_2, RVO_2, V_E, RER and O_2 pulse of 9.3%, 9.5%,11.7%, 4.6% and 6.5% respectively during the (E + M) condition when compared to E only. The magnitude of the increase in AVO_2 (70 ml/min) (Table 5) was greater than the changes (50 ml/min) (Table 2) observed when the subject was listening to music under resting condition. Although the HR increased by 2.5% in the (E + M) condition, it was not statistically significant. This implies that cardiac stress was not significantly altered during this condition. The O_2 pulse is the absolute oxygen consumed per heart beat and is mathematically determined by the product of stroke volume and $(a - v)O_2$ difference. In the present study O_2 pulse showed a significant increase in the (E + M) condition. This increase was due to the increase in AVO_2 without any significant increase in HR. Since O_2 pulse is a good predictor and indirect measure of stroke volume (Bhambhani et al., 1994), it is possible that the (E + M) condition may have led to increase in stroke volume.

The V_E/VO_2 and V_E/VCO_2 ratios were not significantly altered during the (E + M) condition. The V_E/VO_2 ratio represents the economy of ventilation (McArdle, 2001). The fact that this ratio was unaffected by music implies that the efficiency of ventilation was not significantly altered.

A significant decrease occured in both the central and peripheral RPE during 10 minutes of wheelchair exercise, despite an increase in the wheeling speed, AVO_2 and V_E. These observations are in agreement with previous studies that have observed a decrease in RPE when subjects exercised with music (Potteiger et al., 2000; Szmedra et al., 1998). One possible explanation is that music had a distracting effect, thereby decreasing the RPE. In contrast, Atkinson et al. (2004) reported an increase in RPE when subjects showed an improvement in power and speed of cycling while listening to music. The reason for this discrepancy is unclear. It is possible that the lower RPE observed in the present study was due to the fact that the subjects selected their own music which had a distracting effect.

Previous studies have evaluated the effects of music on exercise during tredmill running, bench stepping and cycling (Szmedra et al., 1998; Hayakawa et al., 2000; Atkinson et al., 2004; Becker et al., 1994). The results of these studies are summarized in Table 9. In almost all of these studies, the music was selected by the researchers and not by the subjects. In the present study, we observed an increase in wheeling distance, HR, AVO_2 and RVO_2, V_E and O_2 pulse during the sub-maximal exercise. Though the HR increased by 2.5% for (E + M) condition, it was not statistically significant. It is evident from Table 9 that these studies did not evaluate the metabolic responses during exercise. The results obtained for HR are consistent with those obtained by Potteiger et al. (2000) who also found no significant difference in sub-maximal HR at 70 % of cycling VO_{2max} when subjects listened to classical music, fast music, self selected music and no music during four separate exercise sessions. In contrast to our study, Szmedra et al. (1998) found a significant decrease of 4.6% in the HR in male subjects in the music trial during treadmill running at 70% of VO_{2max}. These researchers selected slow rhythmic music which tends to have a soothing effect on the subjects. Moreover the subjects were well trained and had a mean VO_{2max} of 63 ml/kg/min. It is unclear whether this discrepancy is due to the type of music selected, training status of the subjects or other unknown factors. A study by Emery et al. (2003) in which patients with coronary artery disease listened to music during treadmill exercise at 85% of VO_{2max} demonstrated that HR increased significantly during the music condition.

Table 9: Summary of the studies that have evaluated the effects of music during sub-maximal wheelchair exercise

Study	Subjects	Exercise mode	Performance	HR	AVO_2	V_E	O_2 pulse	RPE	Other variables
Current study	20 male	Wheelchair	↑ Wheeling distance	Not significant	↑	↑	↑	↓	---
Szmedra et al. 1998	10 male	Treadmill	----	↓	----	----	----	↓	↓ Lactate, Norepinephrine, Systolic Blood pressure
Potteiger et al. 2000	27 14 male 13 female	Cycling	----	Not significant	----	----	----	↓	----
Emery et al. 2003	33 19 male 14 female	Treadmill	↑ Exercise time but not significant	↑	----	----	----	----	↑ Blood pressure
Atkinson et al. 2004	6 male	Cycling	↑ Velocity	↑	----	----	----	↑	

Cerebral and muscle oxygenation/blood volume responses

In the current study, there was considerable variation in the cerebral and muscle NIRS responses during wheelchair exercise. It should be noted that the intersession reproducibility of cerebral (Koike et al., 2004) and muscle (Kell et al., 2004) NIRS during the dynamic exercise has been documented. It is likely, therefore, that the large variations observed in the cerebral and muscle NIRS variables could be due to: (1) possible differences in the probe placement across the three sessions, (2) excessive adipose tissue thickness in the subjects, and (3) the effects of music on the NIRS responses. With respect to the probe placement, considerable care was taken to ensure that the cerebral and muscle NIRS probes were secure at the same reference points across sessions. Although the NIRS results were not statistically significant, these finding do have some clinical significance. Therefore the trends in the NIRS responses are discussed in this context for both sub-maximal and maximal exercise.

Effects of music on cerebral and muscle oxygenation/blood volume responses during sub-maximal exercise

Cerebral tissue

To the best of our knowledge, the current study is the first to simultaneously measure cerebral, biceps and triceps blood volume and oxygenation during wheelchair exercise. During the 10 minutes of sub-maximal exercise, an increase in the cerebral oxygenation and blood volume was observed in both (E + M) and E condition in almost all the subjects. The blood volume showed a greater increase than that of oxygenation. This is consistent with the study by Obrig et al. (1996) who demonstrated an increase in oxygenation and blood volume in the cerebral tissue during finger tapping activity. Nielsen et al. (2001) reported an increase in cerebral oxygenation during sub-maximal cycling exercise with and without resistive breathing. Since arterial CO_2 the is a regulator of cerebral blood flow, they attributed this increase to the CO_2 produced during the exercise. Ide et al. (1999) showed an increase in blood volume and oxygenation when subjects cycled at 60% of their VO_{2max}, but at 30% of VO_{2max} exercise, the changes were not significant.

Increases in cerebral oxygenation and blood volume have been associated with enhanced neuronal activation (Obrig et al. 1996; Nielsen et al. 2001). In the current study, the increase in blood volume and oxygenation were more pronounced in (E + M) condition compared to the E condition in the frontal cortex. These observations suggest that music may stimulate neuronal activation in some subjects and thereby enhance motor unit recruitment and improve wheeling performance.

Biceps muscle

At the onset of sub-maximal wheelchair exercise, there was an initial decline in muscle blood volume and a concomitant increase in muscle oxygenation. This is consistent with the observations of Bhambhani et al. (1998), who also demonstrated an initial increase in biceps oxygenation at the onset of arm cranking exercise. These changes in blood volume and oxygenation can be attributed to increase in demand of ATP on initiation of exercise, leading to redistribution of blood to the active muscle. In contrast Jensen-Urstad et al. (1995) showed a decrease in muscle oxygenation at the initiation of arm cranking exercise. They attributed the decrease in oxygenation to a transient imbalance between oxygen supply and oxygen uptake, thus resulting in higher anaerobic metabolism. In this study, the biceps oxygenation initially remained slightly lower than the baseline in most of the subjects. A marked decline was seen only in five subjects. The plateau observed in the oxygenation can be attributed to use of other synergist muscles like the brachioradialis and wrist extensors for propelling the wheelchair. In the current study, the decrease in oxygenation in the (E + M) condition tended to be lower when compared with E condition, suggesting that there was less extraction in (E + M) condition. However, this was compensated by an increase in blood volume during the (E + M) condition when compared with E condition. It is possible that listening to music during exercise may have resulted in increase in blood flow to the biceps muscle.

Triceps muscle

Unfortunately not much data are available which has looked at the changes in triceps muscle blood volume and oxygenation during sub-maximal exercise. In the current study, there was initial decline in the blood volume in 14 subjects, but there was no change in the blood oxygenation during this period. This slight decline in the blood volume can be attributed to change position of elbow from 90 degree flexion during rest to extension at the starting of exercise, suggesting that triceps muscle was not extracting much oxygen. It is conceivable that biceps were more active than triceps at the starting of exercise. After the initial decline, the triceps blood volume increased continuously till the end of sub-maximal exercise period. The muscle oxygenation also showed a concomitant increase, but the magnitude of increase was not higher than that of the blood volume. It was hypothesized that the changes in the muscle blood volume and oxygenation would be significantly higher in (E + M) condition. However, the results demonstrated a marginal decrease of 0.68% and 2.79% in the blood volume and oxygenation respectively during (E + M) when compared to E condition. These observations suggest that the contribution of triceps muscle was low during sub-maximal wheelchair exercise. This is supported by previous EMG research, which has shown that activity of triceps muscle is lower than other prime movers during sub-maximal wheelchair exercise (Schantz et al., 1999).

Relationship between wheelchair exercise performance and cardio-respiratory responses during sub-maximal exercise

No significant correlations existed between wheeling speed and AVO_2 and RVO_2 during 10 minutes of sub-maximal exercise (Figure 9). The correlations for the E condition were AVO_2 (r = .74) and RVO_2 (r = .78), while for the (E + M) condition were AVO_2 (r = .57) and RVO_2 (r = .68). This is consistent with previous research which has reported significant correlations of speed and distance with VO_2 during 12 minutes treadmill running in untrained healthy men (Miura et al., 1995). However, in this study, no significant correlations were found between the delta speed and delta values of other physiological variables (Figure 10). None of the previous studies have reported correlations between changes in performances and physiological variables when subjects were listening to music. The current observation suggests that the improvement in the wheelchair distance and speed during (E + M) was not due to the increased metabolic rate and other factors were most likely implicated.

Relationship between wheelchair exercise performance and NIRS responses during sub-maximal exercise

Significant correlations were found between delta wheelchair speed and delta cerebral oxygenation (r = .42, P<.10) and cerebral blood volume (r = .33, P>.10) (Figure 11). Results of hierarchical analysis suggested improvement in wheelchair speed was closely related to cerebral oxygenation. Although a weak correlation was found between delta cerebral blood volume and delta speed, none of the other variables showed a significant correlation. It appears, therefore, that increase in speed during sub-maximal wheelchair exercise was more likely due to changes in cerebral activation and not related to changes in localized muscle oxygenation status.

Part III: Maximal responses

Effect of music on metabolic and cardio respiratory responses during maximal wheelchair exercise

The subjects increased their velocity to maximal levels at the end of 10 minutes of sub-maximal exercise and continued propelling the wheelchair till voluntary exhaustion, or when the criteria set by ACSM for maximal exercise were fulfilled. It was demonstrated that AVO_{2max}, RVO_{2max}, HR, V_E and O_2 pulse in the (E + M) condition were significantly higher than the E condition. These values were higher by 9.2%, 9.4%, 3.8%, 12.2% and 5% respectively. Time to exhaustion measured during (E + M) condition was significantly higher than that in E condition by 11.2%. None of the subjects had any previous experience of propelling the wheelchair, nor were they engaged in any form of exercise which required pushing the wheel in sitting posture. Still they showed an improvement in VO_{2max} in (E + M) condition. It appears, therefore, that listening to music during the wheelchair exercise had a positive effect on the maximal physiological responses.

Unfortunately not much data are available which has looked at the changes in physiological responses of the subjects while listening to music during maximal exercise. The results of these studies are summarized in Table 10. In agreement with Copeland et al. (1991), the stimulatory effect of music on physiological responses is evident. The time to exhaustion was significantly higher in the groups which listened to both slow and fast music than in the no music group. However, the fast music chosen in their study didn't increase the HR of the subjects as the slow music. This could due to the fact that all the subjects in their study listened to the same music chosen by the researcher, and perhaps, they didn't like the selection. These investigators didn't measure the VO_{2max} and other physiological variables due to non availability of equipment. Szabo et al. (1999) reported an increase in work load efficiency in the subjects when the tempo of the music was changed from slow (72 beats/min) to fast (144 beats/min) on reaching 70% of their respective HR reserves during the maximal exercise. In this study the music was selected by the researcher. Yamamoto et al. (2003) did not find any significant difference in HR. blood lactate and ammonia concentration when subjects listened to slow and fast music before 45 sec supra-maximal cycling exercise in two separate test sessions. Since the researchers didn't have any control condition, it is difficult to compare their results with our study.

In the current study, only central RPE was significantly lower in the (E + M) condition. No significant difference was found in peripheral RPE. All the subjects reported peripheral fatigue over central fatigue as the primary reason for the termination of exercise. This was supported by the results that none of the participants reached their age predicted maximum HR. It is interesting to note that the central RPE was significantly reduced in the (E + M) condition despite the fact that both HR and V_E, variables that directly influence the central RPE, were significantly higher. The reason for this is unclear and needs to be further investigated.

Table 10: Comparison of the physiological responses with other studies during maximal wheelchair exercise

Study	Subjects	Exercise mode	Performance	HR	AVO_2	V_E	O_2 pulse	RPE	Other variables
Current study	20 male	Wheelchair	↑ Time to exhaustion	↑	↑	↑	↑	↓ in Central, Peripheral not significant	↑ RVO_2
Copeland et al. 1991	24 11 male 13 female	Treadmill	↑ Time to exhaustion	↑ with slow, popular music	---	----	----	↓	---
Szabo et al. 1999	24 12 male 12 female	Cycling	↑ Work load	Not significant	----	----	----	---	----
Yamamoto et al. 2003	6 male	Cycling	----	Not significant	-----	----	----	----	↓norepinephrine with slow music

Effects of music on cerebral and muscle oxygenation/blood volume responses during maximal exercise

Cerebral tissue

In the present study, at the sudden onset of maximal wheelchair exercise the blood volume and oxygenation increased simultaneously and then decreased just before the end of exercise. It is likely that the decrease in these variables was due to a reduction in arterial PCO_2 which has a direct influence on cerebral blood flow (Bhambhani et al., in press). In the previous studies, it has been suggested that an increase in cerebral oxygenation is associated with increased neuronal activation (Nielsen et al., 2001). In the current study, the magnitude of increase of cerebral blood volume tended to be higher during the E condition and interestingly, that of cerebral blood oxygenation tended to be higher during the (E + M) condition. This suggests that music stimulated an increase in neuronal activation which could have accounted for the improvement in maximal performance.

Biceps

Different patterns observed for blood volume and oxygenation in the biceps muscle could be attributed to the changes in intra-vascular and intra-muscular pressure. With the sudden increase in speed, the oxygen demand of the muscle increased which was compensated for an increase in blood volume. The metabolic demand for oxygen by the muscle is determined from the rate and contraction force (McArdle, 2001). Once the intra-muscular pressure exceeded intra-vascular pressure, the blood volume tended to decline. The initial increase in the muscle oxygenation in some subjects could be due to the increased force of contraction of the muscle. It is interesting to note that this increase was more prominent in (E + M) condition. After the initial changes the muscle oxygenation declined systematically, followed by a plateau or increase towards the end of exercise. These results are consistent with Bhambhani et al. (1998) who reported an initial increase in muscle oxygenation followed by a decline, and thereafter three different patterns of continuous decline, plateau and increase towards the end of maximal arm cranking exercise.

The current findings indicated no significant differences in mean muscle blood volume and oxygenation between (E + M) and E conditions. According to the Fick equation, the oxygen consumption at the localized muscle is the product of blood flow and arterial oxygen content (McArdle, 2001). Hence any change in blood flow, hemoglobin concentration or saturation results in change in oxygen consumption of the muscle. In this study, the magnitude of increase in blood flow and deoxygenation tended to be higher during (E + M) condition, suggesting that, biceps muscle was able to extract a more oxygen in (E + M) condition than in E condition.

Triceps

With the increase in speed of the wheelchair the contact time of the hand with the rim is longer (push phase) than the time of retraction or flexion of elbow (pull phase) (Schantz et al., 1999). Previous research looking at the EMG of the muscles during wheelchair exercise has shown that triceps muscle is more active than biceps muscle when the wheelchair is propelled at a faster speed. (Schantz et al., 1999). This is also supported by research which has shown that firing rate in the muscle undergoing concentric contraction increases with the increase in intensity of exercise (Linnamo et al., 2003). In the current study, the mean value of triceps blood volume during (E + M) condition tended to be higher than that in the E condition. This could be attributed to the longer time to fatigue in the (E + M) condition.

The muscle oxygenation decreased initially at the onset of exercise followed by an increase towards the end of exercise. The localized oxygen requirements were met by an increase in blood volume. These trends were similar to that found by Muraki et al. (2004), who found an increase in triceps oxygenation of the female subjects during maximal arm cranking exercise. In current study, muscle deoxygenation tended to be higher by 45.37% during (E + M) compare to the E condition, suggesting that muscles tended to extract more oxygen during (E + M) condition.

Relationship between wheelchair exercise performance time and cardio-respiratory responses during maximal exercise

No significant correlation was found between delta wheelchair exercise time and delta changes in AVO_2, RVO_2, HR, V_E and O_2 pulse. Hierarchical analysis, performed with wheelchair exercise time taken as dependent variable, did not select any variable. These observations suggest that all the subjects responded differently to the music during maximal wheelchair exercise. It should be noted that none of the studies cited in Table 8 evaluated the relationship between the improvements in exercise performance and the changes in physiological responses. The reason for the improvement in the exercise performance in all these studies is unclear and needs to be further investigated.

Relationship between wheelchair exercise performance time and NIRS responses during maximal exercise

No significant correlation was observed between delta wheelchair exercise time and delta changes in cerebral and muscle blood volume and oxygenation. Due to this low correlation, hierarchical analysis performed with wheelchair exercise time taken as dependent variable, did not select any variable. It was hypothesized that the improvement in exercise performance will be more closely related to cerebral blood volume and oxygenation but the current observations does not support it. The results were inconclusive and could not predict any variable most closely related to improvement in exercise performance time. These observations suggest that all the subjects responded differently to the music during maximal wheelchair exercise.

Implications for Occupational Therapy

The present study contributes to developing knowledge that supports the use of music in occupational therapy settings. It is evident from the current findings that wheeling distance, speed, AVO_2, RVO_2, V_E, and O_2 pulse increased significantly when exercising with self selected music during sub-maximal and maximal exercise. Although, the improvement in wheelchair performance was accompanied by an increase in the physiological responses, the central and peripheral RPE decreased during the sub-maximal wheelchair exercise. These observations suggest that music may act as a distracter to the physiological stress leading to increase in exercise performance. The correlations between sub-maximal wheelchair exercise speed and NIRS responses suggest that improvement in the performance was more closely related to the cerebral activation and not due to the alterations in the muscle performance. These observations however can be generalized to healthy males within the ages of 18 to 35 years who were not wheelchair users.

Previous studies have reported use of music in subjects with cognitive, perceptual disorders, pain relief and other neuro-muscular disorders (Minato et al., 2004; Hagen et al., 2003; Zelazny et al., 2001). However, in these studies, the music was selected by the researcher and not the patients. The functional ability in individuals with neuro-muscular (head injury, neuropathies, spinal cord injury) and musculo-skeletal (arthritis, back pain, fibromyalgia) diagnoses tends to be reduced which leads to decreased interest in exercise. Hence, increasing the capacity of the cardio-respiratory system is advisable to facilitate increased fitness in this population. Music can act as an external motivation for these individuals. Self-selected music, with a tempo greater that 124 beats/min, can act as distracter for the pain and enhance the individual's aerobic capacity and their ability to tolerate the physiological stress of the activities of daily living.

One of the objectives of the study were to obtain an in depth picture of influence of the music on cerebral and muscle blood volume and oxygenation. Though the NIRS results were not statistically significant due to the high standard deviation of the measurements, it still provided us some vital information about the changes in cerebral and muscle oxygenation and blood volume while listening to music. To verify these findings, studies need to be conducted in patients with head injury, neuropathies, back pain, arthritis, spinal cord injury and other neuro-muscular and musculo-skeletal disorders. Occupational therapist can use NIRS in different medical conditions and settings. Further research is required to measure NIRS variables in other functional activities.

Chapter VI: Summary and Conclusions

This study provided initial insights into the effect of music on the physiological responses, and cerebral and muscle oxygen kinetics during wheelchair exercise in healthy young men. The results support the following conclusions during sub-maximal exercise:

1. Distance and speed: The wheelchair speed and distance increased significantly when exercise was performed with music.
2. Physiological responses: Listening to music during exercise elicited a significant increase in AVO_2, RVO_2, V_E, RER and O_2 pulse with no significant alteration in the HR.
3. NIRS variables: There were no significant changes in cerebral and muscle blood volume and oxygenation.
4. The improvements in the wheelchair exercise performance were more likely due to the changes in cerebral blood volume and oxygenation compared to muscle blood volume and oxygenation.

With respect to maximal exercise the following conclusions are justified:

1. Performance: The subjects were able to propel the wheelchair for longer duration when exercise was performed with music.
2. Physiological responses: A significant increase in AVO_2, RVO_2, V_E and O_2 pulse was found when exercise was performed with music.

3. NIRS variables: There were no significant changes in cerebral and muscle blood volume and oxygenation.
4. There was no significant correlation between changes in exercise performance time and the physiological and NIRS responses.

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Appendix A

CONSENT FORM

Part 1 (to be completed by the Principal Investigator):

Title: ***Impact of music on cerebral and muscle oxygenation during wheelchair exercise***

Principal Investigator(s): Dr. Yagesh Bhambhani *Phone*: 492-7248

Co-Investigator(s): Rohit Malik *Phone*: 492-0404

Part 2 (to be completed by the research subject):

Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached Information Sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason and it will not affect your student status.	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records?	Yes	No
Do you want the investigator(s) to inform your family doctor that you are participating in this research study? If so, please provide your doctor's name:	Yes	No

______________________________.

This study was explained to me by: ______________________________

I agree to take part in this study.

______________________________ ____________________ ______________________________
Signature of Research Participant Date Witness

______________________________ ______________________________
Printed Name Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

______________________________ ____________________
Signature of Investigator or Designee Date

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH SUBJECT

Before the exercise test is started, we will connect you to the following pieces of equipment:

- A metabolic cart which weighs one pound will be placed around your neck. This instrument will measure how much oxygen you are using and how hard you are breathing. To get these measurements, we will put a mask over your nose and mouth.
- A heart rate monitor that will be strapped around your chest. This will tell us how fast your heart is beating.
- Three instruments that use light to measure how fast the muscles and brain are using oxygen. To get these measurements, we will place three light sources on the front and back of the right arm muscles and the left forehead. These light sources will be held in place with an elastic bandage.

All these machines have been checked and they are working properly. Only the researcher who knows how to use them will test you. If we see anything unusual while you are being tested we will stop the test immediately.

In this test, you will first rest for two minutes. After that, you will start pushing the wheelchair for two minutes at a speed of 2km/hr. You will then be asked to gradually increase the speed by 1 km/hr every minute until you are tired and cannot push the wheelchair at the same speed. *You can stop exercising at any time during the test if you feel you cannot continue or do not want to continue.*

Sessions Three, Four and Five (30 minutes each):

You will be asked to complete these three sessions in random order. In one of these sessions you will be required to sit quietly on the wheelchair and listen to your favorite music for 10 min. In the remaining two sessions, you will be asked to:

- propel the wheelchair for 10 minutes without any music, or
- propel the wheelchair while listening to your favorite music.

During these tests you will be connected to the same instruments that were used in second testing session.

Risks

During the wheelchair exercise tests you may feel tired, have difficulty in breathing, and sweat. You may feel nauseous and dizzy during or after the maximal exercise test. This usually happens when a person exercises maximally and it may last for a few minutes.

Appendix C

PAR-Q form

Appendix E
Summaries of ANOVA procedures

Table 11 Summary of analysis of variance: AVO_2 during sub-maximal exercise (L/min)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Abs._VO21
2	Abs._VO22
3	Abs._VO23

Descriptive Statistics

	Mean	Std. Deviation	N
Abs. VO21	.29522096774194	.058989937491333	20
Abs. VO22	.72279032258065	.196607635679746	20
Abs. VO23	.78822580645161	.235432733941065	20

Pairwise Comparisons

Measure: MEASURE_1

					95% Confidence Interval for Difference[a]	
(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-.428*	.046	.000	-.548	-.307
	3	-.493*	.053	.000	-.632	-.354
2	1	.428*	.046	.000	.307	.548
	3	-.065*	.021	.015	-.119	-.011
3	1	.493*	.053	.000	.354	.632
	2	.065*	.021	.015	.011	.119

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 12 Summary of analysis of variance: RVO$_2$ during sub-maximal exercise (ml/kg/min)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Rel_VO21
2	Rel_VO22
3	Rel_VO23

Descriptive Statistics

	Mean	Std. Deviation	N
Rel VO21	3.82146774193548	.791364743558280	20
Rel VO22	9.18708986175115	2.361345988792190	20
Rel VO23	10.02141066504201	2.857916737907809	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-5.366*	.518	.000	-6.725	-4.006
	3	-6.200*	.619	.000	-7.825	-4.575
2	1	5.366*	.518	.000	4.006	6.725
	3	-.834*	.258	.013	-1.512	-.156
3	1	6.200*	.619	.000	4.575	7.825
	2	.834*	.258	.013	.156	1.512

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 13 Summary of analysis of variance: HR during sub-maximal exercise (bpm)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	HR1
2	HR2
3	HR3

Descriptive Statistics

	Mean	Std. Deviation	N
HR1	72.158064516129	9.184950556237160	20
HR2	96.694193548400	10.2751531430136	20
HR3	99.142580645160	10.8904008065730	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-23.119*	1.787	.000	-27.810	-18.428
	3	-24.815*	2.286	.000	-30.817	-18.812
2	1	23.119*	1.787	.000	18.428	27.810
	3	-1.695	1.617	.173	-5.940	2.550
3	1	24.815*	2.286	.000	18.812	30.817
	2	1.695	1.617	.173	-2.550	5.940

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 14 Summary of analysis of variance: V_E during sub-maximal exercise (L/min)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	VE1
2	VE2
3	VE3

Descriptive Statistics

	Mean	Std. Deviation	N
VE1	9.712	2.4984	20
VE2	22.890	7.3786	20
VE3	25.521	9.5299	20

Pairwise Comparisons

Measure: MEASURE_1

					95% Confidence Interval for Difference[a]	
(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-13.178*	1.806	.000	-17.919	-8.436
	3	-15.808*	2.260	.000	-21.741	-9.875
2	1	13.178*	1.806	.000	8.436	17.919
	3	-2.631*	.889	.024	-4.964	-.297
3	1	15.808*	2.260	.000	9.875	21.741
	2	2.631*	.889	.024	.297	4.964

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 15 Summary of analysis of variance: RER during sub-maximal exercise (ratio)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	RER1
2	RER2
3	RER3

Descriptive Statistics

	Mean	Std. Deviation	N
RER1	.9503983870968	.04799611052185	20
RER2	1.025000000000	.06672521025156	20
RER3	1.046693548387	.04813697379143	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.^{a}	95% Confidence Interval for Difference^a	
					Lower Bound	Upper Bound
1	2	-.075*	.017	.001	-.120	-.029
	3	-.096*	.015	.000	-.135	-.058
2	1	.075*	.017	.001	.029	.120
	3	-.022	.009	.047	-.044	.001
3	1	.096*	.015	.000	.058	.135
	2	.022	.009	.047	-.001	.044

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 16 Summary of analysis of variance: O_2 pulse during sub-maximal exercise (ml/beats)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	O2_pulse1
2	O2_pulse2
3	O2_pulse3

Descriptive Statistics

	Mean	Std. Deviation	N
O2 pulse1	4.149	.9129	20
O2 pulse2	7.575	2.0680	20
O2 pulse3	8.112	2.2241	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.^{a}	95% Confidence Interval for Difference^a	
					Lower Bound	Upper Bound
1	2	-3.427*	.471	.000	-4.662	-2.191
	3	-3.964*	.508	.000	-5.297	-2.631
2	1	3.427*	.471	.000	2.191	4.662
	3	-.537*	.195	.038	-1.049	-.025
3	1	3.964*	.508	.000	2.631	5.297
	2	.537*	.195	.038	.025	1.049

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 17 Summary of analysis of variance: V_E/VO_2 during sub-maximal exercise (ratio)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	VEVO2_Ratio1
2	VEVO2_Ratio2
3	VEVO2_Ratio3

Descriptive Statistics

	Mean	Std. Deviation	N
VE/VO2 Ratio1	31.38870967741936	5.503106929811140	20
VE/VO2 Ratio2	32.14861842330000	5.830941970428000	20
VE/VO2 Ratio3	32.77967741935000	6.250758320390200	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.630	1.616	1.000	-4.872	3.612
	3	-1.321	1.572	1.000	-5.447	2.805
2	1	.630	1.616	1.000	-3.612	4.872
	3	-.691	1.361	1.000	-4.264	2.882
3	1	1.321	1.572	1.000	-2.805	5.447
	2	.691	1.361	1.000	-2.882	4.264

Based on estimated marginal means

[a] Adjustment for multiple comparisons: Bonferroni.

Table 18 Summary of analysis of variance: V_E/VCO_2 during sub-maximal exercise (ratio)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	VEVCO2_Ratio1
2	VEVCO2_Ratio2
3	VEVCO2_Ratio3

Descriptive Statistics

	Mean	Std. Deviation	N
VE/VCO2 Ratio1	31.462903225806	4.153369951509838	20
VE/VCO2 Ratio2	30.332258064516	3.004279766697682	20
VE/VCO2 Ratio3	30.225806451613	4.769120417533070	20

Pairwise Comparisons

Measure: MEASURE_1

					95% Confidence Interval for Difference[a]	
(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	1.131	1.035	.865	-1.587	3.848
	3	1.237	.990	.680	-1.363	3.837
2	1	-1.131	1.035	.865	-3.848	1.587
	3	.106	1.063	1.000	-2.684	2.897
3	1	-1.237	.990	.680	-3.837	1.363
	2	-.106	1.063	1.000	-2.897	2.684

Based on estimated marginal means

[a] Adjustment for multiple comparisons: Bonferroni.

Table 19 Summary of analysis of variance: Cerebral blood volume during sub-maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Brain_BV1
2	Brain_BV2
3	Brain_BV3

Descriptive Statistics

	Mean	Std. Deviation	N
Brain BV1-	.006691	.0219151	20
Brain BV2	.02122915265591	.027679905188369	20
Brain BV3	.02414677701882	.043996339261484	20

Pairwise Comparisons

Measure: MEASURE_1

					95% Confidence Interval for Difference[a]	
(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-.015	.006	.079	-.030	.001
	3	-.017	.010	.330	-.045	.010
2	1	.015	.006	.079	-.001	.030
	3	-.003	.011	1.000	-.032	.026
3	1	.017	.010	.330	-.010	.045
	2	.003	.011	1.000	-.026	.032

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 20 Summary of analysis of variance: Cerebral oxygenation during sub-maximal exercise (ratio)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Brain_O21
2	Brain_O22
3	Brain_O23

Descriptive Statistics

	Mean	Std. Deviation	N
Brain O21	.003520	.0093405	20
Brain O22	.00996728335502	.021859221453157	20
Brain O23	.01478516544612	.018938822583473	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.006	.006	.792	-.021	.008
	3	-.011	.005	.124	-.025	.002
2	1	.006	.006	.792	-.008	.021
	3	-.005	.006	1.000	-.021	.011
3	1	.011	.005	.124	-.002	.025
	2	.005	.006	1.000	-.011	.021

Based on estimated marginal means

[a] Adjustment for multiple comparisons: Bonferroni.

Table 21 Summary of analysis of variance: Biceps blood volume during sub-maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Biceps_BV1
2	Biceps_BV2
3	Biceps_BV3

Descriptive Statistics

	Mean	Std. Deviation	N
Biceps BV1-	.016026	.0148887	20
Biceps BV2	.01916729192607	.050144561468349	20
Biceps BV3	.0417046851359	.04866597998064	20

Pairwise Comparisons

Measure: MEASURE_1

					95% Confidence Interval for Difference[a]	
(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-.003	.011	1.000	-.031	.025
	3	-.026	.010	.064	-.053	.001
2	1	.003	.011	1.000	-.025	.031
	3	-.023	.012	.214	-.053	.008
3	1	.026	.010	.064	-.001	.053
	2	.023	.012	.214	-.008	.053

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 22 Summary of analysis of variance: Biceps oxygenation during sub-maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Bicep_O2
2	Bicep_O22
3	Bicep_O23

Descriptive Statistics

	Mean	Std. Deviation	N
Bicep O2	.021688	.0148972	20
Bicep O22	-.00675071733340	.056505536927025	20
Bicep O23	-.00311521785912	.059008563082791	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.028	.012	.103	-.004	.061
	3	.025	.013	.199	-.009	.058
2	1	-.028	.012	.103	-.061	.004
	3	-.004	.015	1.000	-.043	.036
3	1	-.025	.013	.199	-.058	.009
	2	.004	.015	1.000	-.036	.043

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 23 Summary of analysis of variance: Triceps blood volume during sub-maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Triceps_BV1
2	Triceps_BV2
3	Triceps_BV3

Descriptive Statistics

	Mean	Std. Deviation	N
Triceps BV1	.020197	.0126065	20
Triceps BV2	.0419739	.05916565	20
Triceps BV3	.04080107	.032935713	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.022	.013	.350	-.057	.013
	3	-.021	.008	.054	-.042	.000
2	1	.022	.013	.350	-.013	.057
	3	.001	.011	1.000	-.027	.029
3	1	.021	.008	.054	.000	.042
	2	-.001	.011	1.000	-.029	.027

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 24 Summary of analysis of variance: Triceps oxygenation during sub-maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	triceps_O21
2	triceps_O22
3	triceps_O23

Descriptive Statistics

	Mean	Std. Deviation	N
triceps O21	.011239	.0084599	20
triceps O22	.01703169	.025695371	20
triceps O23	.01102081025672	.02601759157095	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.006	.006	1.000	-.021	.010
	3	.000	.006	1.000	-.016	.017
2	1	.006	.006	1.000	-.010	.021
	3	.006	.008	1.000	-.016	.028
3	1	.000	.006	1.000	-.017	.016
	2	-.006	.008	1.000	-.028	.016

Based on estimated marginal means

[a] Adjustment for multiple comparisons: Bonferroni.

Table 25 Summary of analysis of variance: AVO_2 during maximal exercise (l/min)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Abs._VO21
2	Abs._VO22

Descriptive Statistics

	Mean	Std. Deviation	N
Abs. VO21	1.6094	.38123	20
Abs. VO22	1.7555	.48017	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.146*	.039	.001	-.228	-.064
2	1	.146*	.039	.001	.064	.228

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 26 Summary of analysis of variance: RVO_2 during maximal exercise (ml/kg/min)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Rel_VO21
2	Rel_VO22

Descriptive Statistics

	Mean	Std. Deviation	N
Rel VO21	20.60283004356	4.9895100512109	20
Rel VO22	22.50798773079	6.2109892168832	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.905*	.477	.001	-2.905	-.906
2	1	1.905*	.477	.001	.906	2.905

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 27 Summary of analysis of variance: HR during maximal exercise (bpm)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	HR1
2	HR2

Descriptive Statistics

	Mean	Std. Deviation	N
HR1	148.65	14.766	20
HR2	154.00	12.982	20

Pairwise Comparisons

Measure: MEASURE_1

		Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
(I) factor1	(J) factor1				Lower Bound	Upper Bound
1	2	-5.350*	2.020	.016	-9.578	-1.122
2	1	5.350*	2.020	.016	1.122	9.578

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

[a] Adjustment for multiple comparisons: Bonferroni.

Table 28 Summary of analysis of variance: V_E during maximal exercise (L/min)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	VE1
2	VE2

Descriptive Statistics

	Mean	Std. Deviation	N
VE1	67.5970	19.94703	20
VE2	75.500	26.1849	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-7.903*	2.832	.012	-13.830	-1.976
2	1	7.903*	2.832	.012	1.976	13.830

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 29 Summary of analysis of variance: RER during maximal exercise (ratio)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	RER1
2	RER2

Descriptive Statistics

	Mean	Std. Deviation	N
RER1	1.3720	.16227	20
RER2	1.424	.1812	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.051	.049	.302	-.153	.050
2	1	.051	.049	.302	-.050	.153

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 30 Summary of analysis of variance: O_2 pulse during maximal exercise (ml/beats)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	O2_pulse1
2	O2_pulse2

Descriptive Statistics

	Mean	Std. Deviation	N
O2 pulse1	10.936	2.8757	20
O2 pulse2	11.494	3.4448	20

Pairwise Comparisons

Measure: MEASURE_1

					95% Confidence Interval for Difference[a]	
(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-.558*	.262	.046	-1.105	-.010
2	1	.558*	.262	.046	.010	1.105

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Table 31 Summary of analysis of variance: V_E/VO_2 during maximal exercise (ratio)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	VEVO2_Ratio_1
2	VEVO2_Ratio2

Descriptive Statistics

	Mean	Std. Deviation	N
VE/VO2 Ratio 1	43.84	11.799	20
VE/VO2 Ratio2	44.087565308255	11.848686770803	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.245	2.076	.907	-4.590	4.100
2	1	.245	2.076	.907	-4.100	4.590

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 32 Summary of analysis of variance: V_E/VCO_2 during maximal exercise (ratio)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	VEVCO2_Ratio1
2	VEVCO2_Ratio2

Descriptive Statistics

	Mean	Std. Deviation	N
VE/VCO2 Ratio1	32.20	7.730	20
VE/VCO2 Ratio2	31.90	8.950	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.300	1.240	.811	-2.295	2.895
2	1	-.300	1.240	.811	-2.895	2.295

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 33 Summary of analysis of variance: Cerebral blood volume during maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Brain_BV2
2	Brain_BV3

Descriptive Statistics

	Mean	Std. Deviation	N
Brain BV2	.11161	.075870	20
Brain BV3	.103755	.0798872	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.008	.013	.559	-.020	.035
2	1	-.008	.013	.559	-.035	.020

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 34 Summary of analysis of variance: Cerebral oxygenation during maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Brain_O22
2	Brain_O23

Descriptive Statistics

	Mean	Std. Deviation	N
Brain O22	.00946	.039321	20
Brain O23	.020562	.0232757	20

Pairwise Comparisons

Measure: MEASURE_1

					95% Confidence Interval for Difference[a]	
(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-.011	.009	.231	-.030	.008
2	1	.011	.009	.231	-.008	.030

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 35 Summary of analysis of variance: Biceps blood volume during maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Biceps_BV2
2	Biceps_BV3

Descriptive Statistics

	Mean	Std. Deviation	N
Biceps BV2	.06000071536606	.071200762435331	20
Biceps BV3	.06661362041562	.083203176004931	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.007	.018	.722	-.045	.032
2	1	.007	.018	.722	-.032	.045

Based on estimated marginal means

[a] Adjustment for multiple comparisons: Bonferroni.

Table 36 Summary of analysis of variance: Biceps oxygenation during maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Bicep_O22
2	Bicep_O23

Descriptive Statistics

	Mean	Std. Deviation	N
Bicep O22	-.0111456353866	.04731464359752	20
Bicep O23	-.0353785110579	.06768689860750	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.024	.016	.146	-.009	.058
2	1	-.024	.016	.146	-.058	.009

Based on estimated marginal means

[a] Adjustment for multiple comparisons: Bonferroni.

Table 37 Summary of analysis of variance: Triceps blood volume during maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	Triceps_BV2
2	Triceps_BV3

Descriptive Statistics

	Mean	Std. Deviation	N
Triceps BV2	.0036749817143	.04730529644331	20
Triceps BV3	.0138	.06163	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.010	.015	.496	-.041	.020
2	1	.010	.015	.496	-.020	.041

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Table 38 Summary of analysis of variance: Triceps oxygenation during maximal exercise (OD units)

Within-Subjects Factors

Measure: MEASURE_1

factor1	Dependent Variable
1	triceps_O22
2	triceps_O23

Descriptive Statistics

	Mean	Std. Deviation	N
triceps O22	-.00968574347703	.018331890310855	20
triceps O23	-.0213	.07021	20

Pairwise Comparisons

Measure: MEASURE_1

(I) factor1	(J) factor1	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.012	.015	.439	-.019	.043
2	1	-.012	.015	.439	-.043	.019

Based on estimated marginal means

[a] Adjustment for multiple comparisons: Bonferroni.