Independent Research Project
Acute centripetal acceleration is correlated with increased heart rate and R-wave amplitude

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Abstract

In the present study, we set out to discover the correlation between the exposure of acute centripetal acceleration in human subjects and cardiovascular function across the following three dimensions: Heart rate, R-wave amplitude and QRS interval. This was accomplished by measuring the above properties via Lead II Bipolar ECG trace, after having spun the subject at 0.8 revolutions per second in an office chair for successively, 30, 60 and 90 seconds. It was determined that heart rate showed strong positive correlation (n = 3, average increase between trials of increasing duration, 3.2 beats per minute, s = 1.8). R-wave amplitude showed positive correlation in all subjects up until and including the 60 second trial. There was no systemic correlation between duration of spin and the length of the QRS interval in any of the subjects. The heart is therefore an important effector in response to centripetal acceleration in the human model.

Key Words

electrocardiogram, QRS interval, centripetal force, R-wave amplitude, spinning office chair.

Introduction

The cardiovascular system is a key area of research for the health of individuals globally. Often this research tends to focus upon factors such as diet, obesity, and blood pressure in relation to cardiovascular disease. However, other factors must be considered when studying cardiovascular disease. External factors, such as centripetal force, also place stress upon the cardiovascular system. For example, thrill rides at amusement parks exert centripetal and g-forces upon the rider. In contrast, these forces may be the result of an unpredictable event, such as in car "spins outs" during an automobile accident. Mild centripetal forces are also felt when a car takes a sharp turn. Many roller coasters have caution signs warning those with heart conditions to ride. Thus, centripetal forces may influence the health of an individual by altering cardiac function. However, more research is needed to determine the effect that a cardiac stressors like chronic centripetal force has upon the health of an individual.

Centripetal forces are encountered regularly during the life of an individual. These forces are detected by two internal sensory systems; the semi-circular ducts in the inner ear and via general tonic proprioception. The vestibular apparatus of the ear is used to ensure proper equilibrium maintenance (1). Within the utricle of the ear, the macula plays a critical role in adapting the body to alterations in gravity and acceleration.

In America it is estimated that 60 million people suffer from some form of cardiovascular disease (2). Given that 309 million people visit American amusement parks each year, this indicates that a large group of people are at risk of experiencing cardiovascular problems caused by centripetal forces encountered during "thrill rides" (3). The general trend in the amusement park industry is the development of faster and more thrilling rides. As a consequence of this; riders experience greater centripetal and G-forces during the ride. These G-forces have reached a bone crunching 6.5 times the earth's normal gravity. These increasing forces exerted upon the rider raise concern about the effects on the short and long term health of the individual (3). The most common reason for death caused by riding roller coasters is subdural hematoma[1], artery dissections, hemorrhages, and strokes (3)[2]. In their respective studies, Pelletier and Gilchrist determined that 73% of all deaths from roller coasters were caused by intrinsic 'health related' problems, the remaining 27% were caused by external factors (i.e.: falling out of the ride) (4,5). Common non-lethal problems associated with roller coaster rides are chronic migraine headaches, sleeping problems, upset stomach, and nausea (6).

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[1] Yamakami et al. performed a study on a male who had been in a motorcycle accident which resulted in subdermal hygoma and was manifested as a subdermal hematoma when he later went on several roller coaster rides. The possiblily exists that centripetal forces experienced during the accident and subsequent rides contributed to the development of the hematoma.

[2] Braksiek's results are somewhat controversial because his study fails to mention how the deaths occurred. For example, failure of the harness in a roller coaster that resulted in a rider falling to their death is not considered in his study. However, his results still deserve merit because they provide a general outline how these deaths occur.

Centripetal forces are generally associated with increased levels of sympathetic nervous activity (i.e.: the excitement associated with going on an amusement ride or when your car spins out on an icy road). Thus, we suggest that increased centripetal force would cause increased cardiac output (both the stroke volume and heart rate are expected to rise). Consequently, this would also cause mean arterial pressure (MAP) to increase in the person experiencing these forces.

Materials and Methods

Subjects

Three male subjects took part in the present study. None of the subjects smoked, had prior heart or breathing abnormalities or weight problems. In general, they appeared to be in good health, and were physically fit.

Materials

Electrodes connected to each of our subjects using the Lead I Bipolar configuration electrocardiogram (ECG) are fed into an iWorx/204 switchbox unit connected to a computer set up with iWorx system software. This set up services as the collector for all data collected in this experiment. A spinning chair is used to provide the centripetal acceleration; it is later stabilized with thin shock absorbing gym-mats.

Experimental Design

Each subject had their baseline (control) heart rates, R-wave amplitudes and QRS interval measured via ECG prior to any experimental trials. Experimental trials then proceed as follows. A subject is seated in a spinning office chair and spun around manually by two participants. The rate of spinning was carefully monitored and kept to 0.8 revolutions per seconds (by counting four cycles for every five seconds). After an experimental trial, the subject was immediately and as quickly as possible hooked up to the ECG via previously electrodes previously attached to the subject's body. Within the span of the next ten seconds, recording of the ECG trace is started; ECG trace recordings lasted a minimum of two minutes after each trial. Each subject is exposed to three durations of spinning; thirty seconds, sixty seconds and ninety seconds. It was decided that each of the three subjects would be exposed to the same duration of spinning before moving onto the next duration. This allowed for an implicit resting period between trials involving the same subject. Measurements were taken as an average of three trials for each the controls and each experimental trial duration.

Measurements

The number of pulses was counted in three different samples of ten second intervals for each two minute ECG trace. The amplitude of the R-wave was recorded to infer any changes in stroke volume later on. Arbitrary units (AU) were used for R-wave recording due to some inherent difficulties encountered with the equipment. We defined the control measurement for each subject as 1 AU and will refer to all other data gathered in regards to R-wave as a ratio to the arbitrary unit.[3] R-wave data were collected similarly to pulse data; counted in three different samples of ten seconds for each two minute ECG trace. Finally we recorded the average duration of the QRS interval for each experimental trial.

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[3] R-Wave amplitudes are normally recorded and given in millivolts. It was decided that the range of data between our subjects was too high, thus the results are better presented in relative arbitrary units. The arbitrary units are given by setting the voltage reading during the control trial to 1 unit for each subject. The rest of the readings for a particular subject are given as a ratio of the arbitrary unit for that subject.

Results

Heart rate increased significantly with centripetal acceleration.

Although the resting heart rates of our subjects varied by up to ten beats per minute, our experimental trials consistently indicate a positive correlation between the duration of the applied stimulus (spinning) and an increase in heart rate (average increase between each trial of increasing duration = 3.2 beats per minute, s = 1.8). Some deviation from the general trend was observed. Although the general positive correlation is observed, some trials of increasing duration resulted in slightly reduced heart rate. Whether these observations can be attributed to a systemic phenomenon remains to be seen in further studies involving larger sample sizes.

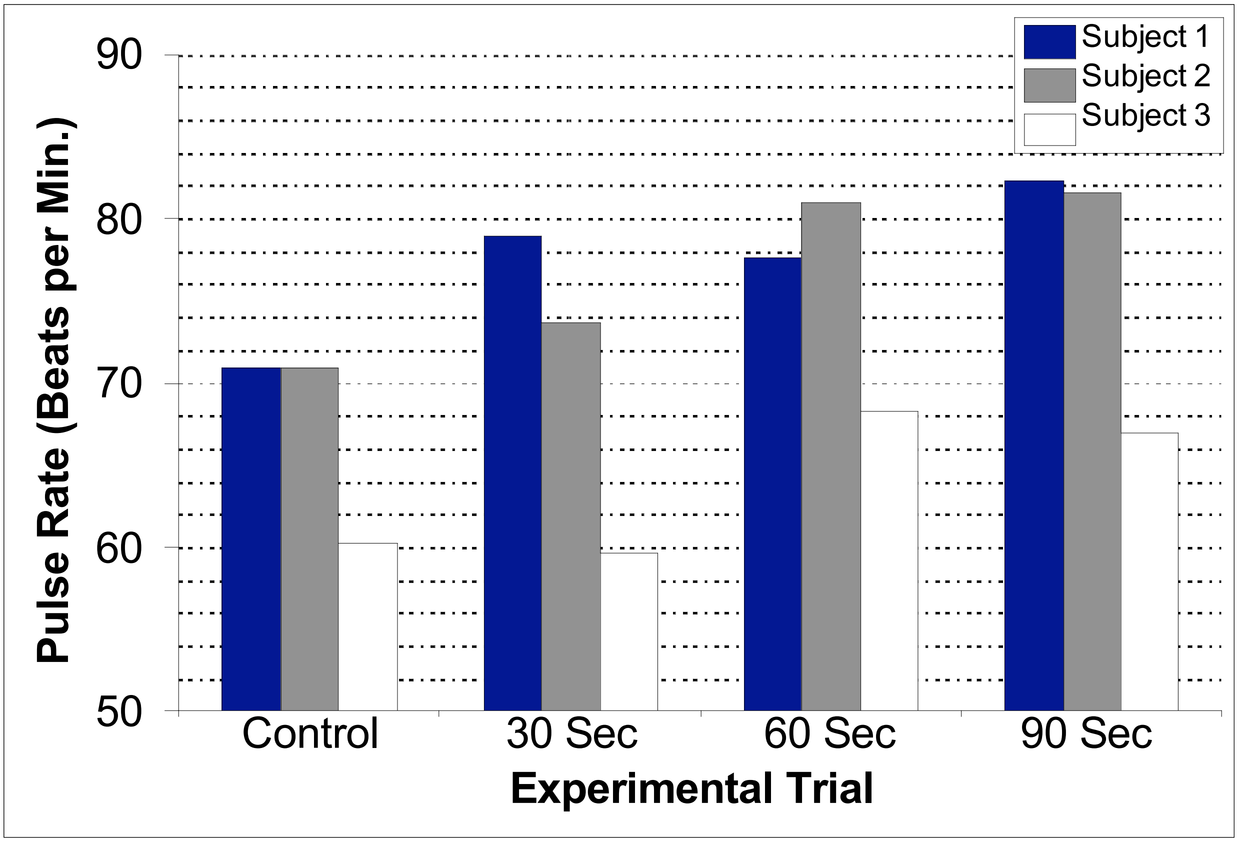

Figure 1. Average pulse rates (beats per minute) for each subject inferred from an ECG trace after three trials each at control conditions; and at a thirty, sixty and ninety second experimental trial length.

Table I. Average pulse rates (beats per minute) for each subject for control conditions, and at the three experimental conditions.

	control reading	30 seconds	60 seconds	90 seconds
subject 1	**71**	**79**	**77.6**	**82.3**
subject 2	**71**	**73.6**	**81**	**81.6**
subject 3	**60.3**	**59.6**	**68.3**	**67**

R-Wave amplitude increases initially with centripetal acceleration.

A definite initial increase is observed in the R-Wave recorded on all subjects with the ECG. The correlation between R-Wave amplitude and experimental trial duration appears to last well up to the sixty-second-long trial. Two sub-trends can definitely be observed from the data collected. The first sub-trend is described as follows. Two of the subjects appear to exhibit a drastic increase between the resting reading and the first reading at thirty seconds (increases of 35 and 38 per cent). These two subjects were also the ones which exhibit the gradual decrease noticeable at sixty seconds. The other sub-trend can be described as a definite and consistent but gradual positive correlation; exhibited by the third subject. The third subject exhibited no significant difference in R-Wave between resting and the first experimental trial (a decrease of 1 per cent). Additional study with more participants is needed to uncover whether these two sub-trends are coincidental or systemic.

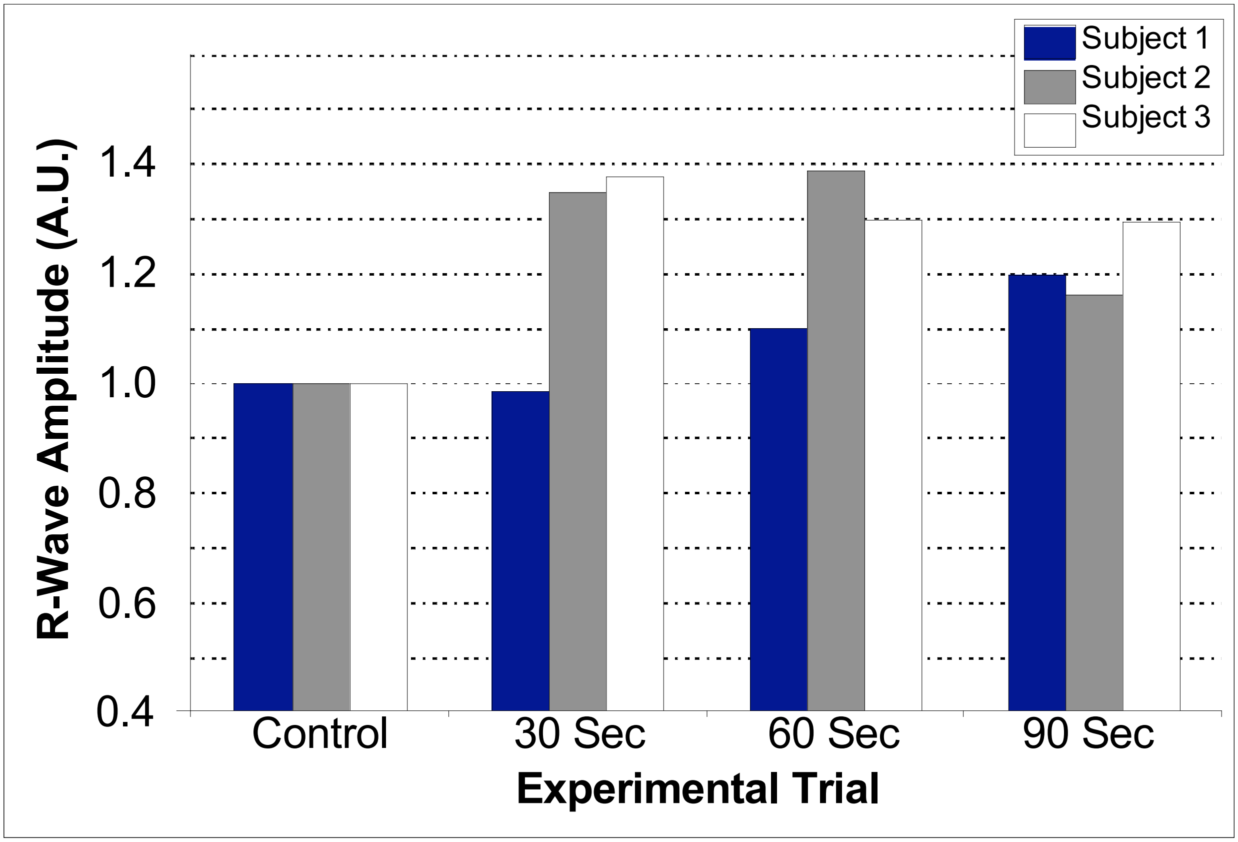

Figure 2. Average R-Wave amplitude in arbitrary units for each of the three subjects inferred from an ECG trace taken after three trials each at control conditions; and at thirty, sixty and ninety second experimental trial durations.

Table II. Average R-Wave (arbitrary units) for each subject for control conditions, and at the three experimental conditions.

	control reading	30 seconds	60 seconds	90 seconds
subject 1	**1**	**0.985**	**1.101**	**1.199**
subject 2	**1**	**1.349**	**1.387**	**1.163**
subject 3	**1**	**1.378**	**1.298**	**1.296**

QRS intervals show no change under the influence of centripetal acceleration.

No trend in the length of the QRS interval could be demonstrated. The QRS interval remained remarkably consistent across both subjects and experimental trials (average reading for all subjects and experimental trials = 0.33, s = 0.02).

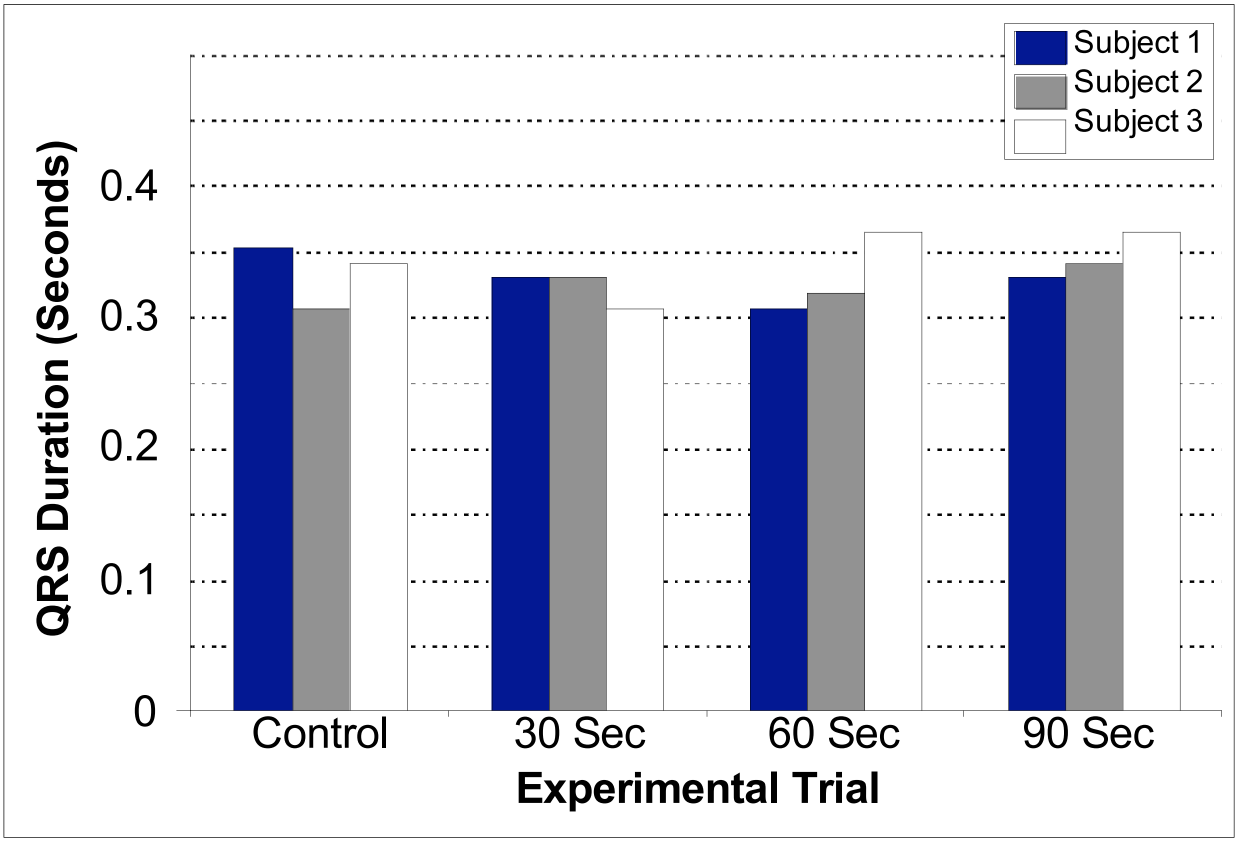

Figure 3. Average QRS duration (in seconds) for each of the three subjects inferred from an ECG trace after three trials each taken for control conditions; and at thirty, sixty and ninety seconds of experimental trial duration.

Table III. Average QRS duration (seconds) for each subject for control conditions, and at the three experimental conditions.

	control reading	30 seconds	60 seconds	90 seconds
subject 1	**0.353**	**0.330**	**0.306**	**0.330**
subject 2	**0.306**	**0.330**	**0.318**	**0.341**
subject 3	**0.341**	**0.306**	**0.365**	**0.365**

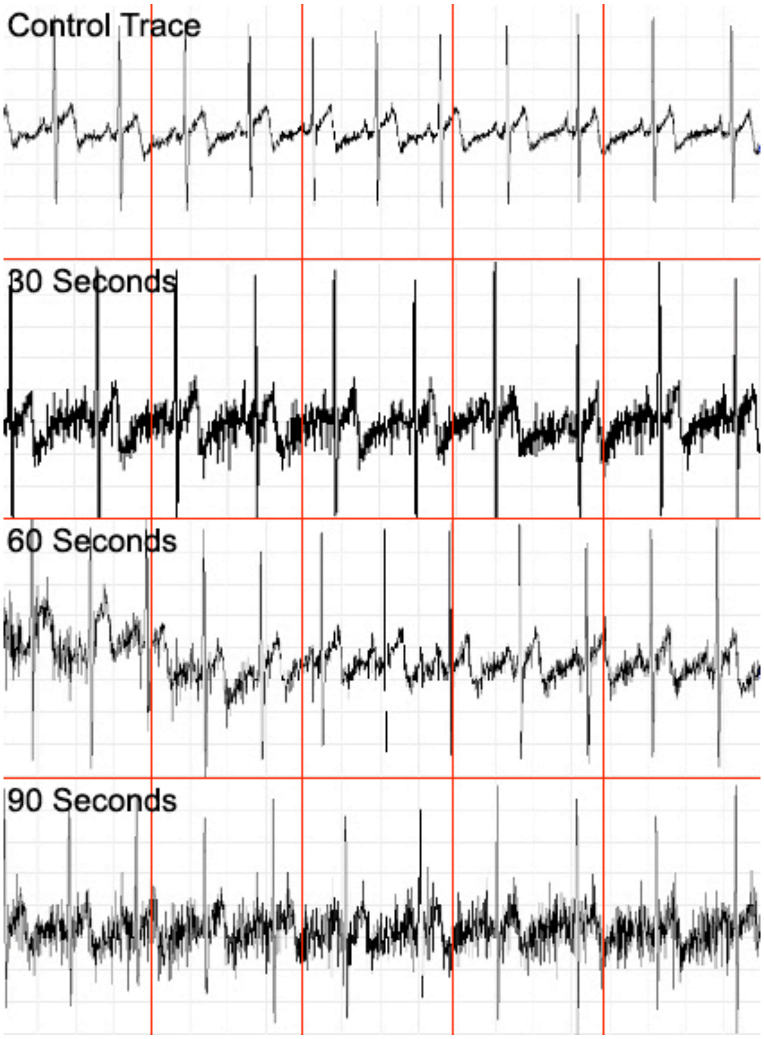

Figure 4. A series of sample ECG traces for one of the subjects; four ten-second traces taken at control circumstances and after thirty, sixty and ninety seconds of spinning are shown above. The red vertical beams indicate the elapse of two seconds. Notice the general trend of increasing heart rate as experimental trial duration increases.

Discussion

The centrifugal force generated from the spinning chair acts on different parts of the body. With the head and spine aligned on the axis of rotation, the blood is pushed by centrifugal force towards the extremities of the body, away from the heart. This increases the work load of the heart since blood is not efficiently returned. Thus a person's autonomic nervous system (ANS) reacts with increasing cardiac output to maintain blood supply to their vital organs. Furthermore, the sympathetic nervous system (SNS) acts on the vasoconstrictor region to the heart. With the blood being forced to the extremities, the blood volume and pressure in the core would drop and would be detected by the baroreceptors. This would result in decreased firing rate of the baroreceptors and resulting in stimulation of the vasoconstrictor region in the upper medulla of the brain. The vasoconstrictor centre secretes norepinephrine which directly causes vasoconstriction, as well as increased heart rate and heart muscle contraction (1).

Heart Rate

The heart rates of the subjects increased with the duration of the spinning cycles as shown in figure 1. This is consistent with the action of the vasoconstrictor region and the research of motion sickness induced by the 'rotating chair test' conducted by Cowlings et al. and the findings of Holmes et al. (7,8).

Amplitude of R-waves

The amplitude of the R-wave illustrated in figure 2 initially increases with the duration of spinning time. R-wave amplitude is proportional to the duration of the spin up to at least sixty seconds. This demonstrates that in an attempt to increase stroke volume, the heart increases muscle contraction. Increased R-wave amplitude is consistent with the action of vasoconstriction during the spin. The reduction observed after this period may be attributable to acclimation of the autonomic nervous system to the spinning stimulus. As earlier noted in the results section, one of the subjects exhibited a much stronger correlation between R-Wave amplitude and duration of spinning stimulus. A further trial was conducted to test whether or not this correlation could be sustained. For this subject, even after a trial of 240 seconds a significant increase was detected; a further 8.6 per cent increase in R-Wave amplitude was detected between the 90 second trial and the 240 second trial.

Duration of QRS intervals

The values of the QRS intervals in figure 3 showed no specific correlation with respect to the changes in the spinning cycle and the baseline control. In addition to the action of the SNS, the parasympathetic nervous system (PNS) may also be a factor in the increased cardiac output. In a study conducted by Gianaros et al. on motion sickness, it is demonstrated that there is a decrease in PNS action on the heart during motion sickness, resulting in increased cardiac output (9).

There are many factors that affected the cardiovascular system during this exercise; psychological anticipation of the experiment and the onset of motion sickness are amongst them. These confounding factors are beyond the scope of this paper. Additional research into cardiovascular function during centripetal acceleration in humans is required to build a fuller picture. One parameter that this team would like to have investigated is blood pressure. As well, experimental trials involving greater speeds and longer durations may strengthen our data by overwhelming confounding variables.

Acknowledgements

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