www.jmscr.igmpublication.org
Impact Factor 5.84
Index Copernicus Value: 83.27
ISSN (e)-2347-176x ISSN (p) 2455-0450
crossref DOI: https://dx.doi.org/10.18535/jmscr/v5i3.79

IGM Publication
Journal Of Medical Science And Clinical Research
An Official Publication Of IGM Publication

Types of Cardiac Arrhythmia Resulting From Centrifugal Acceleration: An Overview of the Effects of Centrifuge Forces on the Heart

Authors
Hamdan M Alotaibi, Aqeel S Almasoudi, Sulaiman I Alhomaid, Ibrahim A Alshehri, Abdullah K Alharbi, Faiz H Alshehri, Bashair S Alharbi, Haya S Aldosari, Ali A Alzahrani, Sattam M Albosaili, Norah I Alzahrani

Abstract
Cardiac arrhythmia is one of the many health conditions that form the basis of aviation medicine. The absence of adequate information around the condition necessitates studies to that effect. The current paper sought to determine the types of cardiac arrhythmias that may result from aviation related forces. The study relied on findings made in centrifugal training experiments, where subjects were placed in a human centrifuge and exposed to $+G_z$ *forces, similar to the motion in a high performance military jet. During such exercises, the tolerance level of the subjects was determined relative to the G-forces. It was found that sinus arrhythmia, premature atrial contraction, premature ventricle contraction, and atrial fibrillation are the common cardiac arrhythmias during such exercises.*
Keywords: *Cardiac arrhythmia,* $+G_z$ *forces, centrifugal acceleration.*

Introduction

Aviation Medicine

An Overview

It's a known fact that the human body is designed to live in a stable and moderate environment, especially in what comes to the temperature, pressure and gravitational force. That's what made preparing the human body to adapt with the extreme environment of flying one of the main priorities and challenges in aviation industry. This challenge has brought more attention to aerospace medicine as a scientific field, and has provided the aerospace research centres around the world with the required fund and specialized qualifications to run more expanded researches.

since that motion forces imposed on the human body inside a flying structure (whether an aircraft or a space shuttle) might have a significant impact on the performance of the human body systems, studying these forces and knowing how to adapt with them has become a crucial need.

With the accelerated evolution and growth in aviation industry came an advancement in aerospace medicine. This scientific field has evolved in an unprecedented way within the last few years as a result of the constantly evolving technology. The latest introductions of more sophisticated equipment into the field such as the highly advanced flight simulators and disorientation capsules have provided an opportunity to train pilots and having them exposed to an environment similar to the one inside the cockpit.

The centrifuge is considered one of the essential training equipment that has played an important role in aviation medicine. No one can imagine an aerospace medical or research centre without a modern centrifuge. The device have been utilized all around the globe in order to train pilots and astronauts by having them exposed to different levels of G-forces, and it will remain an essential device for training and research in the future.

Effects of g-forces on human physiology

G-forces cause stress on the bodies in an aircraft. In line with this, the elements have a physiological effect on human bodies. [1] Hanada et al. [2] affirm this hypothesis in their study on the effects of g-forces on military pilots. Most of the components of the human anatomy have mass. As such, the effects of stress and strain on them vary. Hanada et al. [2] indicate changes in cerebral perfusion as a major impact of these forces. In such cases, the patients tend to suffer from a well-known condition called G-induced loss of consciousness (G-LOC). Such conditions are common among military pilots during maneuvers performed in the fighter jets.

Arrhythmias are another common condition that may result from G loading, especially in instances where flight crew are taken through centrifuge training. [4] In such cases, pilots are subjected to a dynamic environment similar to the operations of a fighter jet. Consequently, the resulting forces may alter the rhythmic patterns of an individual's heartbeat. Because the physiologic effects of G loading may be so severe, Hanada et al.[2] propose the presence of specialists during centrifuge training.

Effects of G-Forces on the Heart

Cardiac arrhythmias and the study question

Different types of arrhythmia could result from being expose to excessive G-force, and it could vary in severity and effect on the body depending on the subject and the circumstances of exposition. Which brings us to our research question, the question that should be answer through this study paper is: what type of arrhythmias that may result from G-forces exposure, and what are the more commonly related types with G-force. In order to have this question answered we shall rely on selective studies involving practical experiments using the centrifuge, and we shall provide numbers and percentages to support our answer.

Cardiac arrhythmia

The functioning of the heart is largely attributed to its electrical properties.[1] The stresses and strains brought about by the g-forces may affect these electrical attributes. As a result, the heart beat can be altered creating an arrhythmia that might vary in type and effected chamber of the heart. The condition is not age or gender specific. Whinnery [3] points out that the condition if often not fatal. However, studies illustrate that cardiac arrest is associated with arrhythmia.[2]

Cardiac arrhythmia can occur in multiple areas of the heart. [1] as it is known that cardiac arrhythmia is categorized according to the effected part of the heart. Rayman [1] points out the existence of four types of cardiac arrhythmia. The first is supraventricular arrhythmia, which is characterized by fast beats rhythm taking place above the atrio-ventricular node in the heart.[1] Second, sinus arrhythmia may result in Bradycardia. This condition usually takes place during negative Gz-force (centrifuge braking). In such cases, the blood hardly reaches the brain.

The third type is ventricular arrhythmias. The occurrence is associated with the lower chambers (the ventricles) of the heart.[1] Finally, there is premature beats, which may be associated with either the atria or the ventricles. Premature beats are a mild form of arrhythmia, whose symptoms are not easily noticeable.[5]

Factors influencing g-force provoked arrhythmia

One of the factors that influence cardiac arrhythmia during centrifugal training is the magnitude of the $+G_{z.}$ Ewalina and Lech [7] performed a study in which they sought to determine hemodynamic changes resulting from centrifugal acceleration and the corresponding cardiovascular responses. The study revealed that an acceleration of $1G_z$can cause acute hemodynamic changes. The same magnitude of acceleration was found to be an activator of cardiovascular responses, arrhythmia being one of them.[7]

Anti-G straining maneuvers (AGSM) may influence g-force-provoked arrhythmia. Ewalina and Lech [7] point out that AGSM has a direct effect on the nervous system, which impacts on the heart's electrical properties. Such measures are seen as an attempt to reduce the effects of g-forces. They limit the impacts of $+G_z$ on the electrical characteristics of the heart.

Other factors include the health status of the subject and the duration of exposure. Latent cardiac medical histories give mixed results. Exposure durations increase the chances of cardiac arrhythmia, which further aggravates the severity of the conditions.

Materials and Methods

Introduction

The current study is hinged on the hypothesis that centrifugal acceleration can results in cardiac arrhythmia. The research relies on a series of peer reviewed articles, which provide a detailed discussion of the topic. More importantly, the articles relied on address the issue of g-forces and their effects on human subjects. They illustrate the various types of arrhythmia and their relationship with g-forces.

The purpose and the main goal of this study

This study relies on several research articles published by different aerospace medical centers from all around the globe. The articles mainly discuss practical experiments conducted within these research medical centers as a part of certain scientific studies. All these studies described in the designated articles are meant to focus and discuss the influence of centrifugal forces on the electrical properties of the heart and the normal cardiac rhythm. Although the studies came from different places, but they all have a common goal and that is to evaluate the burden created by the aeronautical forces on the human heart and heart's rhythm.

My paper's study has depended on selective articles with certain criteria upon which the articles were chosen to be included in this study. Each of the selected articles has described an experiment conducted in an aerospace research center from different parts of the world such as Japan, France, Poland and the United States. All these experiments took place on a healthy individuals being placed inside a standard human centrifuge while having their vital cardiovascular indices monitored. The monitored signs include: heart rate, blood pressure, mean arterial pressure, respiratory rate and in all the experiments the cardiac rhythms were monitored using an electrocardiogram.

Criteria of articles and experiments selection

The study focuses on 5 main experiments with a total of 386 candidates. The included individuals were military pilots in most of the cases, and in some cases they were civilians being prepared for suborbital space commercial flights like the experiment conducted in the National Aerospace Center for Research and Training (NASTAR). All the candidates in every included experiment in the paper have received a comprehensive medical examination and testing prior to the experiment.

The articles that were excluded from my study are the ones that run the experiments on less then completely healthy individuals or individuals with underlying cardiovascular abnormalities. Among the excluded studies two studies where the included subjects in one of them had stage-1 primary hypertension and in the other study the subjects suffered from aortic valve disease. In both studies, the main purpose was to evaluate the effect of centrifugal force on preexisting medical conditions within the heart.

Other sources that I relied on in my study are some major references in aerospace medicine such as Clinical Aviation Medicine by Rayman BR. And the Fundamentals in Aerospace Medicine by Jeffrey RD. certain chapters within these books among others have provided some essential data for my study and have enriched the materials of my paper's topic.

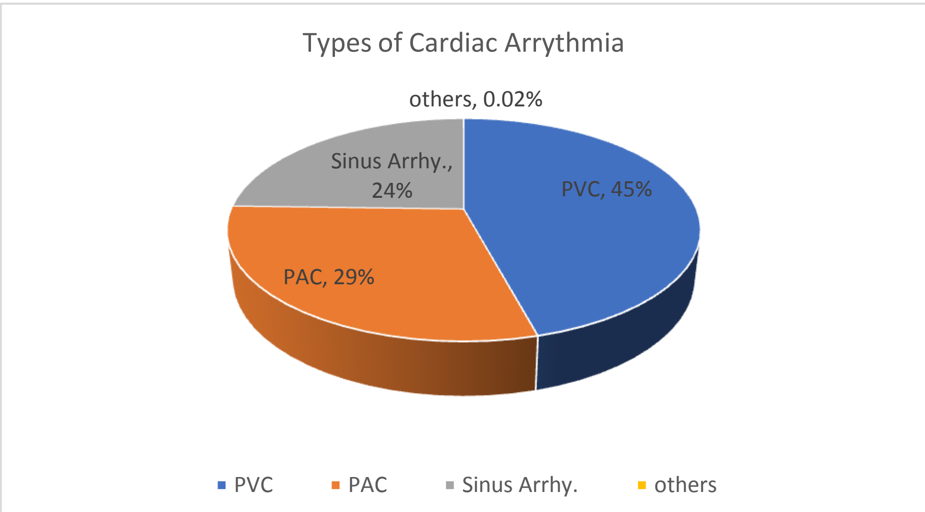
Data

The main 5 experiments that are being discussed here in this paper are: 1- an experiment sponsored by the Japan Air Self-Defense Force (JASDF) conducted by Ryuzo Hanada and included 195 individuals. 2- An experiment sponsored by The Military Institute of Aviation Medicine in Warsaw, Poland, conducted by Ewelina & Lech and it included 40 subjects. 3- An experiment sponsored by The Naval Air Development Center, Warminster, Pennsylvania conducted by James Whinnery and it included 59 subjects. 4- An experiment sponsored by The Aerospace Medicine Laboratory center in Paris, France, conducted by Vettes, Viellefond, and Auffret and it included 15 individuals. 5- An experiment that took place in the National Aerospace Center for Training and Research (NASTAR) sponsored by University of Texas and conducted by Rebecca Blue and included 77 individuals. My paper has relied on these five published experiments among other articles and research reports.

The calmative results of the five experiments

According to the results of the five experiments it seems that most of the participants have suffered from a certain degree of arrhythmia while being exposed to the centrifugal force. Some of the participants had showed even two different types of arrhythmia or even more during the experiments. The following table summarizes the number and the types of arrhythmias in all five experiments.

	Hanada	Ewelina & Lech	Whinnery	Vettes, Viellefond, and Auffret	Blue	Total
Total number of subjects	195	40	59	15	77	386
Total number of arrhythmia incidents	304	15	65	23	80	487
PVC	133	10	31	7	37	218 (44.8%)
PAC	66	2	32	5	37	142 (29.2%)
Sinus arrhythmia	95	3	2	11	6	117 (24.1%)
SVT	3	0	0	0	0	3 (0.006%)
V Tach.	5	0	0	0	0	5 (0.01%)
A fib	1	0	0	0	0	1 (0.002%)
V bigeminal	1	0	0	0	0	1 (0.002%)
total	304	15	65	23	80	487



Results

Introduction to the Results

From the materials and methods and from the data discussed in the previous sections, it is apparent that there is enough evidence to support the hypothesis made in this paper. The evidence suggests that cardiac arrhythmias are caused by g-forces and provides for us enough data to know the chances of each type of arrhythmia to take place.[5] The results of previous studies conducted in this field highlight the various types of arrhythmias and the effect of centrifugal acceleration on the heart rate. In addition, the findings made illustrate the various cardiovascular parameters related to arrhythmia. In line with this, analysis of this condition in relation to centrifuge is outlined in this section.

Types of Arrhythmias (Hanada)

As aforementioned, there are multiple types of arrhythmias. Each of them has unique characteristics that set it apart from the others.[6] In a study to determine the safety measures needed to be put in place during g-flight training, Hanada et al. [2] discovered different types of this condition. The findings are illustrated in Table 2 below:

Table 1: Types of cardiac arrhythmia (Hanada experiment)

Number of Participants	Percentage of Occurrence (%)	Type of Arrhythmia
114	58.5	Single PVC
95	48.7	Sinus Arrhythmia
63	32.3	Single PAC
19	9.7	Paired PVC
5	2.6	Ventricular tachycardia
3	1.5	Paroxysmal supraventricular tachycardia
3	1.5	Repeated PAC
1	0.5	Paroxysmal Atrial Fibrillation
1	0.5	Ventricular bigeminy or trigeminy

Adapted from: Hanada et al.[2]

The study by Hanada et al. [2] reveals 9 types of cardiac arrhythmia associated with centrifuge acceleration. The figures listed in table 1 above were obtained from research conducted by the Japan Air Self-Defense Force. The most common condition recorded during the study was single premature ventricular contraction (PVC) at 58.5 percent. The occurrence of both Paroxysmal Atrial Fibrillation and ventricular bigemny or trigemny was recorded at 0.5% in one of the participants, making it the least common of all.

Centrifugal Acceleration and its Effects on the Rate of Heartbeat (Whinnery)

In their study, Whinnery [3] affirms that g-forces affect an individual's heart rate. Table 2 below illustrates results of the study by Whinnery.[3] The effects of the forces on the human heart are documented in the table.

Table 2: G-force exposure and corresponding heart beat rates

Lown grade Ectopy	Definition	Subjects with highest Lown grade
0	Absence of ventricular premature depolarizations	12
1	<5 PVC	31
2	>5 PVC	3
3	Multiform PVC	1
4A	Paired PVC	8

Source: Whinnery [3]

In this research, Whinnery focused on premature ventricular contractions. As illustrated in table 2 above, the study examined the heart rate in relation to the effects of exposure to $+G_z$ forces. The analysis is based on a Lown grading system. Such a system is used to classify heartbeats with regards to cardiac arrhythmia. [8] Whinnery [3] selected a cluster from the known classifications, as shown in table 2. The experiment analyzed results from a total of 59 participants. It was found that $+G_z$ forces affected an average of 11 subjects. The same is inferred from the data in table 2.

Cardiovascular Parameters (Vettes, Viellefond, and Auffret)

Studies aimed at examining the effects of centrifugal acceleration rely on specified cardiovascular parameters. Vettes et al. [6] posit that the $+G_z$ forces arising from centrifugal acceleration rely on such factors. They determine such responses as cardiac arrhythmia. The said parameters include an electrocardiogram and the visual field of the subject. In addition, the heart rate and humeral arterial pressure of the participants are factored in the study. They make up the cardiovascular parameters recorded during such experiments.[6]

Vettes et al. [6] point out that increased exposure to g-forces was followed by a corresponding increase in the rate of the individual's heart beats. The results from their experiments illustrated that peripheral loss of vision among the subjects was an indicator of the effects of the $+G_z$ forces. The latter is regarded as a key symptom indicating the onset of cardiac arrhythmia. The study by Vettes et al. [6] revealed that the highest recorded heart beat per minute was 113, whereas the lowest was 84.

In terms of pressure, Vettes et al. [6] illustrated that increased exposure to these forces (up to levels of $+3\ G_z$) resulted in a corresponding rise in arterial pressure. To this effect, blood pressure is treated as an essential parameter in understanding cardiac arrhythmia. The same explains the effects of exposure to g-forces. The scenario is similar to electrocardiographic recordings, which vary depending on the accelerations. In their study, Vettes et al. [6] point out that increased cardiac work load was the cause of arrhythmia. The reason is that the pressure led to atrio-ventricular dissociation.

Effects of Centrifuge Training on the Heart (Blue)

The major focus of this study, Blue's, is centrifugal acceleration and its effects on human body. [9] Aviation regulations require pilots (and in some cases passengers) to undergo some level of centrifugal training. Such trainings simulate the acceleration likely to be experienced in fast moving aircrafts. An example of such instances involves commercial space-craft. [5] The high acceleration associated with such crafts requires some training to acquaint the persons with the g-forces.

Blue et al. [5] carried out a similar study in which occupants of a spaceflight were subjected to centrifugal-stimulated sub-orbital flight. The objective was to create conditions similar to those in a fast moving aircraft. The participants in the study were all healthy. The simulation was expected to provide information on how g-forces affect the heart. It was also expected to shed light on the influence of the forces on the occurrence of cardiac arrhythmias. Their study used a total of 81 participants [5].

The research by Blue et al. [5] required healthy individuals. As a result, all the participants were subjected to medical screening. [6] Consequently, the initial number was reduced to 77 subjects. Out of this, 65 were men, while 12 were women. Another group of 21 participants was subjected to cardiac examinations to check for any latent complications.

The examinations revealed that 16 had histories of hypertension, while 5 had diabetes. Another 5 had undergone a coronary heart bypass. In addition, 17 participants had a history of hyperlipidemia. Prior to the simulation, there were 2 individuals who were found to have severe cases of peripheral vascular disease. The objective of these tests was to obtain exact results from the simulations. The aim was to ensure that the findings made were due to g-forces from centrifugal acceleration and not from latent conditions.

The participants with medical histories had little complaints from the centrifugal acceleration in comparison to those without backgrounds of medical conditions. However, both sets of participants complained of nausea. The same is common in cases where subjects are exposed to high centrifugal acceleration.

Another effect of this development was greyout. To this end, participants complained of incidences of mild greyout. Interestingly, none of the participants experienced any form of G-LOC. There were, however, incidences where the participants would perform head movements with the sole objective of self-inducing sensations similar to coriolis.

Six of the participants have reported palpitation, four of them were in the first centrifugal run. And 37 out of the 77 participants (48%) have been reported to experience PAC and PVC on different levels, which according to the study has no significant relationship with the participant's general or medical condition.

Discussion

Overview

From the various experiments highlighted in the current study, it appears that cardiac arrhythmia is caused by g-forces associated with aerodynamics. [10] The various studies made reference to centrifugal acceleration. It is not possible to obtain results from the specific aircrafts that the researchers used to generate centrifugal acceleration. As a result, most studies depend on simulations of conditions found in an aircraft.[11] During such instances, the subjects are rotated at a certain speed that creates a G load equivalent to those in an aircraft.

The G forces effects on the subject are longitudinal. In addition, they are the most common forces that affect the rhythm of an individual's heart when in flight. [13] The different levels of exposure to g-forces are a contributing factor to the occurrence of the various types of cardiac arrhythmia.

The study by Hanada et al. [2] highlighted three types of arrhythmia common among pilots, especially in military jets. The three were identified as PAC, PVC, and sinus arrhythmias. According to Hanada et al. the three occurred due to the variant levels of exposure to $+G_z$. For instance, sinus arrhythmia occurs in instances where subjects were exposed to high Gz forces. In such cases, the resulting levels of stress are high. The same has an effect on the heart rate. This G load distorts the rhythm of these rates once the subject comes to rest.

It is noted that PVC and PAC are the most common types of arrhythmia that result from interactions with high-G training. [14] Hanada et al. [2] addressed this issue by pointing out that these are common in normal day-to-day exercises. The researchers found it prudent to do away with centrifuge in cases where subjects exhibited PAC and PVC. [2] The argument is strengthened by the assumption that the two arrhythmias are a normal occurrence among subjects.

The study by Hanada et al. [2] introduced the element of grading the cardiac rhythms among subjects. The system is essential in determining the degree or severity with which arrhythmia exhibits itself. [15] In this grading system, arrhythmias that are recorded at a grade of three are regarded as severe. It is noted that 10% of the subjects in the study by Hanada et al. [2] exhibited a paired condition of PVC& PAC. The researchers argue that the condition is a direct physiological response to the stress experienced during the centrifugal acceleration in training sessions.

The Lown grading system for ectopy was developed against the backdrop of the need to characterize the different types of arrhythmia. The same explains why, in the study by Hanada et al. [2], PAC and PVC are graded according to the degree of exposure to $+G_z$. An example is in the case where there is paired PVC and PAC, while at the same time single cases of PAC and PVC are noted. In both cases, the Lown format becomes vital in highlighting the severity of the different types of arrhythmia.

The Lown system came to be very useful in the process of evaluating and estimating the level of arrhythmia and premature contractions during the experiments. It is used to determine the types of arrhythmias that are permissible in centrifugal training. An example is evident in the study by Hanada et al. [2], where the system is used to sanction centrifugal training in cases where subjects exhibit paired PVC. However, training sessions are terminated in cases where the arrhythmias go beyond a specific threshold. [2] In such cases, the severity of the condition is determined by such factors as proaxysmal atrial fibrillation.

Hanada et al. [2] posit that there are certain tachycardic arrhythmias that reduce tolerance to G-stress resulting from centrifugal acceleration. In such cases, the subjects exhibit PSVT and VT. Their study revealed that PVST is possibly a major cause of loss of consciousness during centrifugal training.[15]

The findings made in the current study are best understood from the perspective of a detailed discussion of centrifugal acceleration and its effects on the heart. In so doing, the researcher aims to prove that cardiac arrhythmia is a result of centrifugal acceleration. In this section, the specific types of this condition are analyzed in detail.

Protocols for Centrifugal Acceleration

Centrifugal training, as already indicated, is the process through which pilots and other crew members are subjected to controlled conditions of G-stress. During such sessions, aviation medical personnel examine individual subjects' tolerance to G-forces.[2] It is important to take the subjects through certain protocols. Such a move is necessary as it helps in the attainment of accurate results from the exposure to the said forces. Several studies are used to elaborate the importance of these protocols as indicated in the 'methods' section of this paper.

The first and most important protocol to follow in centrifugal training is preliminary medical check-ups. [1] The procedure is evident in the studies by Hanada et al. [2] and Whinnery [3], where the subjects are screened for heart related complications. The objective of such preliminary medical examinations is to ensure the effects of G-stress exposure are not confused with the symptoms of latent medical conditions.

The second protocol during centrifugal studies is the exposure levels.[3] During the training exercises, the subjects must be exposed to varying levels of $+G_z$ so that a proper comparison can be arrived at. For instance, Whinnery and Hickman [8] sought to study mitral valve prolapsed and thus relied on centrifugal acceleration. Their subjects were exposed to stress levels of 1G.15s^{-1} which were gradually increased. There was also another exposure referred to as the rapid onset exposure in which the subjects experienced g-forces of 1 G.s^{-1}. The initial tolerance level is essential in evaluating cardiovascular reflexes.[8] On the other hand the second tolerance level are useful in determining the subjects' tolerance in terms of the hydraulics. During these exposure levels, in centrifugal training, it is expected that the subjects end up experiencing total loss of their peripheral sight. The aforementioned protocols are key in ensuring that the results are obtained as expected.[8]

Arrhythmia Resulting from Centrifugal Training

Overview

The contents of the articles referred to in the current paper reveal that there are 3 major types of arrhythmias that result from centrifugal acceleration. [4] The three include sinus arrhythmia (tachycardia and bradycardia), premature arterial contractionand premature ventricular contraction. [3] In order to categorize each of the mentioned arrhythmias, the author of the current study made observations depending on the levels of $+G_z$ exposure. A detailed discussion is provided in this section.

Sinus arrhythmia

According to Rayman, [1] the heart has a normal specific rhythm to which it beats. Consequently, any external force like g-stress tends to distort the normal pattern of this organ, resulting in a cardiac arrhythmia. From the articles reviewed in this study, subjects in centrifugal training experiments were found to exhibit sinus arrhythmia among other complications known in aerospace medicine. [9]

The study by Hanada et al. [2] revealed that this complication is common during centrifugal training, where the subject's heart rate normalizes immediately after an episode of tachycardia. Interestingly, there were subjects who exhibited this particular kind of sinus arrhythmia prior to centrifuge acceleration and the subsequent exposure to the $+G_z$ forces. As illustrated in table 2, the occurrence of the SA (especially tachycardia) in the participants was recorded at 48%. It is important to appreciate that the high occurrence rate is not really due to the centrifugal acceleration. Hanada et al. [2] argue that the condition is a normal occurrence, especially among persons involved in physical training.

It's well known that the normal heart rate of a healthy adult lies between 60 to 100 beats every minute. [1] However, some studies indicate that the pattern varies between the genders. A normal female's heart rate, for instance, is estimated to fall between 47 and 103 beats for every minute. [17] In men, the estimated HR is placed at the range of 43 to 102 beats per minute. Alterations in heart beat rhythm due to sinus arrhythmia are not fatal. There are cases where the condition cannot be detected. As such, members of a flying crew who are found to have the condition are not in danger.

5.4.3. Premature arterial contraction (PAC)

The human heart is fitted with a pace maker that has electrical characteristics. [1] as a result, when this part is exposed to external forces, there are distortions in its normal functioning.

As a cardiac arrhythmia, premature arterial contraction is a phenomenon where the heart's pacemaker emits signals before the 'stipulated' time.[18] The maker is located above the ventricles, meaning that these chambers respond to the distorted signals. As a result, the heart's contraction is altered by the ventricle's 'irregular' response. An arrhythmia of this kind is usually common when an individual is stimulated either through exercises or as a result of such beverages as coffee. However, the same is also true when an individual undergoes centrifugal training.[2]

In the study by Hanada et al., [2] PAC exhibited itself in a number of the subjects used in the experiments. Despite the fact that the condition is not lethal, it can present itself in a manner that would require a discontinuation of the training. In such cases, it is considered as clinically severe. Hanada et al. [2] point out that repeated PAC is quite severe and advises intermittent discontinuation of centrifugal training among subjects who exhibit the condition.

Premature ventricular contraction (PVC)

The heart's functions rely on the electrical impulses of the pacemaker. [19] In cases where $+G_z$ forces are introduced into the heart, the said impulses are interfered with. When such interferences occur, the functioning of some of the compartments of the heart is impeded, resulting in a distorted rhythm of heart beat. As an example of cardiac arrhythmia, PVC is characterized by the contraction of the heart's ventricles before the expected electrical signal. The name 'premature' is sourced from this irregular contraction of the ventricles. The diagram below is an ECG representation of this condition:

Graph 1: Premature ventricular beats

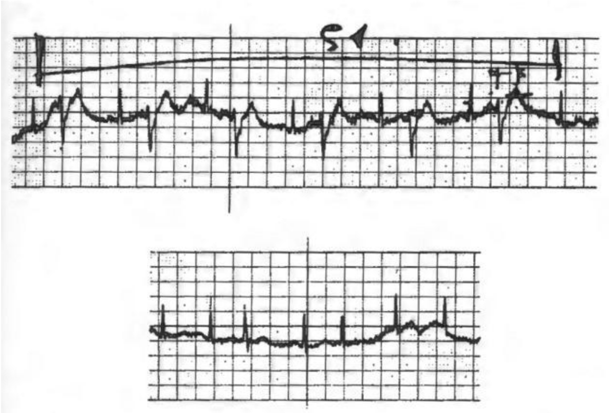


Fig. 3. Ventricular and supra-ventricular premature beats (+4 Gz).

Source: Vettes et al.[6]

The study by Hanada et al.[2] points out that PVC can exhibit itself in different degrees. There is the occasional premature ventricular contraction, which is a mild version of the condition. Subjects who present the said condition are allowed to continue with centrifugal training owing to the fact that it is not harmful. The harmful case of PVC involves repeated PVC such as Bigeminy and Trigeiny PVC. However, in spite of the fact that it is more harmful in comparison to occasional PVC, the latter case calls for the termination of centrifugal training after some time.

A look at the study by Hanada et al.[2] reveals that 19 pilots exhibited the paired PVC condition. The number of subjects who presented the condition in subsequent training sessions kept on decreasing. The same indicates that despite being a common occurrence due to centrifugal training, PVC is only severe when a subject is exposed to High G-

Stress over a long period of time without a break. A case in point is a pilot who travels in an aircraft at speeds that result in a stress of $5G_z.s^{-1}$ without taking a break. Such an individual is likely to experience a severe case of PVC, which might lead to cardiac arrest.[18]

Conclusion

At the end of this study we can conclude to several points which can be described using the results and the data given by the experiment articles. The first conclusion is that G-forces impose a strong stress on the cardiac structure to the level that would cause disturbance in the heart rhythm which might vary in severity according to the level of G load and exposure. According to the results, there is a very high chance that someone might experience some kind of arrhythmia as a result from being under a 5 Gs or more of G load. We can also conclude that there is a high chance that someone might develop more than one type of arrhythmia as a result of being expose to the G-force.

The results have also shown that the most common types of arrhythmias accompanied by G load are premature ventricular contraction (PVC), premature atrial contraction (PAC) and sinus arrhythmia, and these three types form together more than 99% of G-force related arrhythmias. These three types are also considered mild and non-fatal arrhythmias comparing to other more serious types. The other types of arrhythmia which were detected in the experiments are supraventricular tachycardia (SVT), ventricular tachycardia (VT) and atrial fibrillation (AF) and they were so rare in the experiments where they only made less than 1% of the detected arrhythmias.

Vettes et al. [6] point out that centrifugal training, and by extension centrifugal acceleration, has a direct impact on cardiac arrhythmia. In the context of this study, centrifugal acceleration is regarded as an avenue of generating G-forces to create stress on human body. Aviation medicine makes use of centrifugal training to effectively understand cardiac arrhythmia. In essence, this condition is all about the distortion of the normal heart rhythm.

Whinnery [3] introduced the element of human centrifuge in their study. The contraption is used in aviation medicine to conduct experiments on centrifugal acceleration. During such experiments, two main factors determine how G-forces give rise to cardiac arrhythmia. The two include the degree of $+G_z$ and the duration of exposure. Intensity and duration are crucial elements in explaining the various types of arrhythmias.

Hanada et al. [2] point out that centrifugal acceleration in centrifugal training exercises gives rise to 3 main types of arrhythmias. The analysis points out that sinus arrhythmia, premature atrial contraction, and premature ventricular contraction are the most common conditions. Atrial fibrillation is another type of arrhythmia associated with the exercises.

Each of the conditions above is graded on their severity depending on the magnitude of $+G_z$. in addition, the duration in which the participants are exposed to the forces adds to the severity of the conditions. As such, it is important to pay attention to the degree of these conditions among individuals taking part in centrifugal training. The aim is to avert cases of cardiac arrest. Such occurrences are fatal, especially when the subjects are exposed to real time flight conditions.

The recommendations that can be reached at the end of this study is that it is essential to have a comprehensive and thorough medical examination for all candidates in preparation for a high performance aircraft rides including a complete cardiovascular system examination. It's well known that the FAA first class pilot certificate requirements include an EKG for applicants 35 years of age or older, and that it's an annual requirement for pilots 40 years of age or older applying for the same class. Which reflects how much it's important to have pilots with healthy hearts in order to perform their tasks efficiently in the air, and how much stress can the G load impose on the cardiac structure.

It is also recommended that heart rhythm is being monitored whenever a subject is placed in the centrifuge under a magnitude of 5 Gs or higher. It is a protocol for centrifuge operator for many countries around the world to have pilots connected to electrocardiogram inside the centrifuge for every ride of 6 Gs or higher, including the US Air Force, the Royal Air Force and the Saudi Royal Air Force.

Effects of g-forces on human physiology

G-forces cause stress on the bodies in an aircraft. In line with this, the elements have a physiological effect on human bodies. [1] Hanada et al. [2] affirm this hypothesis in their study on the effects of g-forceson military pilots. Most of the components of the human anatomy have mass. As such, the effects of stress and strain on them vary. Hanada et al. [2] indicate changes in cerebral perfusion as a major impact of these forces. In such cases, the patients tend to suffer from a well-known condition called G-induced loss of consciousness (G-LOC). Such conditions are common among military pilots during maneuvers performed in the fighter jets.

Arrhythmias are another common condition that may result from G loading, especially in instances where flight crew are taken through centrifuge training. [4] In such cases, pilots are subjected to a dynamic environment similar to the operations of a fighter jet. Consequently, the resulting forces may alter the rhythmic patterns of an individual's heartbeat. Because the physiologic effects of G loading may be so severe, Hanada et al.[2] propose the presence of specialists during centrifuge training.

Effects of G-Forces on the Heart

Cardiac arrhythmias and the study question

Different types of arrhythmia could result from being expose to excessive G-force, and it could vary in severity and effect on the body depending on the subject and the circumstances of exposition. Which brings us to our research question, the question that should be answer through this study paper is: what type of arrhythmias that may result from G-forces exposure, and what are the more commonly related types with G-force. In order to have this question answered we shall rely on selective studies involving practical experiments using the centrifuge, and we shall provide numbers and percentages to support our answer.

Cardiac arrhythmia

The functioning of the heart is largely attributed to its electrical properties. [1] The stresses and strains brought about by the g-forces may affect these electrical attributes. As a result, the heart beat can be altered creating an arrhythmia that might vary in type and effected chamber of the heart. The condition is not age or gender specific. Whinnery [3] points out that the condition if often not fatal. However, studies illustrate that cardiac arrest is associated with arrhythmia. [2]

Cardiac arrhythmia can occur in multiple areas of the heart. [1] as it is known that cardiac arrhythmia is categorized according to the effected part of the heart. Rayman [1] points out the existence of four types of cardiac arrhythmia. The first is supraventricular arrhythmia, which is characterized by fast beats rhythm taking place above the atrio-ventricular node in the heart.[1] Second, sinus arrhythmia may result in Bradycardia. This condition usually takes place during negative Gz-force (centrifuge braking). In such cases, the blood hardly reaches the brain.

The third type is ventricular arrhythmias. The occurrence is associated with the lower chambers (the ventricles) of the heart. [1] Finally, there is premature beats, which may be associated with either the atria or the ventricles. Premature beats are a mild form of arrhythmia, whose symptoms are not easily noticeable.[5]

Factors influencing g-force provoked arrhythmia

One of the factors that influence cardiac arrhythmia during centrifugal training is the magnitude of the $+G_{z.}$ Ewalina and Lech [7] performed a study in which they sought to determine hemodynamic changes resulting from centrifugal acceleration and the corresponding cardiovascular responses. The study revealed that an acceleration of $1G_z$can cause acute hemodynamic changes. The same magnitude of acceleration was found to be an activator of cardiovascular responses, arrhythmia being one of them.[7]

Anti-G straining maneuvers (AGSM) may influence g-force-provoked arrhythmia. Ewalina and Lech [7] point out that AGSM has a direct effect on the nervous system, which impacts on the heart's electrical properties. Such measures are seen as an attempt to reduce the effects of g-forces. They limit the impacts of $+G_z$ on the electrical characteristics of the heart.

Other factors include the health status of the subject and the duration of exposure. Latent cardiac medical histories give mixed results. Exposure durations increase the chances of cardiac arrhythmia, which further aggravates the severity of the conditions.

References

1. Rayman BR. Clinical aviation medicine. New York: Castle Connolly Graduate Medical Publishing; 2000.
2. Hanada R, Hisada T, Koichiro O. Arrythmias observed during high g-training: proposed safety training criterion. Aviation, Space, and Environmental Medicine. 2004; 75(8):689-91.
3. Whinnery EJ. The electrocardiographic response to high $+G_z$ centrifuge training. Aviation, Space, and Environmental Medicine. 1990; August:716-21.
4. Gan WH, Low R, Singh J. Aviation medicine: global historical perspectives and the development of aviation medicine alongside the growth of Singapore's aviation landscape. Singapore Med J. 2011; 52(5):324-329.
5. Blue SR, Riccitello MJ, Tizard J, Hamilton JR, Vanderploeg MJ. Commercial spaceflight participant G-force tolerance during centrifuge-simulated suborbital flight. Aviation, Space, and Environmental Medicine. 2012; 83(10):929-34.
6. Vettes B, Vieillefond H, Auffret R. Cardiovascular responses of man exposed to $+G_Z$ accelerations in a centrifuge. Aviation, Space, and Environmental Medicine. 1980; April:375-78.
7. Ewelina KZ, Lech HK. Cardiac arrhythmias during aerobatic flight and its simulation on a centrifuge. Aviation, Space, and Environmental Medicine. 2012; 82(6):599-691.
8. Whinnery JE, Hickman JR. Acceleration of asymptomatic aircrew with mitral valve prolapsed and significant $+G_Z$ induced ventricular dysrhythmias. Aviation, Space, and Environmental Medicine. 1988; 59:711-717.
9. Jeffrey RD, Johnson R, Stepanek J, Fogarty AJ. Fundamentals of aerospace medicine. Baltimore: Lippincot Williams & Wilkins; 2008.
10. Whinnery JE. Acceleration-induced ventricular tachycardia in asymptomatic men: relation to mitral valve prolapsed. Aviation, Space, and Environmental Medicine. 1983; 54(1):58-64.
11. Johnston R. Clinical aviation medicine: safe travel by air. Clin. Med. 2001;1:385-8.
12. Rayman RB, MD, MPH, DavMed, et al. Rayman's clinical aviation medicine. New York: Castle Connolly Graduate Medical Publishing; 2013.
13. Kennealy AJ, Kirland SJ, Sneider ER. Bradycardia induced by negative acceler-ation. Aviation, Space, and Environmental Medicine. 1976; 47(5):483-4.
14. Ewelina KZ, Lech HK. Centrifuge breaking effects on cardiac arrhythmias occurring at high $+G_z$ acceleration. Aviation, Space, and Environmental Medicine. 2004; 75:458-60.
15. Whinnery JE. Acceleration-induced atriov-entricular dissociation: hemodynamic consequences. Aviation, Space, and Envir-onmental Medicine. 1982;53(4):432-4.

16. Grossman A, Wand O, Harpaz D, Prokupetz A, Assa A. Acceleration forces and cardiac and aortic indexes in jet fighter pilots. Aviation, Space, and Environmental Medicine. 2011; 82:901-3.
17. Whinnery JE. Post-acceleration chaotic atrial rythm. Aviation, Space, and Environmental Medicine. 1982; 53(4):390-2.
18. Leverett DS, Burton RR. Physiological effect of high sustained $+G_z$ forces on man. Life Sci. Space Res. 1979;17:171-85.
19. Kopka L, Dabrowa R, Bojenko S. Relationship between the value of the Wenckebach point and $+G_z$ tolerance. Aviation, Space, and Environment Medicine. 1984; 55:607-70.
20. Gradwell D, Rainford JD. Ernsting's aviation medicine. Florida: CRC Press; 2006.