Artificial Gravity:
Neurovestibular Adaptation to Incremental Exposure to Centrifugation.

by

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Abstract

In order to counteract the debilitating effects of the space environment on the human body, short-radius intermittent centrifugation is investigated as a possible means to expose astronauts to artificial gravity. Whereas AG is efficient in providing stimuli for muscles, bones and cardiovascular system, short-radius centrifugation elicits discomfort and illusory sensations of motion if particular head movements are made while spinning. Past research has shown that human beings can adapt to these sensations and undergo various stimuli without the disturbing effects of motion sickness, sensations of tumbling and inappropriate eye movements. However, current protocols for adaptation basically consist in repeated exposure to the discomfort. This solution is not satisfactory because the drop-out rate oscillates between 30 and 50%. Since it is not acceptable to spend days of training on astronauts who, in the end, because of this training, could become unsuitable for flight, it is of primary importance to find a training protocol that achieves adaptation without going through permanent discomfort.

Incremental exposure to centrifugation is expected to be a compromised protocol to bring trainees to adaptive level without exposing them to maximum discomfort. Seven subjects were exposed to centrifugation during a five-day protocol, over which the speed of rotation was progressively increased. As in previous protocols of adaptation, subjects performed provocative head movements at all speeds. A control experiment had ten subjects exposed to centrifugation without making head turns, in order to verify to what extent the experimental conditions of measurement impact the subjects' behavior and reactions.

While subjects in the control experiment did not build up adaptation, all subjects in the experimental group who completed the protocol showed signs of adaptation to the stimulus. Only one subject did not complete the five sessions, setting the drop-out rate at about 14%. If this conclusion holds true with more subjects, then a better protocol of adaptation has been unveiled.

Thesis supervisor:	Laurence R. Young
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Last, but not least, all my love and thanks to my family, my parents and my brother for believing in me and supporting me *quoi qu'il arrive!* Thanks so much.

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O Investigator, do not flatter yourself that you know the things nature performs for herself, but rejoice in knowing the purpose of those things designed by your own mind. **Leonardo Da Vinci.**

Gravitation cannot be held responsible for people falling in love. **Albert Einstein.**

Gravity Of Love - Digital picture by Swedish artist **Rasmus Wängelin**. [http://artofrasmus.cjb.net]

Chapter 1

Introduction

1.1 The New Quest for the Next Frontier.

On January 14th, 2004, American President Georges W. Bush announced the new Vision for Space Exploration Program that will drive the National Aeronautics and Space Administration (NASA) for the decades to come. After completion of the International Space Station and retirement of the 30-year-old Shuttle fleet, both by 2010, the agency will draw its efforts to the return of human beings on the Moon, with the aim of building there a permanent research base, that could later become a virtual launch pad for missions to Mars and beyond. To travel to the Moon, and then to Mars, a new transportation system, the Crew Exploration Vehicle (CEV), will be designed. With the successes of the Mars Exploration Rovers missions (Spirit and Opportunity) led by NASA, and of the Mars Express orbiter sent by the European Space Agency (ESA), public attention has recently been more and more focused on the possibilities of a manned mission to the red planet. Debate is still vivid about the need for such an expensive mission whereas money could be spent in enhancing life down here, on Earth. But for the scientific community, there is no doubt space exploration must be accomplished, in order to answer crucial questions about ourselves: how life has emerged, how did our planet evolve, is there life somewhere else in the universe…? (Zubrin, 2003). Sending robots is just not enough to perform accurate and proficient science where clues can be found about our common past and future in the Universe. Human beings are creative, flexible and full of intuition, at the execution of tasks, far better than current robots are. Real time research is only possible with humans on the field: robotic exploration always suffers from time lags. Sending humans out there, in space, is also a formidable dream and stimulant for any science apprentice, and for national or international pride and cooperation.

In June 2004, for the first time in the history of astronautics, a privately built spacecraft has been launched into space. SpaceShipOne, developed by Scaled Composites and funded by Paul Allen's Vulcan Inc., rocketed to 62 miles of altitude (100 kilometers), into sub-orbital space. This flight opened the space frontier to private enterprise, and to the possibilities of affordable missions for launches in near-Earth space. With private companies expanding their capabilities in this area, government-funded space projects may be dedicated to further destinations.

Following the American successes and new impulses for space exploration, international enthusiasm has arisen. In 2003 already, China has become the third country to gain the capabilities to launch a manned vessel to space. Now, the Chinese are already planning to settle a base on the Moon and sending Mars missions for the next decades. The ESA, through its Aurora Program, is also envisaging a manned mission to Mars. Scientific and technological efforts are in progress all around the world, in order to achieve one of the most magnificent goals mankind could dream of: reaching another frontier. May this quest be peaceful and cooperative, and may it bring humanity as one.

"*My wish is that we would allow this planet to be the beautiful oasis that she is, and allow ourselves to live more in the peace that she generates.*"
Ronald E. McNair - NASA Astronaut.

Russian space pioneer Konstantin E. Tsiolkovsky famously said: "*Earth is the cradle of humanity but one cannot live in the cradle forever*". Earth as the cradle of life and mankind is the most beautiful jewel men and women all around the world should preserve, protect, respect and cherish. In a few billion years, the Sun will disappear in a cataclysmic explosion, absorbing in its core every entity of the solar system. The Earth and its inhabitants, if mankind has not disappeared before that, will be exterminated. In a human lifetime, billion years are eternity, and any person reading this will not experience this event. But our descent will. Therefore, may it be a question of exploration or of survival, time will come in humans' history to find a way to leave the cradle.

1.2 Considering Humans' Finitude.

Humans are not perfect. They are finite, and conditioned to live in a specific environment. One might wonder if the environment is responsible for what the human being is, or if the human being modifies its environment to its convenience. A combination of both is obviously the safe answer. The former is concordant with Darwin's evolution theory over a large time scale. The latter goes in favor of the humans’ will and power over their environment, in a lifetime scale: conscious of its finitude, human beings modify their way of living and their close environment in order to adapt it to them, and enhance their own life. But it remains the case that some environments are, so far, not understood or reachable enough to be modified. It is potentially the case for space and extra-terrestrial bodies. The point is that a combination of human adaptation to environment and environmental adaptation to humans will be necessary in space exploration. The trade-off is to be investigated carefully, in order both to preserve human life when swapping between environments, and to preserve the environment from potential human harmfulness.

1.3 Motivation and Rationale.

The motivation for the present research can be summed up in a 7-step rationale. (1) As emphasized in this introduction and by the space community in general, space exploration not only by robots and probes, but also by human beings themselves is both needed and unavoidable in the years, decades, centuries to come. (2) But extensive exposure to space environment is dangerous for humans. Past research and current data collection aboard the International Space Station show that a general deconditioning of the human body occurs due to the absence of gravity, in addition to all the external threats, such as vacuum or radiations. (3) Past and current research also proves that countermeasures exist to fight against the deconditioning: negative body pressure suits, fluid loading, medication, and so on. But none of them targets all physiological effects at once. Artificial gravity is investigated as a general countermeasure targeting the very cause of the deconditioning. (4) Two basic implementations of artificial gravity can be considered: large or short radius centrifugation. The former would either be a gigantic rotating spacecraft or two smaller tethered spacecrafts rotating around a common center. The latter, preferred in current studies, would feature short-radius centrifuges inside the spacecraft. Astronauts would then spend a few hours every day on them to be exposed to an artificial gravity field. (5) But the major drawback to short-radius centrifugation is that head movements performed while spinning elicit sensations of tumbling and general discomfort. (6) Among other, research in the Man-Vehicle Lab at MIT has proven that adaptation to these sensations is possible, and that discomfort can be considerably reduced to tolerable levels. (7) Now the question is: what is the best way to adapt?

Every step of this rationale is explained in details in Chapter 2.

Current protocols of adaptation to the discomfort resulting from head movements on a centrifuge include prolonged exposure to this discomfort so that the body naturally reacts in order not to suffer indefinitely. The advantage is that if astronauts get adapted before flying, then they won't suffer up in space. The major disadvantage of this solution is the drop-out rate: about 30 to 50% of the subjects cannot stand prolonged exposure to this discomfort (Sienko, 2000; Lyne, 2000; Brown, 2002; Newby, 2002). Thus, it is fair to wonder if adaptation could be reached without going through all this discomfort.

For example, progressive exposure to centrifugation, and therefore to the discomfort, may still achieve adaptation while reducing the drop-out rate.

1.4 Hypothesis.

Subjects exposed to centrifugation at incrementally growing rotational speeds will adapt to motion sickness and illusory sensations with less discomfort than in previous full-speed exposure protocols (Sienko, 2000; Brown, 2002). Adaptation will be measured by the reduction in motion sickness scores, in intensity of sensation scores, in illusory body tilt perception and in inappropriate compensatory eye movements, between pre- and post-adaptation phases. The experimental group will be exposed daily to centrifugation at constant speed, but the speed will increase over the days to finally reach the maximum desired speed of 23 rpm. During these exposures, subjects will perform head movements to build up adaptation.

In addition, a control experiment will be implemented: subjects will be exposed to the maximum speed of rotation, but will not perform head movements, so as to verify to what extent the experimental conditions of measurement impact the subjects' behavior and reactions.

It is expected that subjects in the experimental group will build up adaptation without suffering too much from the discomfort: we expect the drop-out rate to be lower than 30%. It is also expected that subjects in the control experiment will build up no or significantly less adaptation than subjects in the experimental group, showing both that head movements are the source of adaptation and that our measurement protocol does not distort the experiment.

1.5 Thesis Organization.

Chapter 1 - Introduction. This chapter was aimed at giving a broad view of the context in which this research was performed.

Chapter 2 - Background. This chapter will provide general background information on all the elements discussed in the Rationale (Section 1.3).

Chapter 3 - Methods. This chapter will explain in details the experimental design of this study, and describe the equipment used, the subject selection process, the measurements made and the technical protocol of experimentation.

Chapter 4 - Data Analysis. This chapter will describe how the data was analyzed.

Chapter 5 - Results. This chapter will expose the results of this study.

Chapter 6 - Discussion. This chapter will discuss the results of Chapter 5, and their significance with regard to other research. Implications of the results will be considered, as well as the incumbent limitations of this work. Recommendations for future work will also be addressed.

Chapter 7 - Conclusions. This chapter will summarize the key findings of this study, and present concluding remarks for this research.

Chapter 2

Background

2.1 Step 1: The Need to Send Humans to Space.

As stated in the Introduction, space exploration will not happen without human beings sent to extraterrestrial destinations.

First of all, and most important, men and women are endowed with flexibility and adaptability qualities virtually unachievable by robots or robotic missions as we know them (Larson and Giffen, 2004). Humans are able to imagine solutions and behaviors in a manner hardly implementable to machines. In some areas, human capabilities extend far beyond the technology currently achievable. For example, pattern recognition of geological activity, in situ experiments and sample findings are areas of performance where humans excel. Humans are also able to make unanticipated decisions, whereas robots have to be programmed for decision-making processes. The rapidity of action of humans and their possibility of self decision-making would be invaluable when time lags separate the crew from the ground-based operative center. Finally, sending humans to deep zones of our knowledge is also a formidable source of motivation for the actual science community, but also for scientists-to-be. Zubrin (2003) explained before the American Congress that "nations, like people, thrive on challenges and decay without it". Such a human challenge would be a major, powerful message to the youth, to regain attention to sciences and cooperative endeavors. International partnerships would be ineluctable, contributing to a better, cordial friendship between participating countries, as it happened after the cold war between the United States and Russia.

But this dream has its drawbacks. Wertz and Larson (2004) explained that human exploration impacts mission design's complexity on four major issues: 1) safety and reliability (survivability of the crew becomes the first concern), 2) pressurized structures and dedicated subsystems (to allow for life support and environmental protection), 3) human factors (sociology, psychology, physiology, comfort and productivity issues must be addressed with more emphasis), 4) logistics (life support systems may need "re-supply" of vital needs, and more maintenance and repair operation may be foreseen). The following paragraphs expose the dangers of the space environment, related to these four categories.

2.2 Step 2: Review of the Effects of Space Environment.

2.2.1 External factors.

2.2.1.1 Vacuum.

Because of space vacuum, spacecrafts and spacesuits may have to be operated at reduced pressure, in order to diminish the overall structural loading. The major risk of such an implementation is decompression sickness and air embolism, phenomena very similar to that of scuba diving (Parker and West, 1973). Current research on spacesuits is aimed at balancing the need for maneuverable devices, to limit the fatigue while using it, with the requirements of stiffness linked to the inside air pressure (Jones and Schmitt, 1992; Newman and Barratt, 1997; Pitts, 2003).

2.2.1.2 Radiations.

Radiation threats include high energy particles, photons and short-wave electromagnetic radiations. These particles can infiltrate humans and the spacecraft's material and structure, leading to a decrease in performance and strength. Looking at all components of the mission, the lowest radiation damage threshold is for living tissues (humans and animals), in the order on

0.1 to 1 Gy (Gy = gray = J/kg). In order of comparison, glasses and ceramic are damaged between 10^4 and 10^6 Gy, and metals between 10^7 and 10^9 Gy (Tribble, 2004). Exposition to such sources may result in acute radiation syndrome, or even cancers. Therefore, spacecraft design must include specific shielding against radiations, more resistant than for the structure itself. High energy particles protection has been demonstrated to be effective for most of them, even though some solar flares might still get through (Ohnishi et al., 2001).

2.2.2 Psychological Isolation and Social Issues.

Psychological issues in an extreme environment can be classified into three types: cognitive, affective and behavioral responses to long-duration space missions (Shaw and Hackney, 1989).

The main effect of long-duration spaceflights on cognitive responses is related to modifications of spatial perception. Illusory sensations (like overturning, inversion of the body, disorientation, movements of objects in the visual field), and time compression phenomena (altered sense of time) occur, and are probably due to high mental workload and interfering cognitive processes (Christenson and Talbot, 1986).

During Russian missions aboard MIR, the affective response was characterized by increased levels of anxiety, of boredom, of irritability, of hostility, and of anger (Santy, 1983). This appeared to be closely linked to the length of mission, since frequency and intensity of psychologically negative events increased with mission duration. Such affective issues can compromise the mission and astronauts' safety in case of interpersonal conflicts both within the crew and between the crew and ground control.

Behavioral responses include increased fatigue and states of lethargy, directly correlated with the affective states (Shaw and Hackney, 1989), decreased motivation, inappropriate psychosocial interactions (Santy, 1983).

Sleep / wake cycle disturbances and sleeping disorders are the major consequences of the modification of global behavioral responses of astronauts in space.

These last two psychological issues can be grouped as psychological isolation problems, and have been well documented in the past decade. Psychological isolation and inter-crew social problems have been noted in the Shuttle/Mir missions (Kanas et al., 2002), although astronauts' selection include the screening of about thirty specific psychological traits aimed at reducing these risks (Santy, 1994). Whereas very few experiments have been planned so far (Tomi et al., 2001), training in space analogs (Brubakk, 2000; Stuster, 2000; Dator, 2003) may help astronauts in areas such as interpersonal tension management, crew cohesion, leadership roles, or enhanced connection with the outer world (Kanas et al., 2001).

2.2.3 Physiological Effects.

2.2.3.1 The Immune System.

Immunological modifications during spaceflight are mainly cell-mediated immune responses: leukocyte proliferation, cytokine production, and leukocyte subset distribution have been noted. But both the causes and consequences of these modifications still have to be established (Sonnenfeld, 2002; Sonnenfeld and Shearer, 2003). Sonnenfeld proposed that a combination of exposure to microgravity, to stress, and to radiations might intervene and interact in the biomedical mechanism that affects the immune system.

2.2.3.2 The Cardio-Vascular System.

Figure 2.1 shows a diagram of the postulated mechanism of cardio-vascular deconditioning.

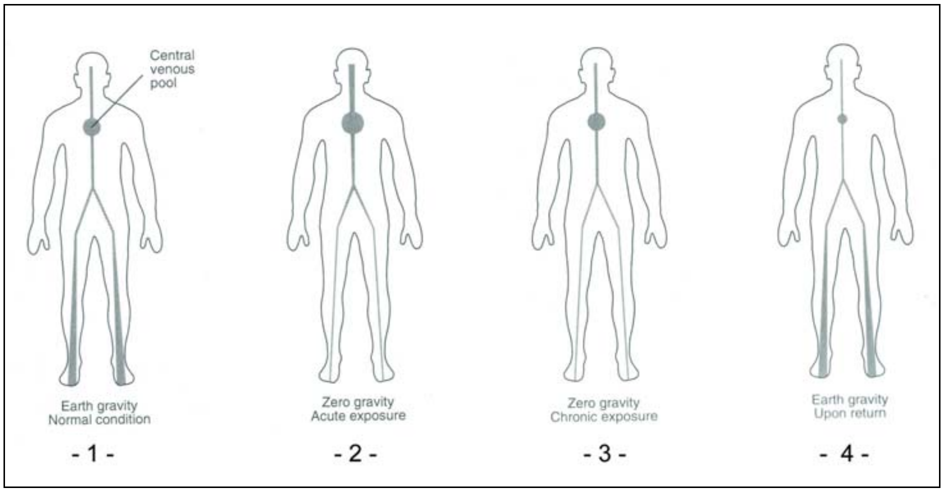


Figure 2.1. Changes in the cardio-vascular system in response
to changes of gravity load (Howard, 1982).

In Earth gravity (-1-), most of the activity and blood presence is located at heart level and in lower limbs. When in weightlessness (-2-), the absence of gravity elicits a fluid shift toward the upper body, increasing the cardio-vascular activity at heart level, in the chest and in the head (hence the facial "puffiness" of astronauts), and decreasing the activity and quantity of blood in the legs and lower body. After less than a week in a zero gravity environment, the body adapts to this condition by eliminating the surplus of blood and body fluids in the upper body (-3-): the renal system activates the processes of diuresis and fluid shedding, in order to get rid of the apparent excess of fluid in the upper body, so as to return to homeostasis. This also leads to the destruction of blood cells. So far, this adaptation is perfectly understandable and logical with regard to the novel environment. This adaptation is not a threat in zero gravity. It becomes one upon re-entry in a gravity field. The effect of gravity is to pull down body fluid to the lower body and the legs, thus decreasing the quantity available at heart level and in the upper body, to a level below what it was before launch (-4-). This situation is dangerous because the lack of a fully capable cardio-vascular system can lead to heart disease and strokes.

2.2.3.3 The Musculo-Skeletal System.

Muscles.

The influence of microgravity on the musculo-skeletal system is asymmetric. As the astronaut is floating in the air, he/she will use his/her upper limbs to navigate in weightlessness, and not the lower limbs. This leads to a maintaining of the upper body muscle activity, but an atrophy in the lower body. There, oxidative slow twitch fibers disappear to the profit of glycolytic fast twitch fibers. The former provide endurance and long-duration posture control; the latter, precision control and short bursts of strength. Muscle fibers basically maintain balance between oxidative, glycolytic, and contractile enzyme activities (Lieber, 1992). Since the body is no longer subject to hydrostatic gradients, a down-regulation of baroreceptors occurs, leading to an atrophy of cardiac muscles. It has been estimated that the reduction in muscle strength of astronauts upon return after one week missions lies between 10% and 40%, and between 20% and 30% for muscle atrophy (Newman, 2003).

Bones.

The absence of load on the skeletal structure leads to a decrease in bone mineral density (BMD), via the imbalance between osteoblasts and osteoclasts activities: bone growth is slowed down because of the reduction in proliferation and activity of osteoblasts. As a result of demineralization, calcium excretion increases in weightlessness, worsening the negative balance. On MIR station, bone loss was quantified as a reduction of 1% to 2% in BMD in a month (Newman, 2003). This is equivalent to ten years of normal aging on Earth, and implies a reduction of bone strength, hence an increase in the risk of fracture, which would be catastrophic if happening on Mars, for example.

2.2.3.4 The Neuro-Vestibular System.

Space motion sickness is the most visible effect of the impact of the absence of gravity on the neuro-vestibular system (Berry, 1970). The otolith organs (see Section 2.5.1.1) in charge of the detection of the difference ($\vec{f} = \vec{g} - \vec{a}$) of gravity ($\vec{g}$) and linear accelerations ($\vec{a}$) are perturbed. It is assumed that the vestibular system infers $\vec{a}$ by subtracting $\vec{f}$ from $\vec{g}$ (Merfeld et al., 2004). In weightlessness, there is no $\vec{g}$, therefore, the vestibular system mis-estimates linear accelerations by a constant component. In the central nervous system, this elicits a conflict between the expected linear acceleration (based on vision, knowledge of conditions…) and the detected linear acceleration (Oman, 1988; Oman, 2003). This is called the Sensory Conflict Theory, and is at the origin of the motion sickness 75% of astronauts suffer from. Because of this lack of cues to maintain balance and motor control, vision becomes a preponderant signal, and otoliths' signals are interpreted as pure linear acceleration. Space adaptation of the neuro-vestibular system is basically the result of its desensitization to certain signals (Lathan and Clément, 1997; Young and Sinha, 1998).

2.2.3.5 Implications.

All these physiological changes are aimed at appropriately adjusting the human body to its novel environment. But, while being bearable and useful in weightlessness, they will induce series of problems upon return in a gravitational field, because of their being inconsistent with the environment. In the case of a Martian landing, immediate medical assistance and facilities will not be available to cope with these problems. Furthermore, after long-duration exposure to weightlessness, the possibilities and conditions of re-adaptation are not well known.

Therefore, any long-duration space mission will have to provide astronauts with countermeasure devices and processes, to maintain their physiological capabilities.

2.3 Step 3: Past and Current Countermeasures.

Current countermeasures to fluid redistribution, cardiac and skeletal deconditioning, and loss of BMD include 1 or 2 hours of daily aerobic and resistance exercise, with treadmills and cycling machines. However, such exercises provoke hull vibrational stress on the spacecraft/station structure, and contaminate the cabin with sweat droplets (Czarnik, 1999). These kinds of exercises are efficient for counteracting muscle atrophy and, to a certain point, bone loss, but remains non-sufficient for cardio-vascular deconditioning. To solve this problem, the use of lower body negative pressure has been combined with classic exercising, but leading to mixed results on Earth-based tests (Zhang, 2001).

Exercising is also envisioned as a countermeasure for psychological problems: it has been shown to enhance affective and behavioral states (post exercise Profile of Mood States showed better scores). The sensation of well-being that occurs after an important exercising activity may be used as a tool to induce positive affective states to crewmembers (Shaw and Hackney, 1989).

2.4 Step 4: Artificial Gravity as a Global Countermeasure.

Despite their effectiveness, existing countermeasures only result in partial reconditioning or maintaining, in the sense that each solution targets a specific problem, but none is able to address all the debilitating effects at the same time.

An optimal countermeasure would address the very cause of the deconditioning, that is the absence of gravity. Re-creating gravity in a spacecraft may be enabled by the use of centripetal acceleration of a rotating environment.

Artificial gravity would then respond to all the physiological problems, as an integrated countermeasure (Young, 1999).

In 1911, Tsiolkovsky first imagined the potential that artificial gravity could bring; in 1927, Hermann Noordung studied the engineering feasibility of an "artificial-gravity station"; and in 1952, Werner Von Braun started his rotating station project (Figure 2.2).

The concept of a large rotating spacecraft as a rotating torus was often presented in the domain of science-fiction (Figure 2.3). However the cost of launch of all elements, and the cost and planning of in-space assembly are still insurmountable obstacles, preventing this solution from being yet demonstrated.

Figure 2.2.
Werner Von Braun's concept
of rotating station.
(Source: http://grin.hq.nasa.gov)

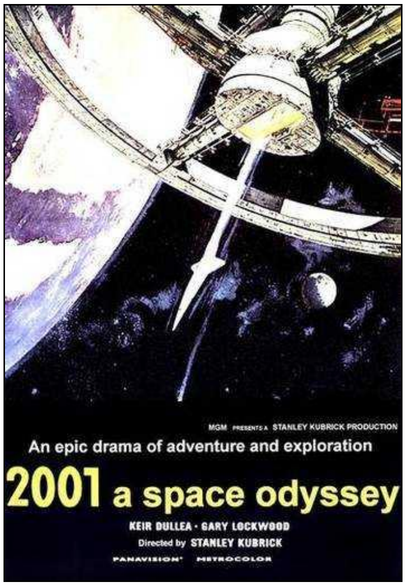


Figure 2.3.
2001 A Space Odyssey, movie poster.
(Source: http://en.wikipedia.org/wiki/Image:2001_movie_poster.jpg)

Another solution would be the tethered spacecraft: a "rope" holding together two separate elements rotating with respect to each other, around a common center of gravity (Figure 2.4). This solution reduces the mass (hence the cost of launch) and allows for very long radii (thus slow rotational rates, minimizing Coriolis forces and gravity gradients). Major problems would occur in case of rupture of the tether, like in the 1996 TSS-1R and 1994 SEDS-2 missions: in addition to the lost of artificial gravity, the mission can be compromised because modules would be ejected outward. The first test of tethered spacecrafts was done in 1966 when Richard F. Gordon and Peter Conrad successfully created the first artificial microgravity system by linking a tethered Agena module to their Gemini capsule (Figures 2.5 and 2.6). The tethered spacecraft was moved into slow rotation in space.

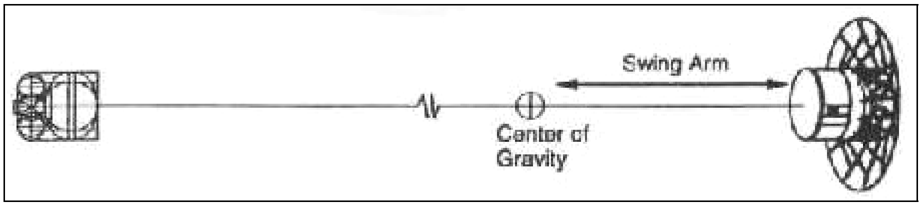
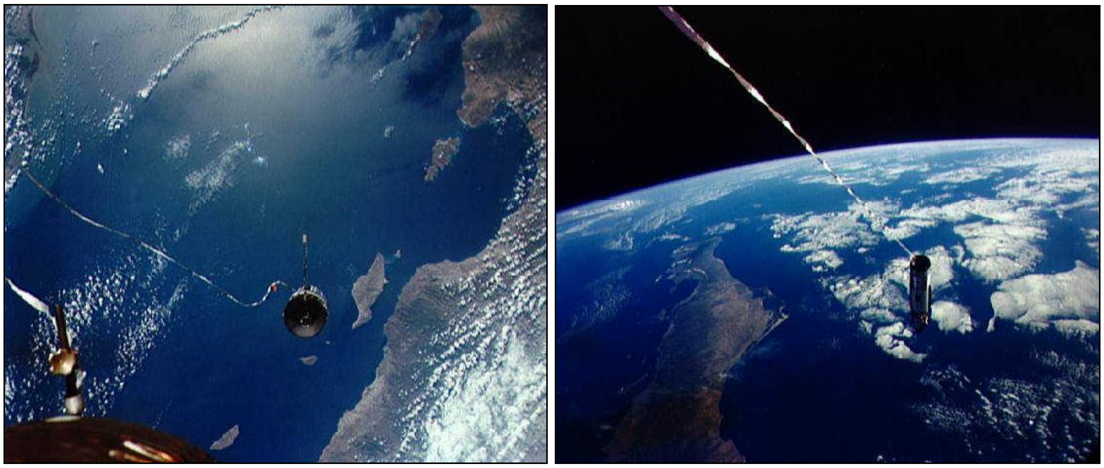


Figure 2.4. Concept of tethered spacecrafts (Czarnik, 1999).



Figures 2.5 and 2.6. Views of the tethered Agena (Gemini 11 Mission).
(source: http://www.astronautix.com/flights/gemini11.htm)

Either consisting of a torus or a tethered vehicle, the spacecraft would be rotating at a low angular velocity in order to produce the required gravity at its rim. In this case, the gradient of gravity (difference of gravity between the head and the feet of the astronaut) would affect human performance: in order to minimize the discomfort of the gravity gradient, the radius should stand between 15.2 and 16.8 meters, in order to provide speeds of rotation under 6 rpm (Stone, 1970; Stone, 1973).

The main advantage for large rotating spacecraft is that no exercise is needed, thus saving precious time for astronauts; and no hazardous material would be floating inside the cabin (Czarnik, 1999). So far, NASA has not ruled out the hypothesis of a rotating spacecraft for the Crew Exploration Vehicle (CEV), even though priority is given to short-radius centrifuges (SRC).

SRC would be used on a regular basis as an intermittent countermeasure to weightlessness, just like any other exercise device (Figures 2.7 and 2.8).

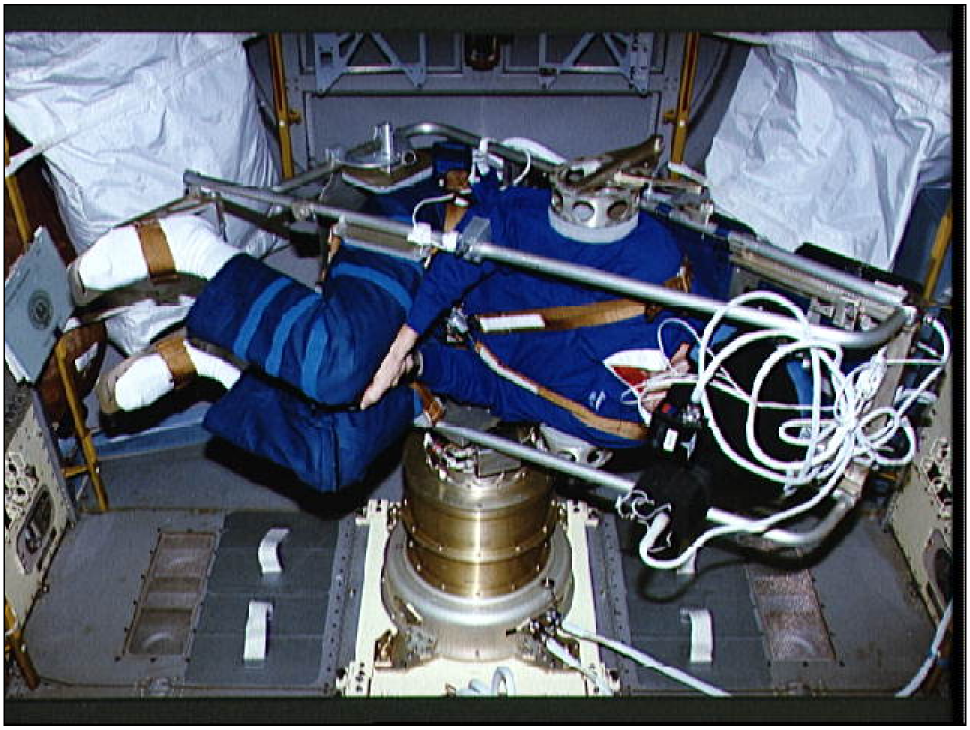


Figure 2.7. STS-42 Mission Specialist Hilmers in IML-1's MVI rotator chair.
(Source: http://images.jsc.nasa.gov)

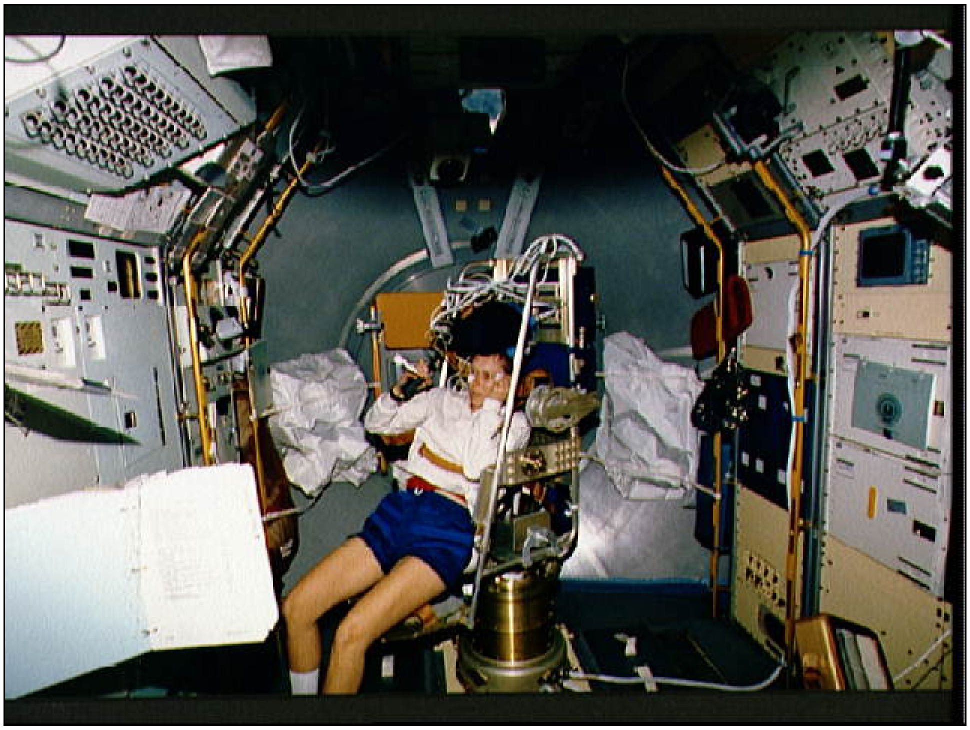


Figure 2.8. STS-42 Payload Specialist Bondar in IML-1's MVI rotator chair.
(Source: http://images.jsc.nasa.gov)

Short-radius centrifugation stimulates efficiently the baroreceptors, which can help reduce orthostatic intolerance upon return on the ground (Burton and Mecker, 1992). Onboard centrifugation of animals on Kosmos-782 in 1975 proved that 1g for 24 hours is sufficient to stop the overall deconditioning (Shipov, 1975). But SRC still suffers from the problem of gravity gradients. The gravity gradient is inversely proportional to the radius of centrifugation, hence short radius means huge gravity gradients, which might affect the cardio-vascular system. However, further studies are needed to better characterize the influence of gravity gradients on physiological systems. In any case, it would be probably bearable since SRC is not a permanent exposure. A second major problem is the impact of SRC on the neurovestibular system. Due to the nature of the vestibular system in the inner ear and to the stimuli given by centrifugation, illusory sensations and motion sickness are elicited when the vestibular system is moved with respect to the planes of rotation. Vestibular functions can disturb an astronaut's ability to perform assigned tasks, and decrease efficiency (Young, 2000).

2.5 Step 5: Why Do Humans Experience Discomfort on a Centrifuge?

Because of busy schedules, it is then not conceivable to force the astronauts to stay motionless on a bed during short radius centrifugation. These periods would better be used by astronauts to do emails, to read, to talk to their families *via* videophone, to exercise, even maybe to sleep. Such activities require certain degrees of freedom of the body and the head, which will probably not be totally restrained. Subsequent paragraphs investigate the problems engendered by head movements in these conditions. In order to understand the phenomena, the related background on vestibular physiology is first exposed.

2.5.1 Vestibular Physiology.

[note: references for this section are Young, 1983; Young, 2003a and 2003b; Oman, 1988; Oman, 2003; Guedry and Benson, 1978]

The vestibular system is a physiological structure that allows for self-motion perception: it sends information to the brain about the relative movement of its organs so that the brain interprets this information and translates it into motion data. The vestibular system is located in the inner ear (one set of it for each ear). Figure 2.9 shows the relative location of the vestibular organs in the inner ear.

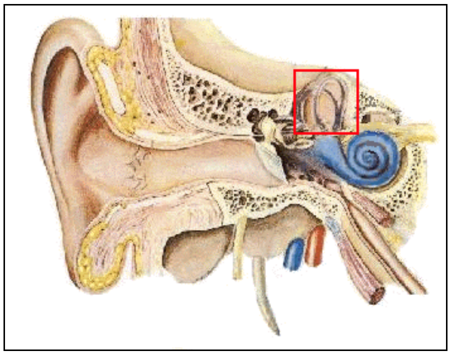


Figure 2.9. Location of the vestibular system in the inner ear.
Illustration taken from McGill Faculty of Medicine website.

The vestibular system consists of two types of motion sensors: the otolith organs (saccule and utricle) which are sensitive to linear accelerations and gravity; and three semi-circular canals (anterior, posterior and lateral canals) which are sensitive to angular acceleration.

2.5.1.1 The Otolith Organs.

The otolith organs are sensitive to linear acceleration and gravity. Each organ (saccule or utricle) consists of a macular plane composed of hair cells projecting into a gelatinous membrane. In its top layer are small calcium carbonate aggregates or otoconia (similar to little stones, hence the name otolith: *oto* = ear, *lith* = stone). In the presence of linear acceleration and/or gravity, the otoconial membrane moves in the endolymph, thus moving the otoconia, activating the hair cells in the direction of the sum of these forces.

In the case of centrifugation, with head at the center of rotation, otoliths should not be stimulated, apart from the natural gravity if centrifugation is operated on Earth.

The accepted mathematical model for the otoliths organs is to consider the otoconia as seismic masses, with linear spring restoring forces due to the macula, and inertial drag due to the surrounding endolymph (see Wilson and Melvill-Jones, 1979, for a complete description of the underlying mathematical model).

2.5.1.2 The Semi-Circular Canals.

The semi-circular canals can be considered as angular accelerometers: they provide both the magnitude and direction of the rotation(s) they undergo, in a three dimensional space. They are almost perpendicular to each other: each semi-circular canal is dedicated to a specific axis of rotation. The canal is lying in the plane which is orthogonal to the axis considered. A canal is “activated” when a rotation around its corresponding axis occurs. See Figure 2.10

for a representation of the axis and the frame of reference (x forward, y to the left and z up).

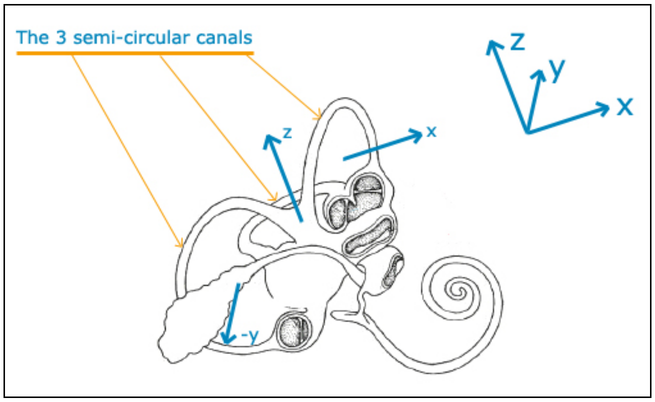


Figure 2.10. Orientation of the semi-circular canals.
Illustration adapted from a drawing from Queen Mary University of London.

The activation of the canals comes from the relative motion between the canal itself and the viscous liquid (called endolymph) it contains. When the canal is rotating around its corresponding axis, the endolymph does not move immediately with respect to the outside frame, because of its inertia. Thus, it implies a relative movement of the endolymph with respect to the canal, but in the other sense of rotation, as if the fluid were rotating inside the canal. Each canal is interrupted by an ampula that contains a thin membrane (the cupula) which supports the pressure of the moving endolymph, and prevents it from circulating freely inside the canal. The vestibular hair cells inside the cupula react to the pressure of the fluid on the cupula and send the information to the brain. See Figure 2.11 for a representation of the mechanism.

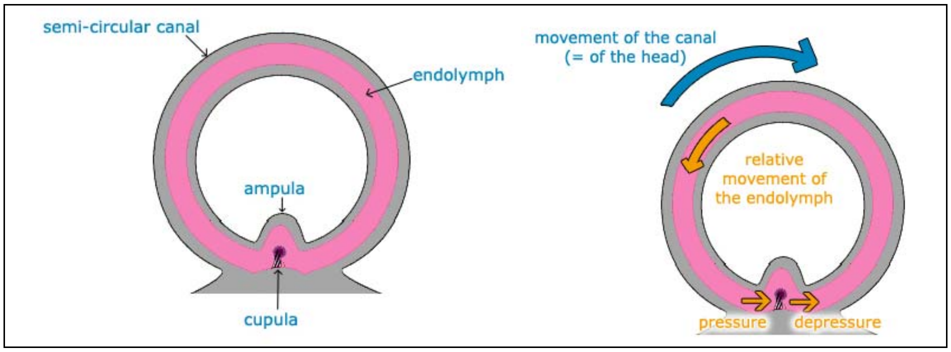


Figure 2.11. Mechanism of detection of self-motion.

Illustration adapted from a drawing from Queen Mary University of London.

The deflection of the cupula by the endolymph results in the transmission of afferent signals successively to the vestibular nuclei, the cerebellum, the ocular-motor nuclei, and finally the cerebral cortex.

If the rotation lasts more than twenty seconds, the effect of inertia stops, and the endolymph starts rotating with the canal. The hair cells are not stimulated anymore and their firing rate goes back to normal. If the constant velocity rotation stops, the same initial phenomenon due to the inertia of the endolymph happens: the hair cells detect an illusory rotation in the reverse direction.

2.5.2 The Physics of Head Turns in a Rotating Environment.

2.5.2.1 Cross-Coupled (Coriolis) Acceleration.

Let suppose that a human being is on a centrifuge, rotating about an axis A_c, with an angular velocity $\vec{\omega}_c$. In addition, his/her head is rotating about another axis A_h, with an angular velocity $\vec{\omega}_h$. This situation generates, for the time of the head rotation (usually about one second), an additional angular acceleration about an axis A_{cc} which is orthogonal to both A_c and A_h. The corresponding angular velocity emerges from the cross-product of $\vec{\omega}_c$ and $\vec{\omega}_h$:

$$\vec{\omega}_{cc} = -\vec{\omega}_c \times \vec{\omega}_h \qquad \text{(eq. 0)}$$

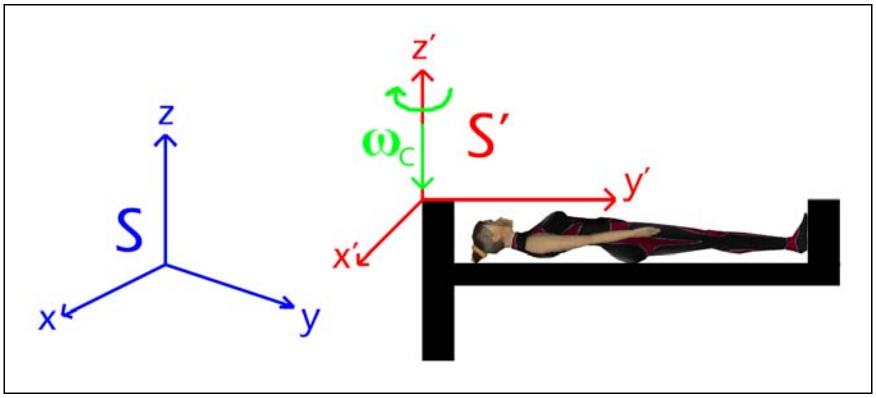


Figure 2.12. Subject lying supine NU on a centrifuge.

Let's define the two frames of reference (see Figure 2.12):

$(S;\vec{x},\vec{y},\vec{z})$ is attached to Earth. $(S';\vec{x}',\vec{y}',\vec{z}')$ is attached to the centrifuge. Suppose the centrifuge is rotating clockwise. Therefore, $\vec{\omega}_c$ is pointing "down":

$$\vec{\omega}_c = -\omega_c.\vec{z}'$$

Let's use the rotation operator that transforms a vector from one frame of reference (S) into another frame of reference (S'):

$$(d./dt)_S = (d./dt)_{S'} + \vec{\omega}_{S'/S} \times . \qquad \text{(eq. 1)}$$

Let's apply this to a vector ($\overrightarrow{position}$) describing the position in the rotating frame of reference S'. We obtain:

$$\left(d\,\overrightarrow{position}/dt\right)_S = \left(d\,\overrightarrow{position}/dt\right)_{S'} + \vec{\omega}_{S'/S} \times \overrightarrow{position}$$

which is equivalent to:

$$\overrightarrow{velocity}_S = \overrightarrow{velocity}_{S'} + \vec{\omega}_c \times \overrightarrow{position} \qquad \text{(eq. 2)}$$

Now, let's apply the left side of eq. 1 to the left side of eq. 2 and the right side of eq. 1 to the right side of eq. 2. We obtain:

$$\begin{aligned}\overrightarrow{acceleration}_S &= \overrightarrow{acceleration}_{S'} + \vec{\omega}_c \times \overrightarrow{velocity}_{S'} \\ &\quad + \left[d\left(\vec{\omega}_c \times \overrightarrow{position}\right)/dt\right]_{S'} + \vec{\omega}_c \times \left(\vec{\omega}_c \times \overrightarrow{position}\right)\end{aligned} \qquad \text{(eq. 3)}$$

Which is also:

$$\begin{aligned}\overrightarrow{acceleration}_S &= \overrightarrow{acceleration}_{S'} + \vec{\omega}_c \times \overrightarrow{velocity}_{S'} \\ &\quad + \vec{\omega}_c \times \overrightarrow{velocity}_{S'} + \vec{\omega}_c \times \left(\vec{\omega}_c \times \overrightarrow{position}\right)\end{aligned} \qquad \text{(eq. 4)}$$

Also written:

$$\boxed{\overrightarrow{acceleration}_{S'} = \overrightarrow{acceleration}_{S} - 2.\vec{\omega}_c \times \overrightarrow{velocity}_{S'} - \vec{\omega}_c \times \left(\vec{\omega}_c \times \overrightarrow{position}\right)}$$

(eq. 5)

Equation 5 is the general expression for the Theorem of Coriolis. It describes linear acceleration in a rotating environment. The term $-2.\vec{\omega}_c \times \overrightarrow{velocity}_{S'}$ is the Coriolis acceleration and the term $-\vec{\omega}_c \times \left(\vec{\omega}_c \times \overrightarrow{position}\right)$ is the centrifugal force.

French and Ebison (1986) extended this expression to angular accelerations. The general expression for angular accelerations in a rotating environment is:

$$\vec{\alpha}_h{}' = \vec{\alpha}_h - 2.\vec{\omega}_c \times \vec{\omega}_h{}' - \vec{\omega}_c \times \left(\vec{\omega}_c \times \vec{\omega}_h\right) \qquad \text{(eq. 6)}$$

where $\vec{\alpha}_h$ represents an angular acceleration of the head in S, $\vec{\alpha}_h{}'$ represents the same angular acceleration of the head in S', $\vec{\omega}_h$ represents the head velocity in S and $\vec{\omega}_h{}'$ represents the head velocity in S'.

The term $-2.\vec{\omega}_c \times \vec{\omega}_h{}'$ is the cross-coupling acceleration term, and is dominant in the expression.

Lyne (2000) summed up the consequences on the canals. In the case of a head turn from RED (Right-Ear-Down) position to NU (Nose-Up) position, the pitch canal is being stimulated from rest by the cross-coupled acceleration. The stimulation can be modeled as a sinusoidal function (because the orientation of the canal changes with regard to the axis of rotation), with a maximum amplitude of $\omega_c.\omega_h$. Thus, the acceleration acting on the pitch canal during a yaw head turn is: $\omega_c.\omega_h.\sin(\omega_h.t)$ (where ω_h depends on time *t*). With a similar rationale, the roll canal is stimulated by a cross-coupled acceleration modeled as $\omega_c.\omega_h.\cos(\omega_h.t)$. The yaw canal stays at rest during a yaw head turn on the centrifuge.

A hypothesis for the use of the sine and cosine functions is their periodicity. At the beginning of the head turn ($t = 0$), the pitch canal gets no stimulation from the centrifuge rotation, but the roll canal gets a stimulation. At the end of a 90° head turn, the pitch canal is stimulated by the centrifuge rotation, whereas the roll canal is not anymore. The sine and cosine functions assure continuity of the stimuli.

2.5.2.2 Canals In/Out of Plane Effect.

This effect emerges from the loss of inertia of the endolymph. When a rotation is sustained in time, after a period of about 20 seconds, the endolymph starts rotating with the canals. Therefore, subject to its elastic restoring force, the cupula returns to its neutral position. If the result of a head movement is a change in the orientation of the plane of the canal with respect to the initial rotation, then the endolymph in the canal will undergo an angular acceleration corresponding to the initial angular acceleration (that of the centrifuge).

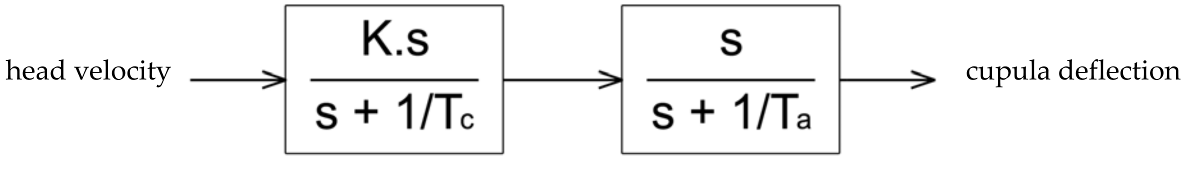
Whereas in a stable situation, head turns cause the canals to follow the profile of angular velocity (acceleration and then deceleration, characteristics of a normal head turn), in a rotating environment, the canals do not. The cupula decay (about 6 seconds) leads to a misrepresentation of $\vec{\omega}$, and thus a perception of self-motion.

Let's go back to the example of the subject lying supine with head at the center of rotation, in the NU position (see Figure 2.12). In this position, the roll canal is stimulated during the rotation, which gives the normal perception of rotation (because the subject knows he/she is lying on his/her back: proprioceptive channel). After a certain period of time (around 20 seconds), the roll canal response declines to zero: the subject feels no motion (which is a false perception). If a head turn RED is made, then two canals are involved: the roll canal goes out of the plane of rotation and the pitch canal goes in the plane of rotation.

The roll canal experiences the change in angular velocity because of the "counter-reaction" of the endolymph stopping its rotation in phase with the canal, and decelerating in the clockwise direction, giving the sensation of a roll to the right. The sensation perceived is strong because only the deceleration phase is present here, not the acceleration that would occur in a stationary environment.

The pitch canal experiences the reverse effect: an acceleration because of the stimulation of the centrifuge rotation. This leads to the perception of pitching backwards (forwards in the case of a Left-Ear-Down head turn).

These effects can be modeled with a block diagram. For example, a modified Young-Oman transfer function model (Young and Oman, 1969) can help visualize the dynamics of the cupula (and thus of the endolymph) and the influence of adaptation of the system (refer to Young and Oman, 1969, for more details).



The first block models the dynamics of the canals (e.g. simple gain K = 1, time constant Tc = 6 seconds); the second block models the neural adaptation (time constant Ta >> Tc, e.g. Ta = 80 seconds). The following graphs were plotted for these values (Lyne, 2000).

Figure 2.13 shows the velocity profile of the roll canal. Initially in the plane of rotation, it goes out of it, thus undergoing a velocity change of 23 rpm in one second (thin line). The response of the cupula (its deflection) is immediate (endolymph motion implies cupula deflection), and then goes back to rest at the neutral position (in about 10 seconds): it does not follow the velocity profile.

Figure 2.14 shows the velocity profile of the pitch canal. Initially out the plane of rotation, it goes in it, thus undergoing a velocity change of 23 rpm in one second (thin line), in the other direction compared to the roll canal. The deflection of the cupula is immediate and then goes back to rest at the neutral position (in about 20 seconds): it does not follow the velocity profile.

Figure 2.15 shows the velocity profile of the yaw canal. Its velocity profile (thin line) corresponds to the normal head turn that would occur in a stationary environment (acceleration and deceleration in one second). The response of the cupula follows the velocity profile and then goes back to rest at the neutral position (in about 6 seconds).

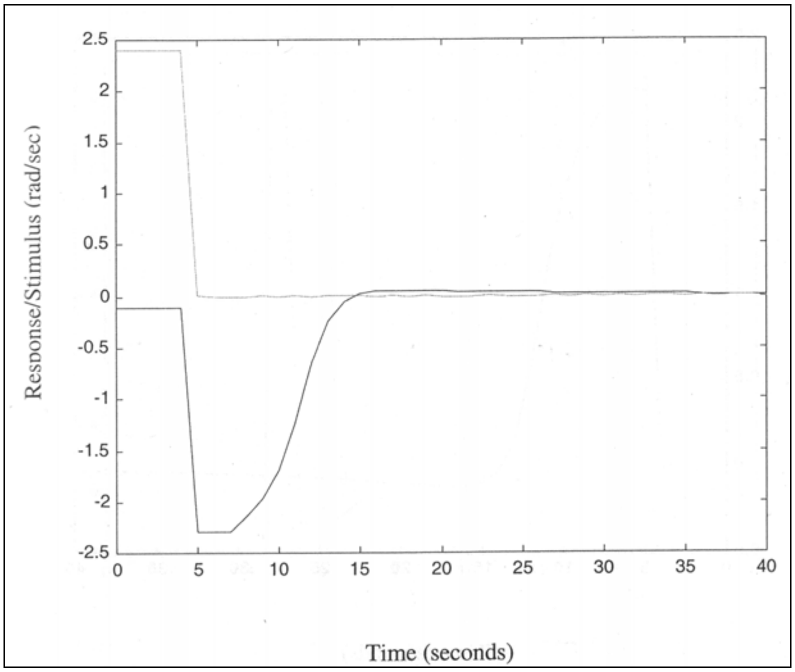


Figure 2.13. Cupula deflection in the roll canal (for a velocity change of 23rpm in 1 second) represented by the tick line. The thin line shows the velocity profile.
(note that the saturation is an artefact of simulation)

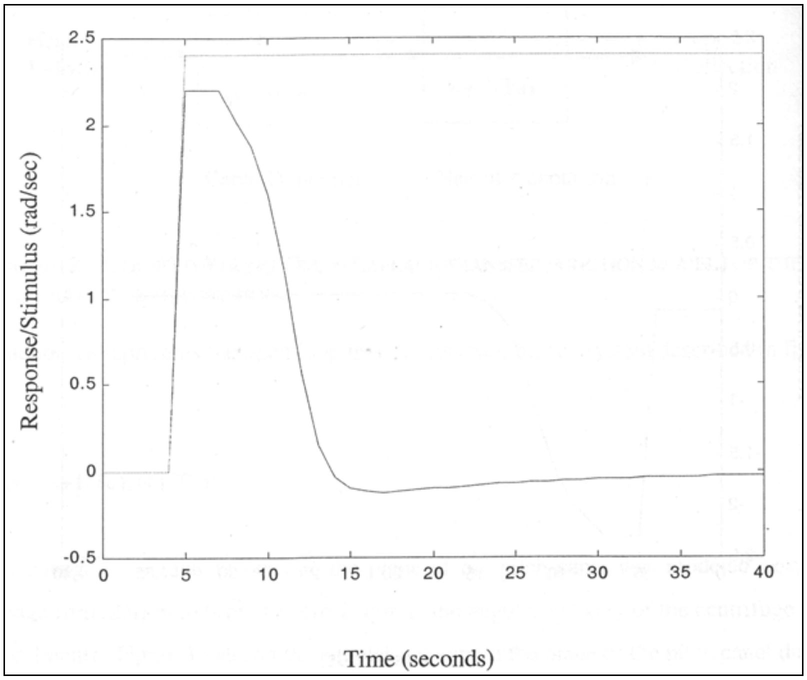


Figure 2.14. Cupula deflection in the pitch canal (for a velocity change of 23rpm in 1 second) represented by the tick line. The thin line shows the velocity profile.
(note that the saturation is an artefact of simulation)

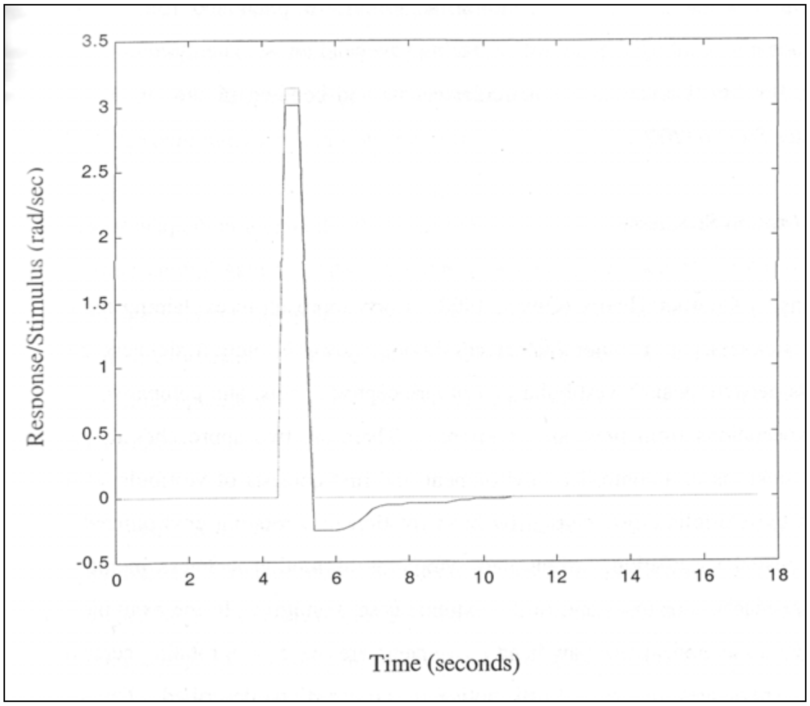


Figure 2.15. Cupula deflection in the yaw canal (for a velocity change of 23rpm in 1 second) represented by the tick line. The thin line shows the velocity profile.
(note that the saturation is an artefact of simulation)

The model shown here is open-loop or feed-forward, which means that if the same input (head velocity) is given, the same output (cupula deflection) will be observed, whatever the situation is: the behavior of the cupula is determined only by the behavior of the head. A feedback model would integrate the current behavior of the cupula to the behavior of the head to modify its response. This would be coherent with the need for adaptation: the vestibular response would be capable of self-regulation, thus achieving the goal of reducing discomfort on its own. But the physiology appears to be different: the integration of the behaviors is located in higher levels. Therefore adaptation occurs in these higher levels, not in the vestibular organs themselves.

2.5.2.3 Comparison between the Two Effects.

The cross-coupled acceleration affects the subject for about 1 sec (duration of the head turn) whereas the canals in/out of plane effect lasts for about 6 sec (time for the cupula to rest: Howard, 1986; and Robinson, 1981). Therefore, this second phenomenon has much more effect on the subject's perception of unreal self-motion.

2.5.2.4 Concerns.

Whereas the semi-circular canal model presented here seems pretty simple, Cheung (2000) showed that this model fails to explain why about 12% of the population feels illusory tilt in an unpredicted plan, and why up to 60% of the subjects feel a compensatory illusory tilt in the same, unpredicted plane. Indeed, several subjects in her experiments felt they were rotating in the opposite direction than predicted by the information generated by the canals. In addition, between 11 and 27% of the subjects (depending on the canal) did not feel self-motion in roll and pitch when doing a yaw head turn on the centrifuge. It is possible that these particular behaviors come from either structural canal asymmetries leading to asymmetric afferent firing responses; or from a mis-understanding of the instructions for verbal to reports. As noticed by Young et al. (2001), the semi-circular canal model is robust enough to predict that, during high speed centrifugation, a majority of subjects experience motion sickness, compensatory vertical nystagmus and illusory tilt; however, it is recognized that other perceptions are not fully predictable by the model. In addition to these variations in direction of sensation, a variation of intensity was found in centrifugation experiments. Head turns to Nose-Up (NU) position are reported more disturbing than Ear-Down (ED) head turns, in terms of duration and magnitude. Since this effect seemed not to be correlated with VOR recordings, a dissociation between the psychophysical interpretation and the physical reaction to stimuli might occur. Newby (2002) showed that the graviceptive information plays a significant role in this case. Mast et al. (2003) presented results showing that not only are head turns toward NU more provocative in magnitude and duration, but the associated sensation decays more slowly, in comparison with an ED rotation.

2.6 Step 6: Adaptation.

Several experiments have proven that subjects can adapt to these effects: they perceive less self-motion and suffer less from motion sickness.

2.6.1 Adaptation to Low Speed Centrifugation.

Stone's evaluation (1973) of the best compromise of radius and velocity for a rotating spacecraft (15.2 to 16.8 meters for 6 rpm), led to immediate testing of adaptation to slow rotation (Graybiel, 1973; Letko, 1973). However, earlier experiments already showed that disorientation and nystagmus due to Coriolis accelerations effects decreased significantly (Guedry and Graybiel, 1962: 64 hours at 5.4 rpm); and that the symptoms of motion sickness could decrease over the days when subjects made repeated head movements in a slowly rotating room (several hours at 7.5 rpm: Guedry, Collins and Graybiel, 1964; 12 days at 10 rpm: Guedry, 1965).

2.6.2 Adaptation to High Speed Centrifugation.

Similar experiments were implemented for short-radius centrifugation, at high-speed of rotation. The same results were obtained: Young et al. (2001) showed that context specific adaptation is possible at 23 rpm, when subjects make repeated provocative head movements. Research was also aimed at testing the maximization of the conflict between perception systems (vision, vestibular, proprioceptive…) to see if increased adaptation resulted (Brown et al., 2001).

2.6.3 Retention of Adaptation.

It has also been showed that subjects can retain part of this adaptation to high speed centrifugation for couple of days (Lyne, 2000). After 4 days of 1h daily exercise at 23 rpm, subjects adapt to centrifugation in a reasonable way: levels of motion sickness and illusory tilts become tolerable. Furthermore, this protocol elicits adaptation that can be retained over five days without further centrifugation. After 12 days, even if compensatory eyes movements are not entirely eliminated, motion sickness symptoms become totally negligible (Sienko, 2000). Earlier experiments had also concluded that, in order to be retained, visual-vestibular adaptation should be elicited over sessions close in time to each other: three drum exposures separated by 4 to 24 days each did not lead to adaptation whereas three drum exposures separated by 48h each achieved adaptation to motion sickness (Stern et al., 1989). These constraints have implication on training and scheduling: if it is done before going to space, then adaptation protocols should occur as close to launch as possible.

2.6.4 Transfer of Adaptation.

Another phenomenon that may have implications for training and scheduling is the transfer of adaptation from a trained protocol to another.

Research involving transfer of adaptation led to opposite results. Spending several hours in a 7.5-rpm-rotating room making specific head turns achieved adaptation to these particular head movements, but failed to transfer to other directions of rotation and quadrants of motion (Guedry, Collins and Graybiel, 1964). Similarly, Graybiel (1977) found a short term loss of adaptation when direction of rotation changed, at low rotation rates (6rpm). On the contrary, during an experiment at 10 rpm that lasted 10 days, if the rotation stopped and restarted in the other direction, then motion sickness reappeared, but less intensely that originally, which was interpreted as a form of transfer of habituation (Guedry, 1965).

Concerning high-speed centrifugation, the adaptation described in Section 2.6.2 was found to carry over to changes in directions of rotation: once a subject is adapted to head turns in one direction or one quadrant, adaptation to head turns in the opposite quadrant is easier (Hecht et al., 2002), proving a form of transfer. Recent research in the Man-Vehicle Lab has investigated the transfer of adaptation from yaw to pitch head movements, but no conclusive effect was found, implying that separate training for each movement might be required (Garrick-Bethell, 2004). Indeed, if no transfer of adaptation or habituation occurs, a complete adaptation will need repeated protocols in all quadrants and directions or planes, which would drastically increase the training time.

All these adaptation, transferring or not, are "context specific" because there is no aftereffect when back in a non rotating environment.

2.6.5 Other factors of Adaptation.

It is of primary importance to understand the influence of the perturbations described previously on the rest of the body and other systems. Specifically, the link between the vestibular system and the motor control system is very strong. DiZio and Lackner (2003) proved that vestibular and motor adaptation are both possible at the same time in rotating environments, and that motor adaptation relies on vestibular cues (among others). In 2003, Brown et al. explained that subjects can adapt to Coriolis cross-coupled effects by intermittent exposure to high speed centrifuge, and, at the same time, maintain their perceptual-motor coordination in non rotating environments.

It has also been showed that visual inputs presented during adaptation play a specific role in this adaptation (Brown, 2000). Whereas VOR adaptation requires a visual-vestibular conflict, reduction in levels of motion sickness was not influenced by this conflict. However, in a slow rotation room experiment, there was no indication of transfer from the Coriolis vestibular stimulus to the nystagmus resulting from the angular acceleration. This implies a specificity of the habituation and adaptation to the exposure conditions.

Interestingly enough, vestibular adaptation can exist even in virtual environments: this is called adaptation of vestibule-driven perceptual-motor systems (Young and Henn, 1974; Stoffregen et al., 1999). Vestibular adaptation as a result of exposures to visual virtual environments has been demonstrated (Cobbs, 1999; Draper, 1998).

In addition, the conditioned compensatory reactions and arousal factors strongly influence habituation. When subjects are maintained in a rather passive state (reverie states with reduced mental activity), nystagmic and subjective reactions decline during prolonged constant accelerations, after a period of increase and stabilization (Guedry et al., 1964). But when subjects are maintained in an alert state, only the subjective reaction to prolonged acceleration declines, whereas the nystagmic reaction does not. An explanation might be that the subjective reaction is attenuated by a central mechanism that does not affect the oculomotor centers (Guedry and Lauver, 1961).

Nevertheless, it remains that the vestibular system is used as an input for the control of eyes movements, and that this relation can change depending on the environment. Indeed, for example in space, after 4 to 10 days in orbit, when velocity storage is recovered, head pitch does not significantly affect nystagmus, whereas earlier it had a strong influence (Oman, 1996).

Finally, Benson et al. (1997) used the potential influence of otoliths on canals and demonstrated that the likelihood of motion sickness in centrifugation is reduced if a radial acceleration stimulates the otoliths organs during the adaptation phases.

2.6.6 Habituation vs. Adaptation.

The term "adaptation" should be used with precaution. Most of the times, "habituation" should be use instead. Physiologically speaking, "adaptation" has also been used to refer to a modification in the firing rate of afferents coding the vestibular information following repeated or sustained stimuli.

In fact, this modification can be described in two distinct phenomena. The first one, named "habituation", is a simple decrease of the response. Motion sickness, illusory tilts and sensation ratings decrease on their scale of evaluation with time. In this phase, the system is just less prone to respond to the stimulus, because it is used to it. Thus, Guedry (1964) used the word "habituation" to designate the phenomenon that consisted in a decrease of discomfort over time.

"Adaptation" is a phenomenon that has an impact on the functional goal of the system: the response comes from a modified interpretation of the signal, sometimes called "re-interpretation". For example, the Otolith Tilt-Translation Reinterpretation theory states that, in space, due to the absence of gravity, the otolith signals are interpreted as only describing linear acceleration (Merfeld et al., 2004). This is a true adaptation, not an habituation. Typically, when an adaptive protocol is repeated over several days, it is easy to distinguish habituation from adaptation. If data decreases within days, that is certainly habituation, and maybe adaptation. If the data decreases between days, that may be adaptation. If the data at the beginning of day n+1 is lower (VOR, MS, IS, IT) than at the beginning of day n, then the word adaptation can be used because something has been retained from one day to another.

This section was aimed at sharpening this vocabulary issue that experimenters usually face in vestibular adaptation research. For more details, see Section 2.8 for a comprehensive review.

2.7 Step 7: Incremental Adaptation.

DuBois-Reymond's excitation law (1848) basically states that a stimulating current is much more effective as a stimulus if it reaches its full strength instantaneously. The conclusion of his experiments showed that it is a common property for living, excitable tissues to be able to resist a gradually increasing stimulus, meaning that incremental exposure to a stimulus will produce less disruption or discomfort than direct exposure. Therefore, it seems very likely that incremental exposure to centrifugation might reduce motion sickness and illusory sensation, according to this law. But the question is: will an incremental protocol still achieve adaptation?

Bergstedt (1965) studied the adaptation of subjects living in a room rotating at 10 rpm. His conclusion was that velocity could be increased gradually using 2-3rpm steps each day, and still achieve adaptation to disorientation. This experiment was repeated (10 rpm for 32 days) with smaller increments of 1 rpm (Graybiel et al., 1969). Vestibular adaptation to the rotating environment was generated by an incremental exposure to the stimulus (head turns), and adaptation is enhanced because less motion sickness than usual was reported. It is to be noticed that previous attempts in 3 days or 40 hours were not successful.

Incremental exposure to visual stimuli was also studied. Lackner and Lobovits (1978) investigated adaptation to visual re-arrangement (adaptation to the wearing of glasses with prisms that induce a lateral deviation of the vision). They found that better adaptation was reached (less motion sickness and less motor coordination deficit) with an incremental profile in the visual deviation, and it was proved to be the result of a progressive adaptation (a random order of stimuli did not achieve adaptation). Therefore, a continuous variation of the stimulus in the same direction is necessary to achieve adaptation. Hu et al. (1991) studied the adaptation to a rotating drum. Three groups exposed to a rotating drum: one direct exposure to maximum duration and maximum speed of rotation (control), one to two short duration pre-exposures at maximum speed before the exposure at maximum duration and speed (pre-exposed), and one to two short pre-exposures of same short duration but incremental speed before the exposure at maximum duration and speed (incremental). The result carried no ambiguity: the incremental group reported less motion sickness symptoms and had lower physiological reactions (tachyarrhythmia, abnormal gastric myoelectric activity, associated with nausea) than both the control and pre-exposed groups, proving that incremental exposure to motion stimuli may be a useful method for training resistance to visually induced motion sickness.

Both experiments (Hu et al., 1991; and Graybiel, Deane and Colehour, 1969) are consistent: incremental exposure leads to a better rate of adaptation. This supports Reason (1978) and Brand's (1975) sensory rearrangement theory which suggests that the severity of motion sickness is a function of the degree of sensory mismatch, and that the degree of sensory mismatch is dependent upon the difference between the present sensory information and the information retained from the immediate past.

2.8 Theory of Adaptation.

2.8.1 Definitions.

In 1969, Brooks sketched “adaptation” as a very basic concept: it is a long, slow process of physiological modifications. Quickly made adaptation of a temporary nature should then be referred to as “accommodations”. The ambiguity is already there: accommodation is a *type* of adaptation, type being defined on a time scale.

About ten years later, Welch (1978) proposed a more precise definition: adaptations refers to "a semi-permanent change of perception or perceptual-motor coordination that serves to reduce or eliminate a registered discrepancy between or within sensory modalities or the errors in behavior induced by this discrepancy". This definition states that adaptation is inevitably linked to a purpose, a goal to achieve (see Section 2.8.2).

More recently, McNab (2002) explained that “adaptations” (note the plural) should designate "modifications of the malleable physiological features with respect to the physical and biological characteristics of the environment, that contribute to the increased reproduction of species". McNab recognizes that, in general, the impact on reproduction is barely identifiable or imaginable. But this definition remains interesting in the sense that both a goal and a context or general frame are provided. Adaptation is aimed at achieving a goal and this operates in the context of the relation between the living material considered and its environment.

Although this last definition is commonly understood and accepted, several biologists have argued that this definition is very close to that of “learning”. Learning is the process through which living beings acquire information and knowledge in an experience-related manner so as to establish new adaptive behavioral strategies (Giurfa and Menzel, 2003). The example of the cyanobacteria helps understand the trade-off between learning and adaptation: these bacteria learn how to respond to the decrease of phosphate supply in their environment (learning) and transmit the modifications to successive generations (adaptation) (Giurfa and Menzel, 2003). It seems therefore that adaptation is deeply linked to the survivability of the living organ/tissue/being.

This last example of transmission of survival techniques can be confounded with evolution in its broader sense. Brooks (1969) notes that evolution is then the slowest adaptation process for living organisms; he also considers that conditioned reflexes and learning can also be referred to as adaptive processes, while recognizing at the same time that adaptation should be restrained to phenomenon with slow time courses! He advises to use the terms "adjustments" or "evolutionary processes" when the adaptation is to environmental circumstances.

In the end, Brooks merely uses the word "adaptation" as an umbrella for several phenomena: accommodation, adjustments, evolution, learning, conditioned reflexes… even though there are, within these words, huge differences in their mode of acquisition or implementation, and time course.

2.8.2 Goals.

It seemed in some definitions that adaptation was inevitably linked to its purpose. Several authors attempted to define adaptation through its goals and potential achievements.

Slobodkin (1964) argued that adaptation is aimed at maintaining homeostasis (that is maintaining a constant internal environment). Basically, all physiological responses to a change in the environment are aimed at maximizing the ability to respond to further modifications. The first, immediate response is called behavioral response (McNab, 2002), and if the change is sustained, then physiological adjustments occur (ex: genetic modification). This would satisfy Brooks' (1969) definition of "genetic adaptation": a "process of mutational change (…) with maintenance of biological constancies". He also defined two major goals that adaptation is suppose to reach: 1) to effect continuing or permanent changes to better meet environmental requirements and 2) to maintain an essential constancy of body state despite changing environmental demands. These definitions of adaptive goal may seem to go against each other: goal 1 states that physiological changes must occur to match environmental needs, whereas goal 2 advocates for a maintaining of the body state whatever the environment requires. In fact, there is no paradox. The former definition must be understood at the molecular, cellular and organ levels; whereas the latter target the whole living human body.

To sum up this section on adaptation theory, let us use McNab's (2002) list.

1- Adaptations are modifications in organisms that increase reproduction, and therefore survivorship, in a particular environment.

2- A hierarchy of physiological responses to variation in the environment may exist, including responses that are short term, seasonal, and long term (climatic), all to some extent involving genetic changes.

3- Several potential solutions to an environmental challenge normally are available.

4- All solutions have side effects.

5- Some adaptations constrain future possibilities, whereas others open new opportunities.

6- Adaptation can be limited by the interaction of factors involved in the mechanisms of adaptation, by ecological opportunities, and possible by the set of responses accumulated through time.

2.9 Psychophysics.

Sensations that seem to lie in a continuum domain are very interesting in the psychophysics area, since they allow for being ordered on a scale from "faint" to "intense" (Stevens, 1975). These perceptual continua can be of two sorts: metathetic or prothetic. Metathetic continua, such as the pitch of a sound, are qualitative continua (varies from low to high); whereas prothetic continua, such as the loudness of a sound, are quantitative continua (they can be described with degrees of magnitude).

Indirect scaling of sensation perceptions exposes the observer to different stimuli, and he/she has to tell when the two stimuli are different. It's a measure of sensation through measurements of discrimination. Experiments using direct scaling convert observers' judgments of their sensations directly into measurements of sensory magnitudes (Gescheider, 1985).

Ratio scaling is a form of direct scaling. Introduced in 1888 by Merkel, it was really developed in the 50s by Stevens. Stevens asked his subjects to assign numbers to their sensations (ex: loudness of a sound, brightness of a light, taste, smell…) as they fit appropriate. This is also called magnitude estimation.

Over the past 50 years, more than 50 perceptual prothetic continua have been investigated through magnitude estimation. They all led to an empiric relation between the input (stimulus magnitude = Φ) and the output (sensation magnitude = Ψ) of the form:

$$\Psi = k.\Phi^{\beta}$$

The magnitude of the sensation is proportional to a power function of the stimulus magnitude. k is basically a scaling factor to adjust for the units of measurements. β is considered as a "signature" of the sensory continuum considered and the conditions in which it is studied (experimental conditions, see Table 2.1). This relation is called the psychophysical law (Stevens, 1975).

β determines the curvature of the power function, that is, basically, its general behavior (see Figure 2.17). If β>1 (ex: electrical shock), the representation is a concave upward line, with increasing slope (to infinity). This means that, at low stimulus magnitude, sensation does not vary a lot; and that at high stimulus magnitude, sensation goes to infinity. If β=1 (ex: length), the sensation varies directly with the stimulus. If β<1 (ex: brightness), the representation is a concave downward line, with the slope going to 0 (horizontal line). The sensation is limited in its scale: discrimination in sensation occurs at low stimulus magnitude. At high stimulus magnitude, sensations are pretty similar.

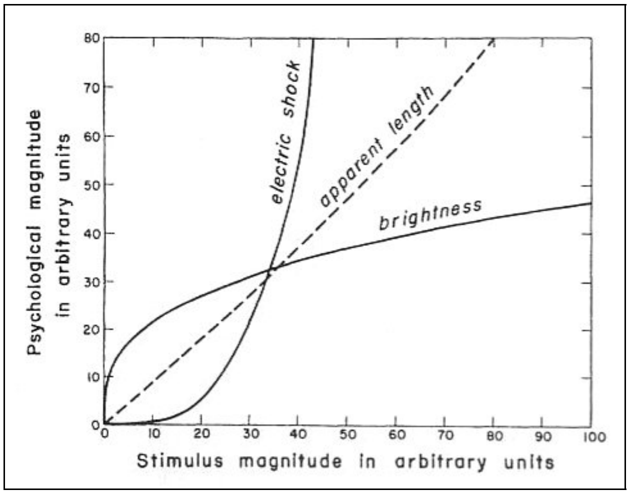


Figure 2.17. Psychological magnitude vs. stimulus magnitude.
β = 3.5 (electric shock); 1 (apparent length); 0.33 (brightness).

Continuum	Measured exponent	Stimulus condition
Loudness	0.67	Sound pressure of 3000-hertz tone
Vibration	0.95	Amplitude of 60 hertz on finger
Vibration	0.6	Amplitude of 250 hertz on finger
Brightness	0.33	5 degree Target in the dark
Brightness	0.5	Point source
Brightness	0.5	Brief flash
Brightness	1	Point source briefly flashed
Lightness	1.2	Reflectance of gray papers
Visual Length	1	Projected line
Visual Area	0.7	Projected square
Redness (saturation)	1.7	Red-gray mixture
Taste	1.3	Sucrose
Taste	1.4	Salt
Taste	0.8	Saccharine
Smell	0.6	Heptane
Cold	1	Metal contact on arm
Warmth	1.6	Metal contact on arm
Warmth	1.3	Irradiation of skin, small area
Warmth	0.7	Irradiation of skin, large area
Discomfort, cold	1.7	Whole body irradiation
Discomfort, warm	0.7	Whole body irradiation
Thermal pain	1	Radiant heat on skin
Tactual roughness	1.5	Rubbing emery cloths
Tactual hardness	0.8	Squeezing rubber
Finger span	1.3	Thickness of blocks
Pressure on palm	1.1	Static force on skin
Muscle force	1.7	Static contractions
Heaviness	1.45	Lifted weights
Viscosity	0.42	Stirring silicone fluids
Electric shock	3.5	Current through fingers
Vocal effort	1.1	Vocal sound pressure
Angular acceleration	1.4	5-second rotation
Duration	1.1	White noise stimuli

Table 2.1. Representative exponents of the power functions relating subjective magnitude to stimulus magnitude (Stevens, 1975).

There are two ways to apply the magnitude estimation principle (Stevens, 1958): the first one is to expose the subject to a fixed, standard, baseline stimulus and tell him/her that the sensation produced has a pre-determined numerical value such as 10. This value is called the modulus. On subsequent exposures, the observer assigns numerical values to sensations relative to the value of the modulus. Instruction to the observer states that the judgment has to reflect how many times greater or smaller a sensation is with respect to the baseline stimulus. In order to combine the judgment of several observers, it is advised to use the median or the geometrical mean for all data referring to a specific stimulus. The arithmetic value is to be avoided because it is highly influenced by a few unrepresentative outliers. The second version is similar to the first but with the difference that the modulus is not specified by the experimenter but by the observer him/her-self. This method would not be applied in vestibular experiments, because the sensation is very uncommon and it might be difficult for subjects to give appropriate value in a limited period of time. In addition, more computation of the data is needed to scale all judgments altogether.

In magnitude estimation, the average of the number assigned to a particular stimulus is called the "psychological scale value" for that stimulus (Stevens, 1960). The psychological magnitude function is the average magnitude estimation plotted as a function of some property of the stimulus.

The main limitation in this process is that it is recommended to expose observers to different orders of stimuli. But this is not possible in experiments including an incremental protocol, since it is the very goal of it to have some sort of learning.

The question is to know if magnitude estimation is accurate. Past research tend to answer this question with a yes. Frankenhaeuser, Sterky and Järpe (1962) found a positive relationship between magnitude estimation of stress and epinephrine secretion following varying levels of gravitational stress produced in a human centrifuge. Later on, Frankenhaeuser (1967) found out very similar and close relationships between magnitude estimations of stress and physiological responses during "Stroop Color - Word Inference Tests". Guedry et al. (1971) established that their subjects were able to estimate accurately angular displacements in the y and z axis, with a mean of 89% correlation between actual displacement and estimation, making this result very accurate.

Magnitude estimation is extremely efficient, and permits quick acquisition of huge amounts of data, ideal for use in experiments requiring the scaling of a large number of stimuli.

But Gescheider (1985) asked whether ratio scaling methods really measure sensation magnitude. Two ways to determine the validity of a method were exposed: 1) the method gives the same results as another method already considered as valid; or 2) additivity of the measurements obtained through the method is verified. 1) is barely possible: there is no widely accepted psychophysical scale of sensation magnitude. So 2) is to be tested. It means that if the observer is presented a stimulus that produces, when presented alone, a sensation of magnitude A, together with a stimulus that produces, when presented alone, a sensation of magnitude B, then the observer should assess a sensation magnitude of A+B. Is this possible to do in intensity of sensation? The answer is yes because the sensation can be characterized in two dimensions: time of duration (see past theses where duration of sensation was measured) and amplitude of the perceived tumbling, which satisfy the additivity criterion.

Chapter 3

Methods

3.1 Experimental Design.

3.1.1 Experimental Group.

The protocol of this experiment consists of five sessions over five consecutive days. During each session, subjects lie in the supine head-on-axis position on the MIT short-radius centrifuge, rotating clockwise when seen from above (see Figure 3.2). They will perform series of yaw Head Turns (HT), in order to be exposed to the sensory conflict explained in Chapter 2, which hopefully will lead to adaptation. The speed of rotation of the centrifuge will increase over the days. This phase of adaptation will happen in a stable visual field created by lighting on-board the centrifuge and an opaque canopy. This condition appeared in past experiments to be the most desirable (Brown, 2002). To achieve this purpose, subjects will be provided with a portable flashlight, allowing, when turned on, a stable, non-rotating visual reference frame, for the retinal slip adaptation phase. This phase of adaptation will be, each day, surrounded by identical phases aimed at collecting physiological data. These phases will occur in the dark (to be able to measure eye movements) and at maximum speed (23 rpm) for purpose of comparison between days (Tables 3.1 and 3.2).

Phase 1 pre-adaptation	**Phase 2 adaptation**	**Phase 3 post-adaptation**
Speed = 23 rpm 3 sets of 2 head turns (RED, NU) In the dark.	Speed = speed[day] 15 sets of 2 head turns (RED, NU) In stable light.	Speed = 23 rpm 3 sets of 2 head turns (RED, NU) In the dark.

Table 3.1. Summary of the experimental design.

Day	speed[day]
1	3 rpm
2	5 rpm
3	8.5 rpm
4	14 rpm
5	23 rpm

Table 3.2. Velocity profile.

Justification for choosing this velocity profile.

When the subject is lying supine on the centrifuge, the otoliths detect the centrifugal force in the same direction as gravity would operate in a normal, steady, upright position. The centrifugal force detected is a function of the square of the speed of rotation:

$$F = r.\omega^2$$

This suggests that the physics of the force is geometrical and not linear: if ω doubles, the force does not double, but is multiplied by four.

We want to operate the adaptation protocol between the speeds of 3 and 23 rpm: $3^2 = 9$ and $23^2 = 529$. The ratio of g's to achieve is thus:

$529/9 = 58.77\ldots \approx 59$.

We are limited in the number of days of availability of subjects: 5 is the maximum allowed. So we need 5 speeds = 4 steps. But we need to find what type of incrementation will be defined.

The psychophysical law states that a perceptual prothetic continuum obeys the following law:

$\Psi = k.\Phi^\beta$ [stimulus magnitude = Φ, sensation magnitude = Ψ]

We hypothesize here that the perception of sensations elicited by head movements while spinning is a continuum, because subjects can refer to it on a vocabulary scale between "faint" and "intense" (Stevens, 1975). By definition, these sensations are prothetic, since it refers to a quantitative perception, described in terms of degrees of magnitude. Therefore, Intensity of Sensation (IS) follows the psychophysical law. We will not discuss the value of k (which is just a unit scaling factor), but will investigate β.

We hypothesize that the β for the IS with gravity/SCC behavior as a stimulus is lower than one. The justification is that the reports at high speed seem not to be very different within a range of +/- 3 rpm (≈10%) around 23rpm. We believe there is some kind of saturation: when the sensation is maximal, even if the stimulus is bigger, the observer sticks to this maximal assessment. On the contrary, at low rotation speed, subjective reports are much more "separated". This corresponds to: $\beta < 1$ (Figure 2.17).

An additional factor is that most of the continua, except hard pain, have a power that is lower than 1, or very close.

Therefore, the most immediate hypothesis for the power in our experiment is that the sensation of gravity-related stimuli has a logarithmic evolution ($\beta<1$), thus implying a geometrically coded signal. To equally differentiate two stimuli (perception axis on Figure 3.1), the difference of their magnitude has to be higher at high magnitudes (stimulus axis on Figure 3.1): Δp (differences in perception) are constant while corresponding Δs (differences in stimuli) are increasing.

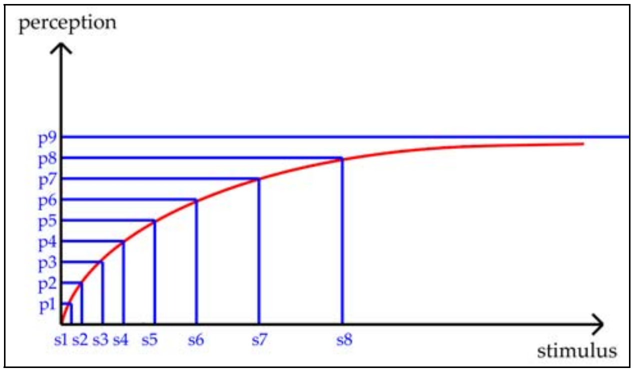


Figure 3.1. Logarithmic evolution of perception to stimulus.

We consider therefore that the stimulus is geometrically coded. Thus, the geometrical factor to implement should then be:

$$\text{ratio}^{(1/\text{number\_of\_steps})} = 59^{1/4} = c \approx 2.8.$$

The steps should thus be:

$$9 \mid 9 \times c \approx 24.92 \mid 24.92 \times c \approx 68.99 \mid 68.99 \times c \approx 191.05 \mid 191.05 \times c \approx 529$$

which transforms into speeds of:

3 rpm | 5 rpm | 8.3 rpm | 13.8 rpm | 23 rpm

These speeds are rounded to the nearest achievable precise speed with our centrifuge (.5 rpm precision):

3 rpm | 5 rpm | 8.5 rpm | 14 rpm | 23 rpm

Justification of the number of head turns in phase 2.

A preliminary study testes an incremental protocol over a period of one, between 1 rpm and 23 rpm, in 2 or 4 steps (1 rpm, 5 rpm, 23 rpm; or 1 rpm, 2 rpm, 5 rpm, 11 rpm, 23 rpm), with subjects making only 2 head turns at each speed level. No adaptation was elicited, and it was concluded that the small number of head turns was the reason for this lack of adaptation. Therefore the present protocol features a very large number of head turns at each speed of rotation.

3.1.2 Control Experiment.

The control experiment basically keeps the same protocol, with a few changes: phase 2 will be implemented at maximum speed (23 rpm) and without any head turn. The control experiment will be repeated only on two consecutive days. The goal of this control experiment is to test the measurement protocol. It is crucial to know if it induces adaptation as we stated before (reduction in inappropriate eyes movements, reduction in motion sickness and illusory sensations). This control experiment is done at maximum speed (23 rpm) because it is hypothesized that, in case the bed has a negative influence, it will be more salient at higher rotational speeds (proven to be the most provocative). The control experiment is repeated only over two days, because past research (Brown, 2002; Newby, 2002; Sienko, 2000; Lyne, 2000; Cheung 2000) has shown that the effects of adaptation are detectable as soon as Day 2.

3.2 Equipment.

3.2.1 The Centrifuge.

The short-radius centrifuge operated in this study is shown on Figure 3.2. It consists of a 2m-long rotating bed, that can bear subjects between 62 and 74 inches (1m57 to 1m88), and up to 200 lbs (91kg). Subjects lie supine on the bed, with their head at the center of rotation. The bed is controlled by a 1 Hp motor, that can provide a maximum speed of rotation of 30 rpm (180°/sec). The centrifuge is mainly operated at 23rpm, in order to provide 1g at the feet of the subjects. An adjustable metallic footplate at the rim of the centrifuge provides support for the subjects' feet: by modifying its radial position on the centrifuge, it is assured that the head of the subject is at the center of rotation (Figure 3.3). The footplate has recently been modified: it includes an exercise device, used in another experiment on cardio-vascular deconditioning. This device can be blocked so as to be used as a basic support.

A rotating helmet is fixed to the axis of rotation and allows yaw movements to the right only. This yaw head movement retainer is pictured on Figure 3.4. It controls the subject's head rotation to and from NU (Nose Up position, Figure 3.5) and RED (Right Ear Down position, Figure 3.6). It is helpful in guiding the subjects' head movements.

A removable opaque canopy (Figures 3.7 and 3.8) is added during the experiments, as a wind-shield to reduce the proprioceptive rotational cues provided by air flow, and to suppress visual indications of rotation.

For safety purpose, a Sony digital video camera with NightShot capabilities is fixed to the bed and allows for constant monitoring of the subject, in all lighting conditions. In addition, a safety belt is buckled during all experiments, an emergency stop button is in the subject's hands, and metal gurney-style sidebars prevent subjects from falling off the bed.

A tetrapod support has been recently added to stabilize the bed and to prevent it from having an unwanted precession movement (Figure 3.9).

For more technical descriptions of the centrifuge, please see Cheung (2000) and Diamandis (1988), who built the rotator.

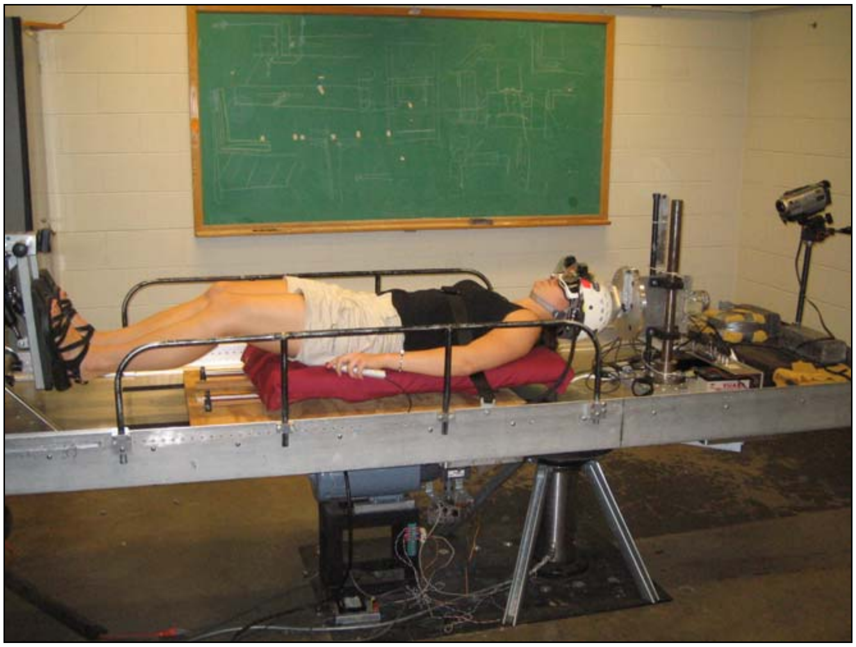


Figure 3.2. General view of the centrifuge.

Figure 3.3. Close view of the new footplate, equipped with an exercising device.

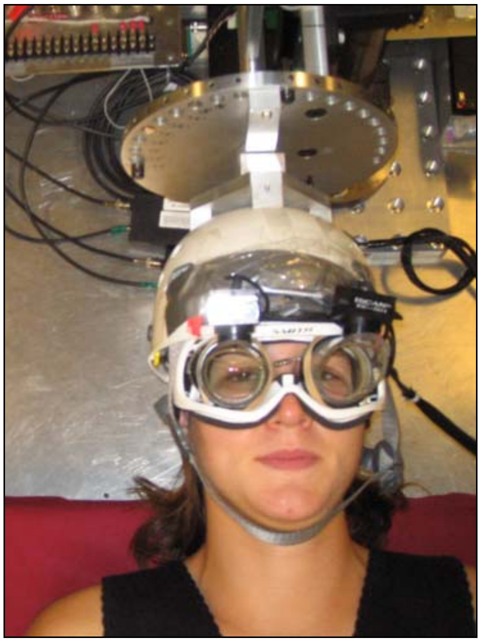


Figure 3.4. Close view of the restraining helmet and its rotating device.

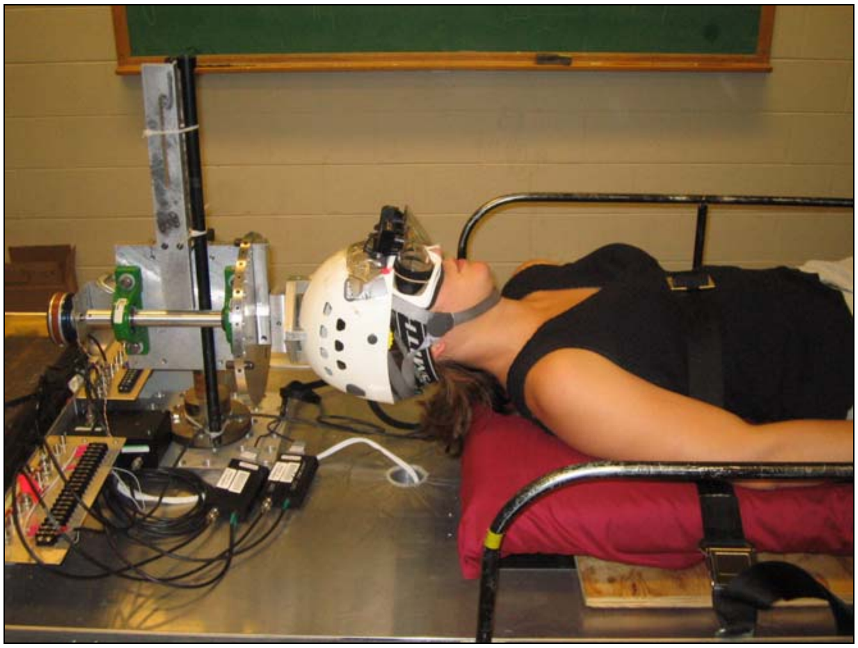


Figure 3.4. Subject in NU (Nose Up) head position.

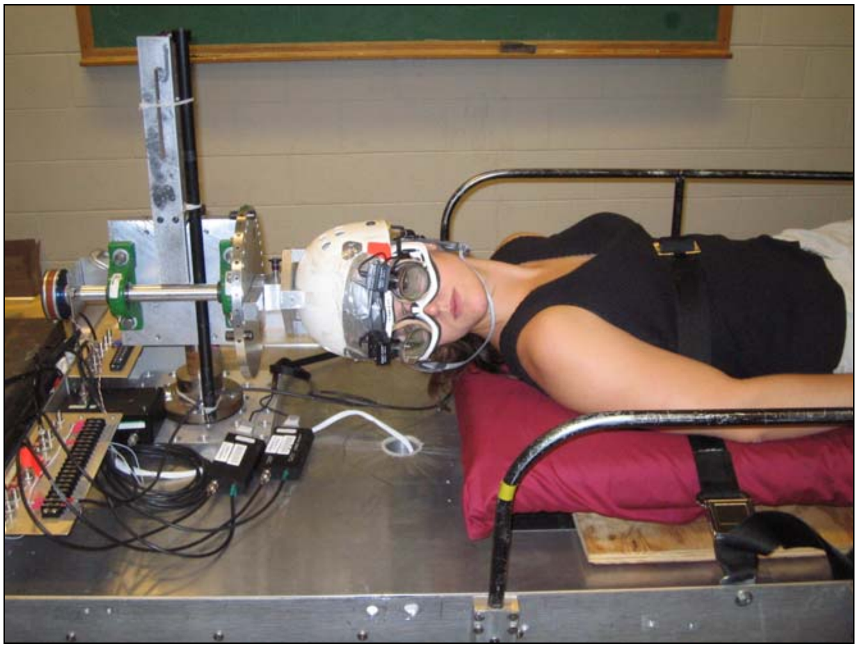


Figure 3.6. Subject in RED (Right Ear Down) head position.

Figure 3.7. Archive view of the centrifuge equipped with the opaque canopy.

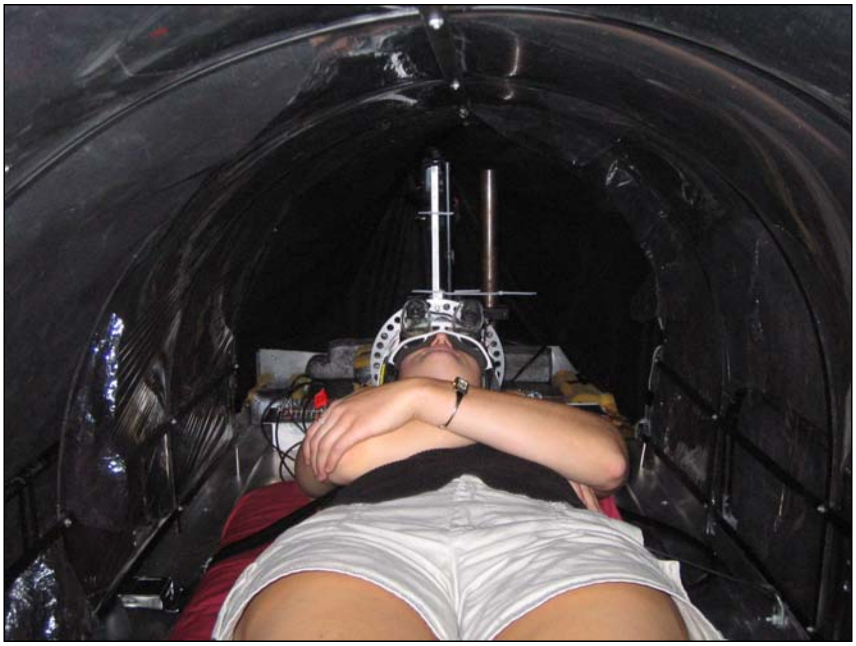


Figure 3.8. Inside view of the centrifuge equipped with the opaque canopy.

Figure 3.9. View of the new stabilizing tetrapod.

3.2.2 Eye Movements Recording Goggles.

During all experiments, subjects wear a ski mask equipped with binocular miniature video cameras (Figure 3.10).

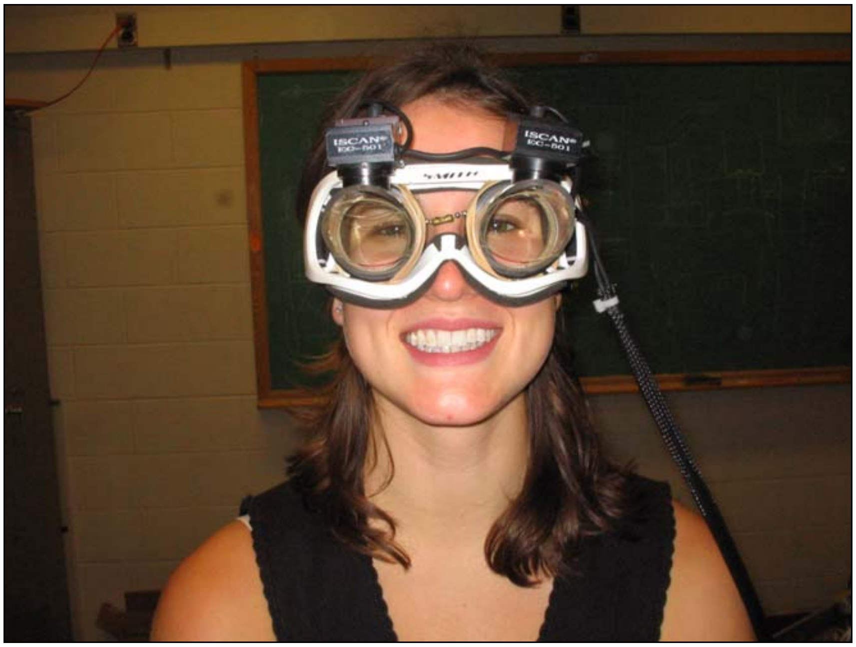


Figure 3.10. Happy subject wearing the new eye-movements measurement device, a ski-mask equipped with miniature cameras.

The cameras are ISCAN (Burlington, MA) Model RK-416PC. The eye tracking system is based on infrared (IR) illumination of the pupil. The IR sources are not coaxial with the eye imaging cameras: the pupil captures IR emissions, but its surrounding areas reflect IR to the cameras, creating "dark pupil" images. The video signals are transmitted to a computer, and processed with ISCAN software. The software basically computes the 2D position of the center of mass of the dark area, assumed to be the center of the pupil of the subject. The software options include the possibility of adjusting the threshold of IR to detect, which allows for modifying the dark area so as to lock the detection correctly on the pupil.

Prior to the experiment, the signals need to be calibrated, in order to normalize the data for comparison between subjects. An overhead cross with five dots (center, left, right, up, down positions) is placed at 73 centimeters from the subjects' eyes, in order to calibrate for a 10° eye movement.

During the phases when eye data was collected, subjects were asked to put a blindfold on the ski mask, in order to cancel any external light source that might affect their vision.

3.3 Subjects.

15 subjects, 13 males and 2 females, aged 17 to 27, participated in the experiments. Most of them were MIT undergraduate and graduate students, recruited through posters disposed around campus. The Control group was composed of 8 subjects, 6 males and 2 females, aged 17 to 24; all of them completed the experiment. The Experimental group was composed of 7 subjects, exclusively males, aged 21 to 27; 6 of them completed the experiment. All subjects provided written consent to participate (Appendix A) and were screened for medical conditions (Appendix B). The Experimental group was tested before the Control group. Therefore, subjects were not randomly assigned to the two groups.

3.4 Measurements.

3.4.1 Physiological Measurements: Eye Data.

Subjects wore the ski mask with the cameras during the entire experiment. During phases 1 and 3, eyes movements were recorded through the ISCSAN goggles. Subjects were instructed to keep their eyes wide open and to avoid blinking during and after each head movement. During phase 2, eyes movements are not recorded: it is the "adaptation period" in stable surrounding light.

The eyes movements are characterized by two metrics: the peak amplitude (A) of the slow phase velocity (SPV) and the time constant of its decay (τ). In our experiments and further analysis, the slow phase velocity is normalized with respect to the speed of rotation of the centrifuge and the head turn maximum angle. This is for comparison purpose between different experiments where speed of rotation and angle of head turn change. In our experiments, eyes movements are always recorded at maximum speed of rotation, and after 90 degrees head turns. The normalized slow phase velocity (NSPV) is given by the formula:

$$\mathrm{NSPV} = \mathrm{SVP} / (\mathrm{speed\_of\_rotation} \times \sin(\mathrm{angle\_of\_head\_turn}))$$

$$\mathrm{NSPV} = \mathrm{SVP} / (138°/\mathrm{sec} \times \sin(90°))$$

$$138°/\mathrm{sec} = 23\mathrm{rpm}$$

The denominator of the NSPV is the velocity component of the semicircular canals moving in/out of the plane of rotation.

3.4.2 Subjective Assessments.

3.4.2.1 Motion Sickness (MS).

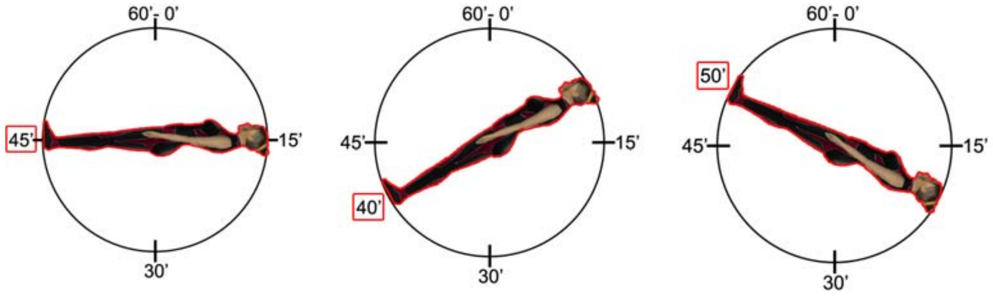
The MS score is an estimation of how *bad* the subject feels (Brown, 2002). MS is rated on a 0 to 20 scale to represent the overall feeling of discomfort. A score of 0 is for "I am fine" and a score of 20 is for "I am about to vomit". MS ratings where asked after each head movement during phases 1 and 3, and after each head movement of every other set of two during phase 2.

3.4.2.2 Intensity of Sensation (IS).

The IS score is aimed at reflecting how much the subjects feels the sensations of tumbling. The sensation experienced during the very first head turn (Day 1, Phase1, HT 1) is the modulus, to which an arbitrary baseline value of 10 is assigned. When asked to report IS, the subject has to give a relative value for the subjective intensity of the sensation experienced as a result of the head turn just made. This value is established in reference to the baseline. For instance, a turn twice the intensity of the sensation of the first turn is called a 20, and a turn with half the intensity is called a 5. If the turn feels identical to a turn made while not spinning on the centrifuge, it has a subjective intensity of 0.

3.4.2.3 Illusory Tilt (IT).

The specificity of the required head turns (right ear down and nose-up) generates an illusory sensation of pitching forward or backward. Subjects are asked to report this sensation, based on an analogy with a clock dial, assuming no perception of bending. At rest, the body is lying on the 45-15 minutes axis (feet at 45', head at 15'). If feeling a forward pitch, then the subjects' feet will move between 30 and 45 minutes. If feeling a backward pitch, then the subjects' feet will move between 45 and 60 minutes. The perceived feet position is reported as the IT score.



Position at rest. Pitching forward. Pitching backward.

Figure 3.11. IT report explanation.

3.4.2.4 Applied Psychophysics.

This section rapidly gives some justification for the subjective assessments encountered in the experiments. Refer to section 2.9 for psychophysics basis.

Motion sickness should be measured on an ordinal because we cannot say with confidence that a 4 is twice the sensation of a 2, it is more like subjects ranking their sensations.

IS is by definition and instruction to subjects a ratio scale: if the sensation is twice as big, then the number has to be twice as big, too (this is the definition of an interval scale) AND a value of 0 (zero) means that there is no sensation.

IT is an interval scale: the difference between a 35 and a 40 is the same as between 45 and 50 (but a value of 0 does not mean that there is no sensation).

3.5 Protocol.

3.5.1 Pre-Experiment.

Pre-experimental procedures started with questions asked of the subject about their personal motion-sickness history. They were ask to sign a medical form certifying they did not have medical issues, including, but not limited to, neurovestibular, vision, or cardio-vascular problems (Appendix A). Minimum requirements for subjects to participate were checked: regular moderate exercise activities, weight/height physical limitations for the centrifuge, no ingestion of caffeine, alcohol, drug in the past 24h. Subjects who qualified for the experiment were informed of the risks of the experiment (mainly being subject to motion sickness while spinning on the bed), and detailed consent forms were provided for information and signature (Appendix B). Subjects were specifically reminded that they were free to drop out the experiment anytime.

Subjects were then introduced to the short-radius centrifuge and its safety equipment; and to the experimental protocol (Appendix C). A quick explanation of motion sickness symptoms and sensations was also provided.

Subjects stepped on the bed and lay down. They were given the ski-mask with the miniature cameras, and instructed to put their head in the restraining helmet. They were given the blindfold, the flashlight and the "kill-switch" (emergency device operated by the subject to stop the centrifuge). They were allowed to practice head turns, in one second each. Adjustment of the safety belt and the footplate completed this pre-calibration set-up. Calibration of the goggles was done using the dotted cross placed above the subject's head. Once calibration was done and the cross removed, the canopy was added to the centrifuge and lights were turned off.

3.5.2 Experiment.

3.5.2.1 Experimental Group.

The following protocol was identically repeated over the five consecutive days. The only change was in the speed of phase 2 as described in the experimental design.

Each yaw head turn (RED or NU) was performed in 1 second, and the head was maintained in position for about 30 seconds before doing the next head movement.

Phase 1:

- section 1.1: ramp up to 23 rpm, in the dark, 30 seconds.

- section 1.2: 3 sets of 2 commanded head turns (RED and NU), in the dark. Measures after each head movement: motion sickness (MS), intensity of sensation (IS) and illusory tilt (IT), eye movements. Duration = 3 minutes.

- section 1.3: ramp down to 0 rpm, in the dark, 30 seconds.

- section 1.4: 1-minute optional break.

Subject is asked to remove the blindfold and to turn the flashlight on.

Phase 2:

- section 2.1: ramp up to the intermediary speed of the day (Day 1 = 3 rpm, Day 2 = 5 rpm, Day 3 = 8.5 rpm, Day 4 = 14 rpm, Day 5 = 23 rpm), in stable light, 30 seconds.

- section 2.2: 15 sets of 2 commanded head turns (RED and NU), in stable light. Measures after each head movement of every other set of 2: motion sickness (MS), intensity of sensation (IS) and illusory tilt (IT). Duration = 15 minutes.

- section 2.3: ramp down to 0 rpm, in stable light, 30 seconds.

- section 2.4: 1-minute optional break.

Subject is asked to put the blindfold back on and to turn the flashlight off.

Phase 3:

- section 3.1: ramp up to 23 rpm, in the dark, 30 seconds.

- section 3.2: 3 sets of 2 commanded head turns (RED and NU), in the dark. Measures after each head movement: motion sickness (MS), intensity of sensation (IS) and illusory tilt (IT), eye movements. Duration = 3 minutes.

- section 3.3: ramp down to 0 rpm, in the dark, 30 seconds.

Subjects were then debriefed.

3.5.2.2 Control Group.

The following description was identically repeated over two consecutive days.

Each yaw head turn (RED or NU) was performed in 1 second, and the head was maintained in position for about 30 seconds before doing the next head movement.

Phase 1:

- section 1.1: ramp up to 23 rpm, in the dark, 30 seconds.

- section 1.2: 3 sets of 2 commanded head turns (RED and NU), in the dark. Measures after each head movement: motion sickness (MS), intensity of sensation (IS) and illusory tilt (IT), eye movements. Duration = 3 minutes.

- section 1.3: ramp down to 0 rpm, in the dark, 30 seconds.

- section 1.4: 1-minute optional break.

Subject is asked to remove the blindfold and to turn the flashlight on.

Phase 2:

- section 2.1: ramp up to 23 rpm, in stable light, 30 seconds.

- section 2.2: subjects rest motionless in stable light. Duration = 15 minutes.

- section 2.3: ramp down to 0 rpm, in stable light, 30 seconds.

- section 2.4: 1-minute optional break.

Subject is asked to put the blindfold back on and to turn the flashlight off.

Phase 3:

- section 3.1: ramp up to 23 rpm, in the dark, 30 seconds.

- section 3.2: 3 sets of 2 commanded head turns (RED and NU), in the dark. Measures after each head movement: motion sickness (MS), intensity of sensation (IS) and illusory tilt (IT), eye movements. Duration = 3 minutes.

- section 3.3: ramp down to 0 rpm, in the dark, 30 seconds.

Subjects were then debriefed.

Chapter 4

Data Analysis

4.1 Eye Data Analysis.

4.1.1 Basic Goal of Eye Data Analysis.

During post-rotatory nystagmus, the behavior of the slow phase velocity of eyes movements is characterized by two primary parameters: the amplitude of the Normalized Slow Phase Velocity (noted A) and the time constant of its decay (noted τ). This decay is commonly modeled as an exponential decay:

$$A.e^{-t/\tau}$$

The goal of the eye data analysis is to find, for every head turn performed on the centrifuge, in the dark, the couple (A, τ) that characterizes the eye response.

4.1.2 Data Processing.

Recorded eye movements data from the ISCAN is transferred *via* an ASCII file to the Matlab software, for analysis, using a software package regularly used in the Man Vehicle Lab for this purpose (Sienko, 2000; Garrick-Bethell, 2004). The complete Matlab code used in this analysis is available in Ian Garrick-Bethell's thesis (2004).

Each ASCII file generates several additional Matlab arrays of data: one for each run of recording, that is then separated into four files, one for each eye (left/right) combined with each direction (horizontal/vertical). The operator has the choice to analyze any of these files. In our experiment, the vertical direction is studied (because yaw head turns are performed in and out of the plane of rotation). Both eyes were used during the analysis, depending of the signal's quality of each run.

The eye data is first filtered out for noise and blinks, with several Butterworth and Order Static filters (*batch_eye_channel.m*). Then, the slow phase velocity of the eyes movements is extracted using an Adaptive Asymmetrically Trimmed-Mean Order Static filter (see Balkwill, 1992, for more description of this process).

The original routine featured an automated exponential fit program that sequenced the data and determined on its own the different, successive (A, τ). Unfortunately, this program was not very robust to remaining noise, and a manual routine was created (*eye_anal_manual.m*).

The operator has to delimit the beginning and the end of the portion of SPV to fit to the exponential model. He/she is presented with a plot of SPV over time (Figure 4.1), and clicks on the curve at the locations he/she finds appropriate to be the beginning of the decay (maximum absolute amplitude) and the end (close to zero amplitude), usually delimiting a section of about 10 to 15 seconds (Figure 4.2).

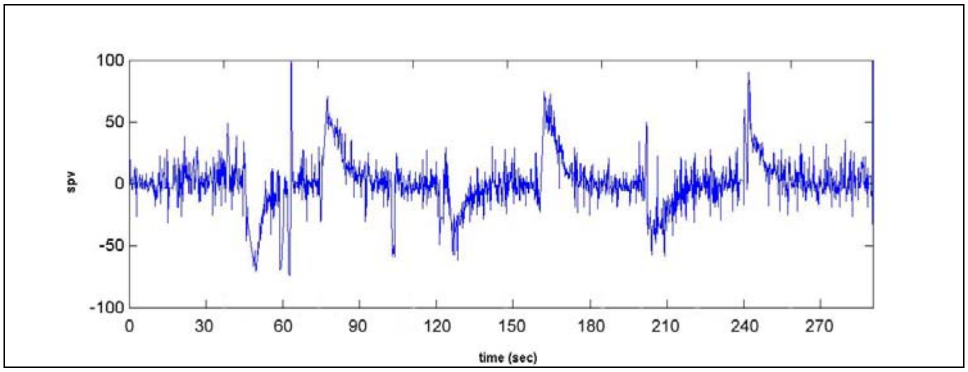


Figure 4.1. Typical SPV recording, over a period of 4 min 30 seconds.
(Subject 5, Day 2, Phase 1)

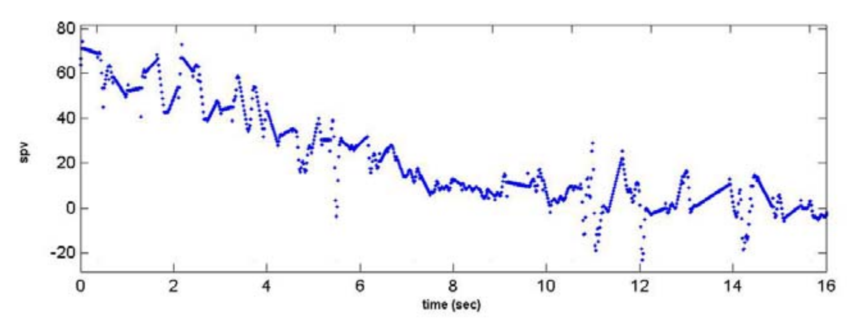


Figure 4.2. Typical SPV decay over a period of 16 seconds. (Subject 5, Day 2, Phase 1, HT 4)

Once the portion of SPV to analyze is selected, the operator can "clean" the data by eliminating what clearly appears as remaining noise and blinks (Figure 4.3) that would affect greatly the fitting process. It appeared that the quantity of noise increased during the experiments, probably a consequence of the heating of the miniature cameras. Since the human eye is very proficient at determining trends and pattern, the operator could clean the data as much as desired to obtain the best result in later operations. Data elimination (*data_eliminator.m*) allows the operator to delimit polygonal areas on the plot of the selected section of SPV. All data points included in these areas are eliminated from further processes (see Garrick-Bethell, 2004, for a complete description of the algorithm behind the data elimination routine). This procedure is very efficient (see Figures 4.4 and 4.5).

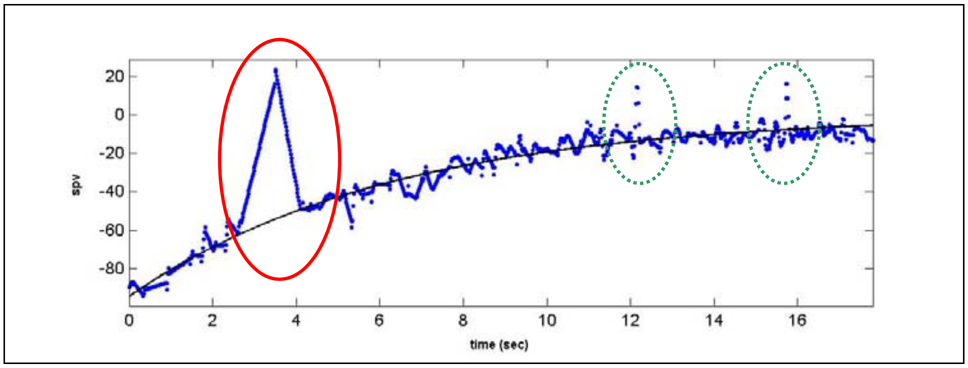


Figure 4.3. Typical gaze shift (solid line), residuals of blink activity (doted lines), and exponential fit (curved) as seen by the human eye. (Subject 3, Day 1, Phase 3, HT 3)

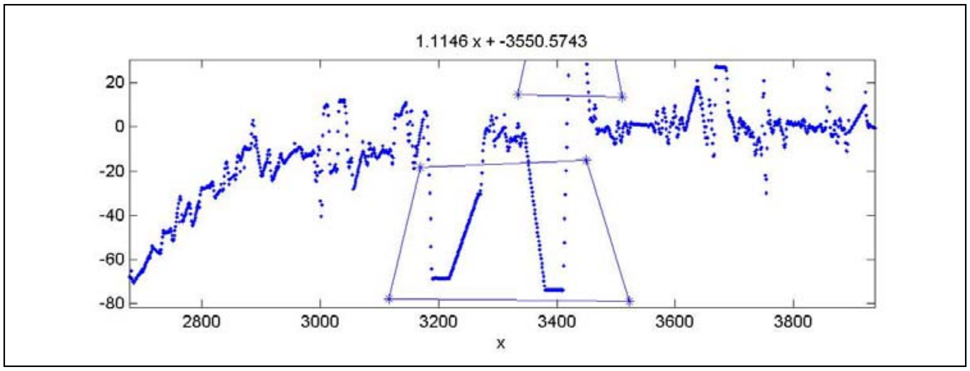


Figure 4.4. Working plot of data elimination routine. The polygons delimit the areas where data points should be removed. (Subject 5, Day 2, Phase 1, HT 1)

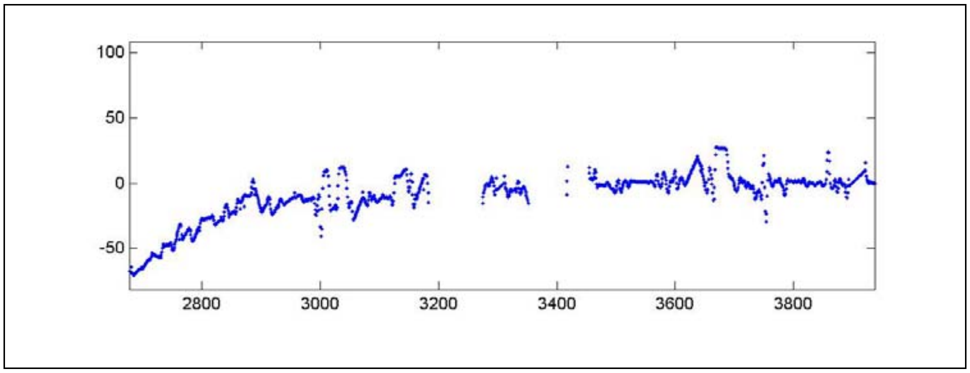


Figure 4.5. Working plot of data elimination routine, after data removal (from Figure 4.4). (Subject 5, Day 2, Phase 1, HT 1)

Finally, with the remaining data points, a regression-based curve fitting procedure is performed to find the best curve (Figure 4.6). The goodness of fit is evaluated using an F-test (ratio of the regression mean square error to the residual mean square error). All regressions have F-values greater than 3 (corresponding to a level of significance $p < 0.05$). It is confirmed here that data elimination improves the fit of curves (Figures 4.7 and 4.8).

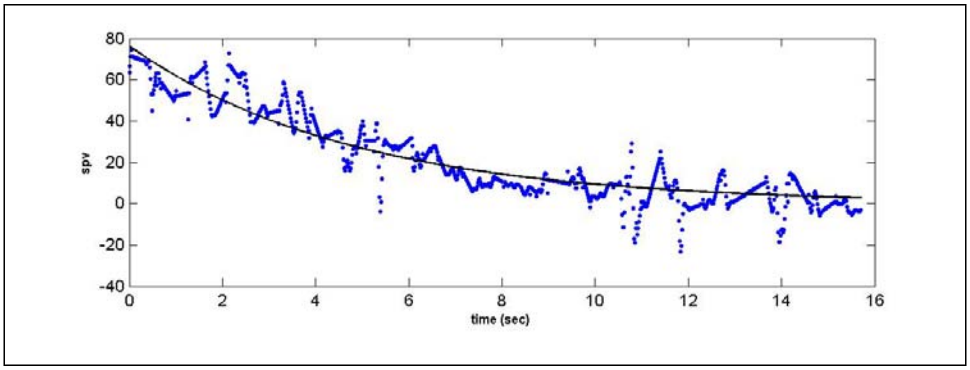
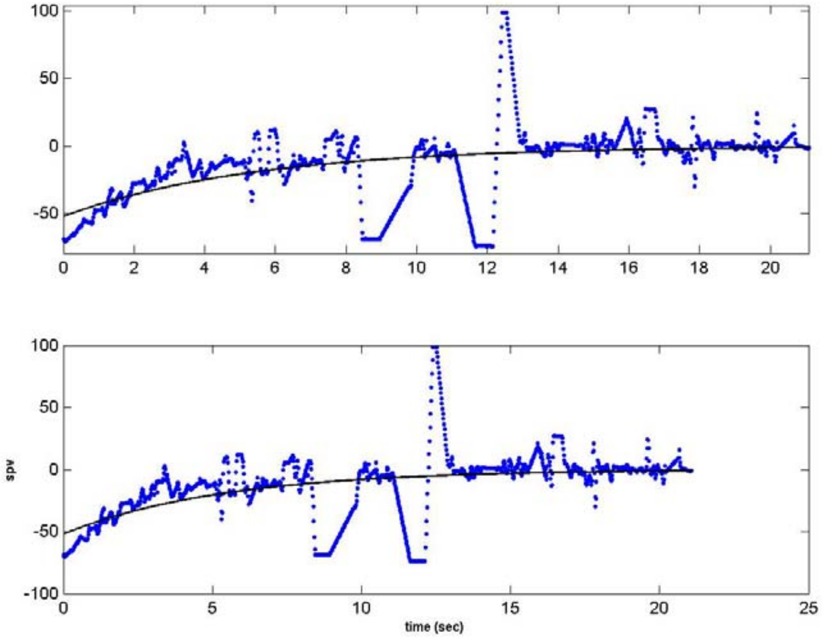


Figure 4.6. Fitted curve: (A, τ) = (76.25, 4.77). F = 3588. (Subject 5, Day 2, Phase 1, HT 4)



Figures 4.7. Exponential fit on SPV recoding, without data elimination.
(A, τ) = (-51.9664, 5.4226). F = 207. (Subject 5, Day 2, Phase 1, HT 1)

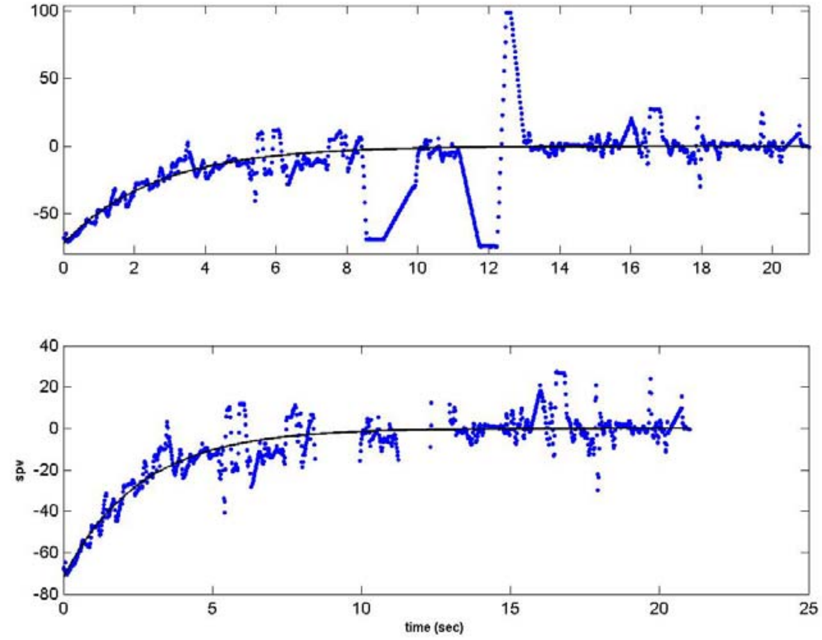


Figure 4.8. Exponential fit on SPV recoding, after data elimination.
(A, τ) = (-72.03, 2.59). F = 2610. (Subject 5, Day 2, Phase 1, HT 1)

[to compare with (A, τ) = (-51.9664, 5.4226), F = 207, without data elimination]

The outputs of the whole procedure (amplitude A and time constant τ) are recorded in a classical Microsoft Excel spreadsheet.

4.2 Subjective Assessments Analysis.

Subjective ratings of motion sickness, intensity of sensation and illusory tilt are recorded by the experimenters using Microsoft Excel spreadsheets (see Appendix D). Data for all subjects, in all sessions of both experiments are then concatenated in a single spreadsheet, to which all physiological data (amplitude and time constant of the eyes movements) were added. These Excel spreadsheets are easily transferable to the statistics software used in the next chapter.

4.3 Missing values.

In spite of the rigorous protocol and of the care taken, several data points were lost for eye movements (τ and amplitude), due to hardware malfunction and/or excessive blinking by the subject. In the 31 such cases, τ and amplitude values could not be determined using the Matlab procedure, because of an extremely noisy signal coming from the goggle. In order to compensate for the lack of data, these missing values were replaced by inserts when possible: we averaged the values of the two other points for the same phase and direction (since in most cases, only one point was missing within a phase/direction combination). 7 out of 31 missing data points were treated. The remaining 24, all for subject INC7 on Days 3 and 4, were irrecoverable because the entire data set for the two days was missing.

Chapter 5

Results

5.1 Overview.

There were significant signs of adaptation in the experimental group: the time constant of the SPV decay, motion sickness, and the intensity of illusory sensation decreased over days in Phases 1 and 3. As expected, the motion-sickness scores and the intensity of illusory sensation ratings increased over the experimental day in the adaptation phase (Phase 2) as the stimulus increased, day by day, following the experimental design.

In the control experiment, the same measured quantities did not change detectably in the pre- and post- adaptation phases, 1 and 3. Only the motion sickness reported in phase 2 decreased significantly from day to day, but the fractional decrease was slight.

Table 5.1 summarizes the statistical methods used in this chapter. Significance is at the $p < 0.05$ level. The SYSTAT software package (v. 10, Systat Software Inc.) performed the mixed regressions and the General Linear Model (GLM) univariate repeated measures ANOVA. Page tests were performed using StatXact software (v. 4, Cytel Software Corporation).

	Experimental Group	Control Experiment
Physiological Measures	Mixed Regression and GLM ANOVA	GLM ANOVA
Subjective Measures	Page Test	Page Test

Table 5.1. Summary of statistical methods used.

Section 5.2 will address drop-out issues. Sections 5.3 and 5.4 respectively present in details the results obtained for the experimental group and the control experiment.

5.2 Comments on Drop-Out.

Only one subject (INC6) dropped out the experiment, after the first session (Day 1). Although reports of intensity of illusory sensation and of illusory tilt remained in normal ranges, motion sickness assessment were greater than 10 for three head turns in Phase 1, even reaching 12 for the last head turn, just before the limit of 13 at which the operator has instructions to stop the experiment. During Phase 2, MS reports were among the average with other subjects. In Phase 3 however, these assessments reached again high values, including 13 for the last head turn. At this point, the operator asked the subject if he would come back on Day 2. The subject politely refused, explaining that he would not be able to undergo such stimuli a second time.

Apart from INC6, all six other subjects for the experimental group completed the whole protocol. The proportion of drop-out is therefore 1/7 ≈ 14%, with no doubt lower than drop-out rates in previous experiments (Sienko, 2000; Lyne, 2000; Brown, 2002; Newby, 2002).

5.3 Experimental Group.

5.3.1 Eye Data.

5.3.1.1 Peak Amplitude of SPV (A).

We studied the absolute value of the amplitude. Figure 5.1 presents its distribution for each subject, and shows that those distributions are consistent with the belief that they are normally distributed.

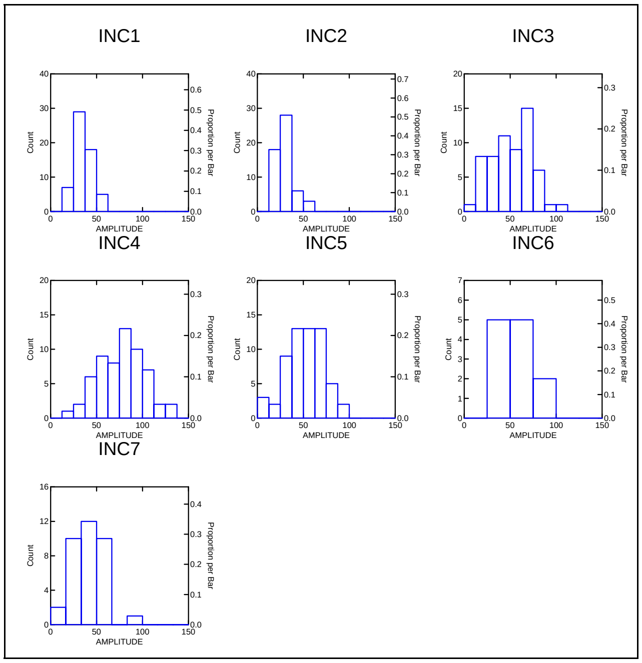


Figure 5.1. Distribution of A (deg/sec), by subject.

We performed a mixed regression on the amplitudes against the variables Day and Replication, with the categories Phase and Head Turn Direction. Table 5.2 summarizes the results.

	Amplitude		
	Estimate	(+/-) Error	p-value
Day	0.140	0.129	p = 0.278
Phase	-2.596	4.874	p = 0.594
Rep	-0.093	0.598	p = 0.877
Direction	2.646	1.014	p = 0.009

Table 5.2. Summary of the results of a mixed regression on Amplitudes.

The turns to-RED led to bigger peak SPV-amplitudes than those to-NU (p = 0.009, Figure 5.2). This confirms observations in previous experiments (Sienko, 2000; Brown, 2002), where the peak amplitude of the slow phase velocity was significantly higher for head turns made to Right-Ear-Down than to Nose-Up.

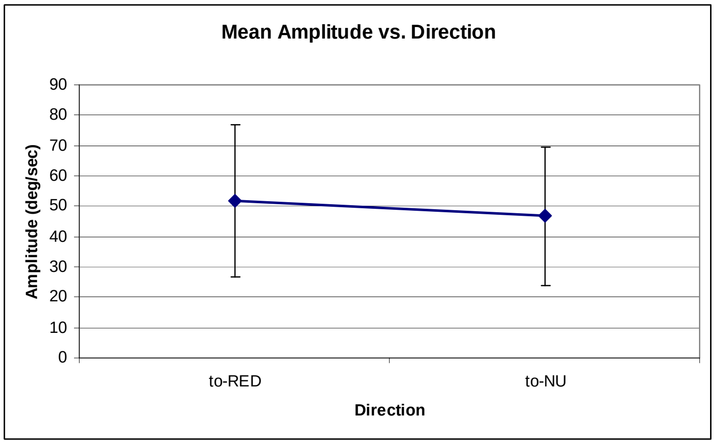


Figure 5.2. Amplitude (deg/sec) vs. Direction.

No significant effects were found by the GLM repeated-measures ANOVA.

5.3.1.2 Time Constant of SPV Decay (τ).

Figure 5.3 presents the distributions of τ by subject. They are consistent with the assumption of normality.

We performed a GLM ANOVA on the time constants against the categories Phase and Head Turn Direction, and the variables Day and Replication (Table 5.3).

	Tau	
	F	p-value
Phase	F(1,4) = 13.087	p = 0.022
Direction*Rep	F(2,8) = 5.305	p = 0.034

Table 5.3. Summary of the results of a GLM ANOVA on τ.

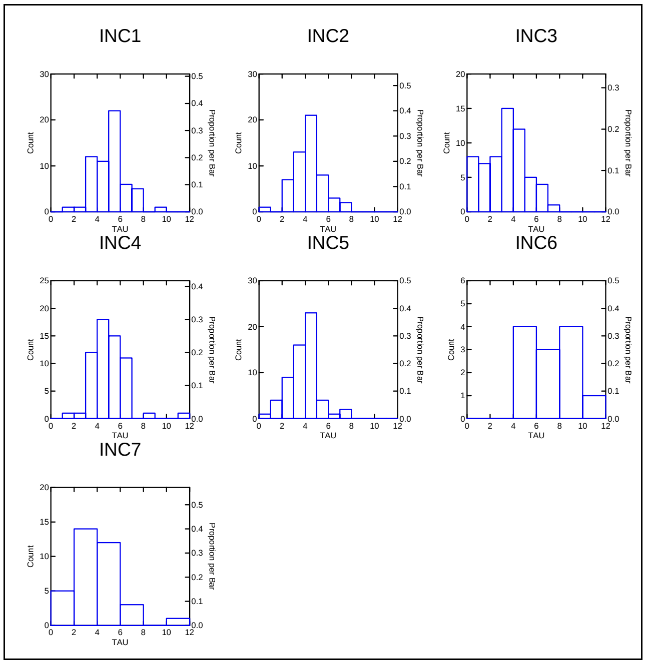


Figure 5.3. Distribution of τ (sec) for each subject.

The time constant of the decay of SPV decreased over Phases (p = 0.022, Figure 5.4). This is a prominent sign that subjects adapted within a day, over phases. Phase 2 had a significant impact on the time constant over time: it decreased over phases. This suggests that the experimental intervention (the increasing speeds of rotations in the adaptation phase) is efficient in eliciting adaptation.

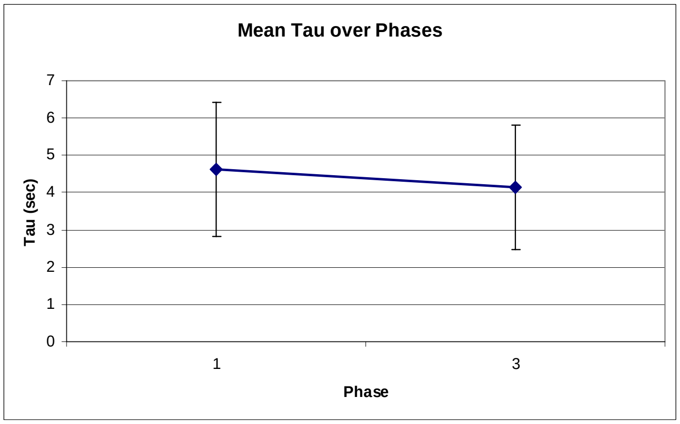


Figure 5.4. Decrease of τ (sec) over Phases.

The significant cross-effect Direction*Rep (p = 0.034, Figure 5.5) was found. Although there was no significant main effect of Direction (of head-turn on time constant) nor of Replication number, the effect of Replication was significantly higher for the to-RED than for the to-NU direction.

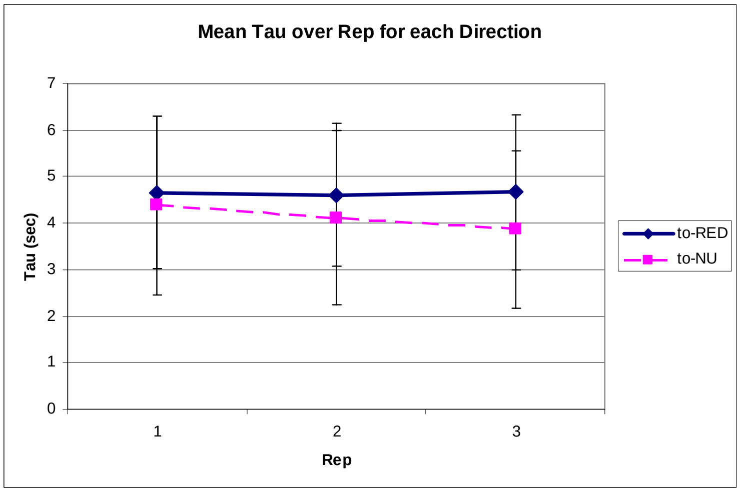


Figure 5.5. τ (sec) over Rep for each Direction.

As mentioned in Section 4.3, some data points were missing, which voided the full data set for a subject under GLM ANOVA. Therefore, we also performed a mixed regression because of its greater robustness in the use of data (Table 5.4).

	Tau		
	Estimate	Error	p-value
Day	-0.281	0.053	p = 0.000
Phase	0.638	0.168	p = 0.000
Rep	-0.068	0.047	p = 0.146
Direction	0.226	0.079	p = 0.004
Phase*Day	-0.136	0.051	p = 0.008

Table 5.4. Summary of the results of a mixed regression on time constants.

The time constant of the decay of SPV decreased over Days (p = 0.022, Figure 5.6). This suggests that Phase 2 is efficient in creating adaptation that is preserved and enhanced from day to day.

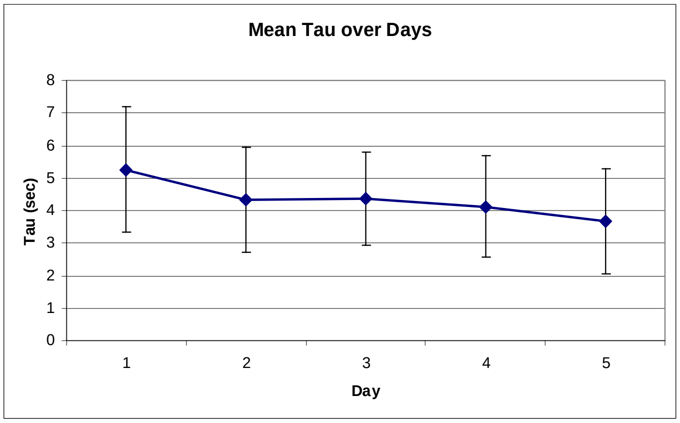


Figure 5.6. Decrease of τ (sec) over Days.

The cross-effect of Phase*Day was significant (p = 0.008, Figure 5.7) which indicates that the effect of phase (on time-constant) was different from day to day. This was expected, since the adaptation phases were driven at increasing speeds of rotation from day to day. This elicited more conflict, and, as we had expected, more adaptation.

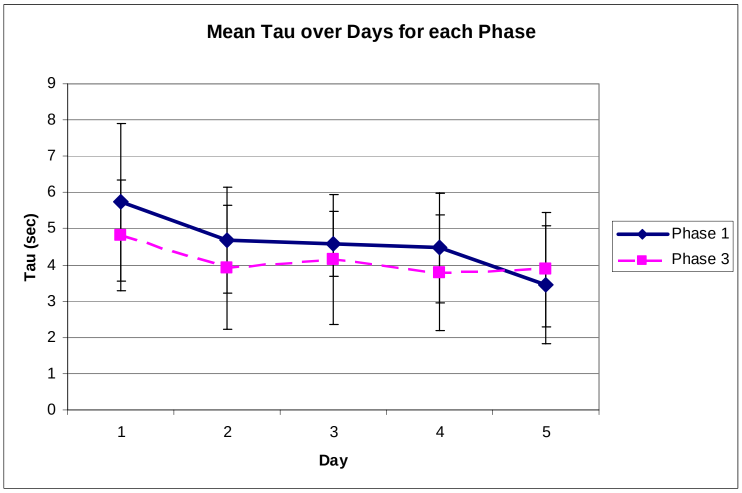


Figure 5.7. τ (sec) over Days for each Phase.

It also appeared that to-RED head turns led to bigger time constants than to-NU head turns (p = 0.004, Figure 5.8), the result we found with peak amplitudes, which is in accord with earlier research (Sienko, 2000; Brown, 2002), and our findings with Amplitudes.

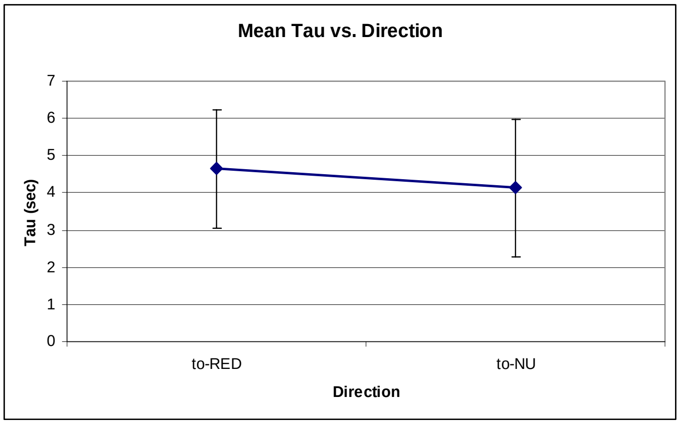


Figure 5.8. τ (sec) vs. Direction.

5.3.2 Subjective Assessments.

We performed non-parametric Page tests on the subjective measures (motion sickness, intensity of illusory sensation, and illusory tilt), at the $p < 0.05$ level to search for possible trends over the days of the experiment. The Page test tests for trends of monotonic increase (or decrease) among measures presented in a fixed order (Table 5.5).

	MS	IS	IT
Phase 1 to-RED over 5 days	p = 0.1416	p = 0.0000	p = 0.1459
Phase 1 to-NU over 5 days	p = 0.0060	p = 0.0002	p = 0.2949
Phase 2 to-RED over 5 days	p = 0.0000	p = 0.0000	p = 0.0970
Phase 2 to-NU over 5 days	p = 0.0001	p = 0.0000	p = 0.0002
Phase 3 to-RED over 5 days	p = 0.5	p = 0.0000	p = 0.1384
Phase 3 to-NU over 5 days	p = 0.0488	p = 0.0000	p = 0.1051

Table 5.5. Summary of the results of Page tests on subjective assessments.

5.3.2.1 Motion Sickness (MS).

Subjective ratings of Motion Sickness decreased significantly over days for to-NU head turns in Phase 1 ($p = 0.006$, Figure 5.9) and in Phase 3 ($p = 0.0488$, Figure 5.10), suggesting that adaptation occurred and was retained over days. No significant trend was found in the to-RED direction.

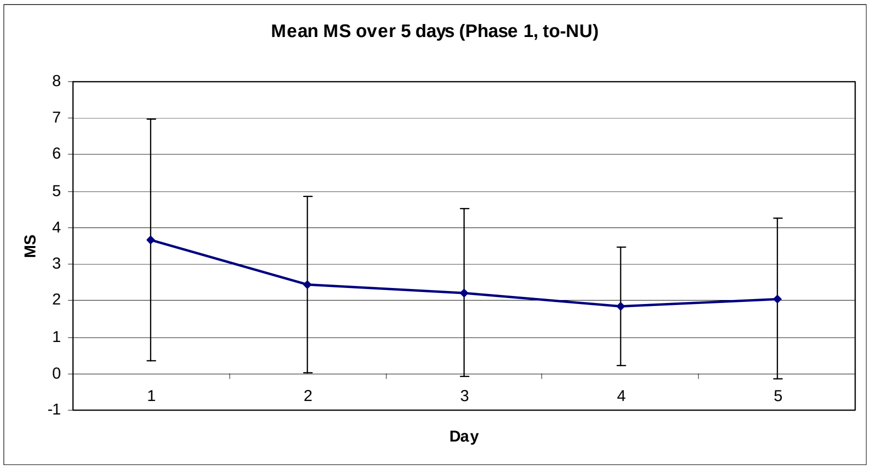


Figure 5.9. Decrease of MS over days (Phase 1, to-NU).

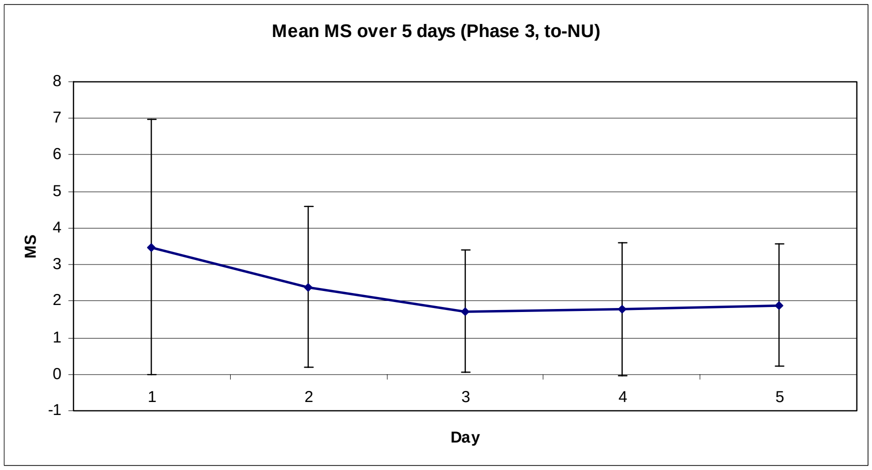


Figure 5.10. Decrease of MS over days (Phase 3, to-NU).

Conversely, and as expected, MS scores significantly increased over days for Phase 2, in both to-RED ($p < 0.00005$, Figure 5.11) and to-NU ($p = 0.0001$, Figure 5.12) directions. This may be attributed to the increase in speed of rotation and therefore in the cross-coupled stimulus that was administered in this adaptation phase.

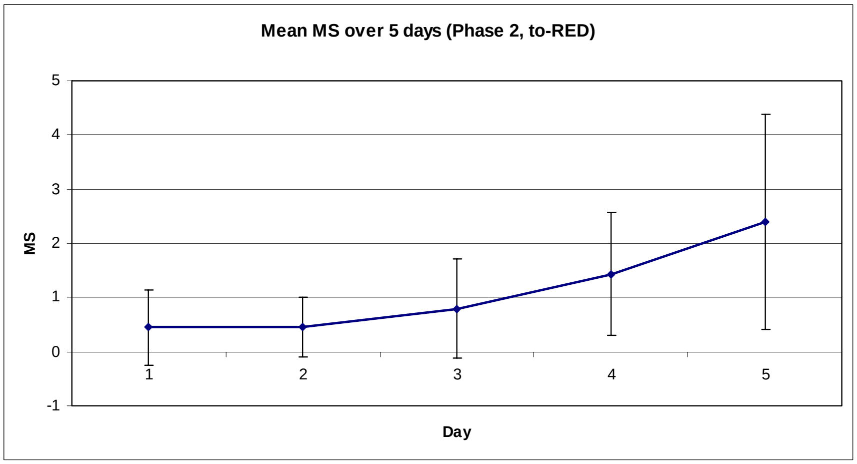


Figure 5.11. Increase of MS over days (Phase 2, to-RED).

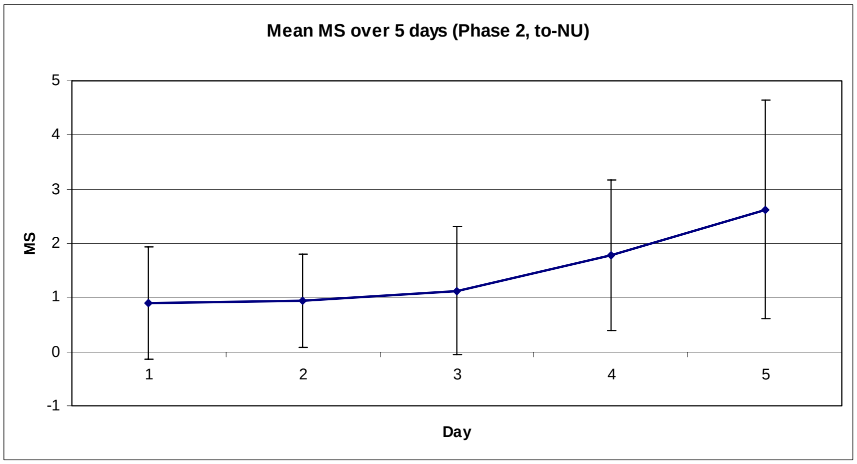


Figure 5.12. Increase of MS over days (Phase 2, to-NU).

5.3.2.2 Intensity of Sensation (IS).

Subjective ratings of intensity of illusory sensation decreased significantly over days in Phase 1 for both to-RED ($p < 0.00005$, Figure 5.13) and to-NU ($p = 0.0002$, Figure 5.14) directions; and in Phase 3 for both to-RED ($p < 0.00005$, Figure 5.15) and to-NU ($p < 0.00005$, Figure 5.16) directions. Again, this is a sign that adaptation occurred and was retained throughout the weekly protocol

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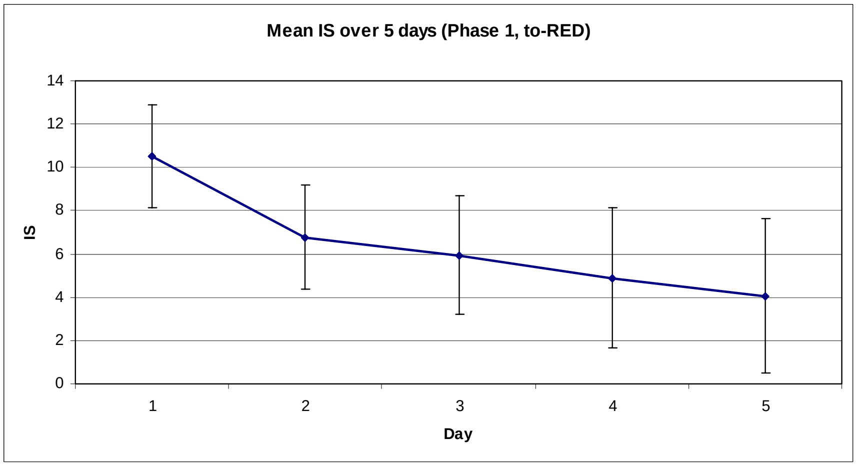


Figure 5.13. Decrease of IS over days (Phase 1, to-RED).

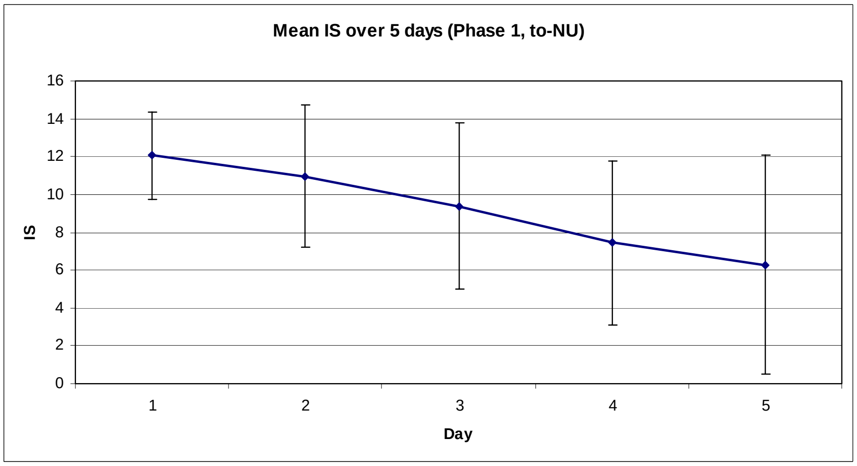


Figure 5.14. Decrease of IS over days (Phase 1, to-NU).

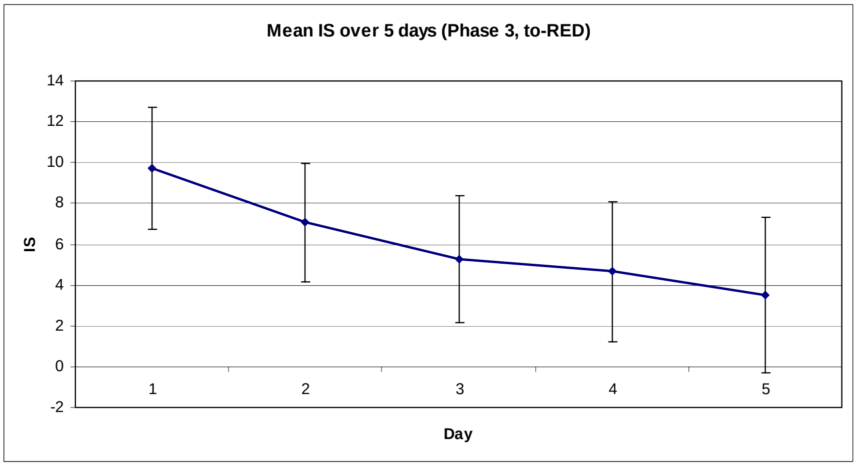


Figure 5.15. Decrease of IS over days (Phase 3, to-RED).

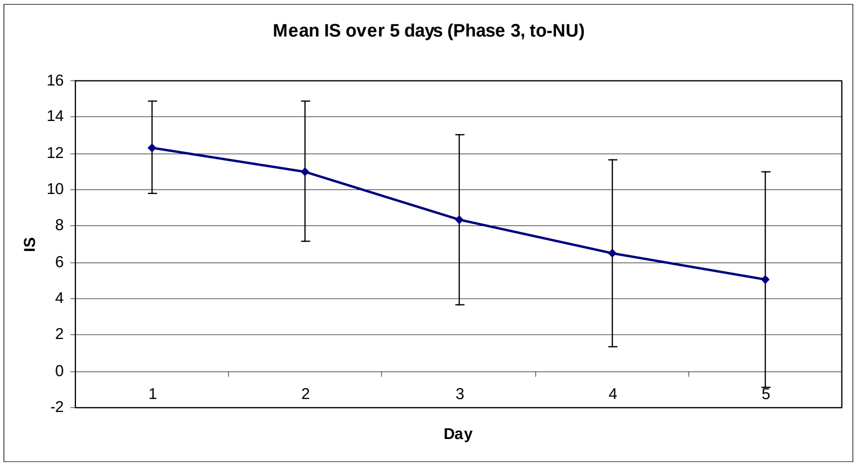


Figure 5.16. Decrease of IS over days (Phase 3, to-NU).

Conversely, and as expected, IS scores increased significantly over days for Phase 2, in both to-RED ($p < 0.00005$, Figure 5.17) and to-NU ($p < 0.00005$, Figure 5.18) directions. The increasing stimulus in Phase 2 provoked increasing intensity of illusory sensation in both directions.

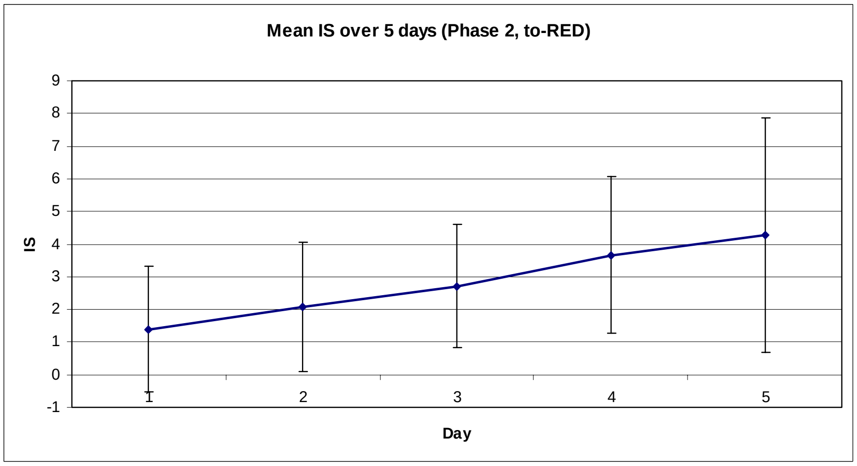


Figure 5.17. Increase of IS over days (Phase 2, to-RED).

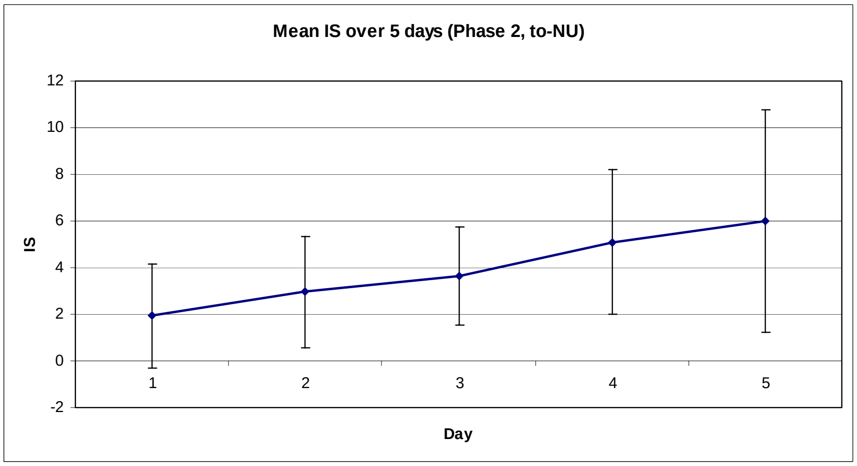


Figure 5.18. Increase of IS over days (Phase 2, to-NU).

5.3.2.3 Illusory Tilt (IT).

Reports of perceived body tilt decreased over days in Phase 2, for to-NU head-turns (p = 0.0002, Figure 5.19). This result was expected: to-NU directions elicit a sensation of pitching forward, which corresponds to values lower than 45 in IT. As the stimulus increases over days in Phase 2, the reported IT falls farther below 45. There was no sign of a complementary increase of IT for the to-RED direction.

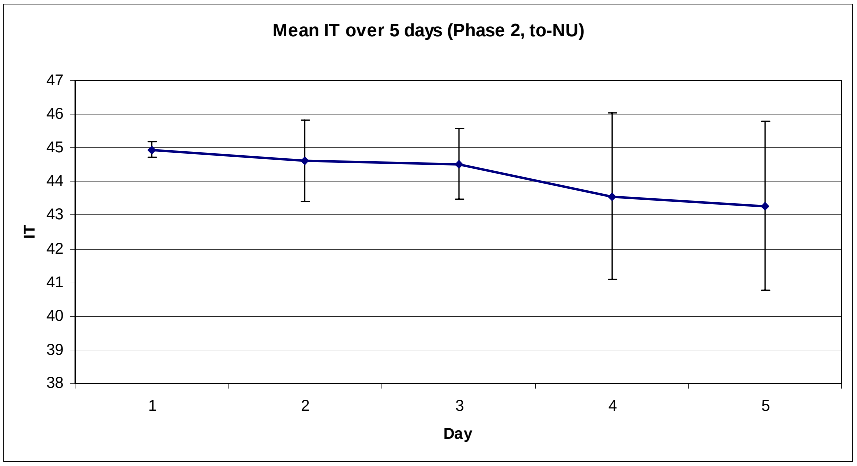


Figure 5.19. Decrease of IT over days (Phase 1, to-RED).

5.4 Control Experiment.

5.4.1 Eye Data.

5.4.1.1 Peak Amplitude of SPV (A).

Phase (p = 0.048, Figure 5.20) and Direction (p = 0.021, Figure 5.21) had significant main effects on amplitude; Day*Phase*Rep (p = 0.01, Figures 5.22 and 5.23) and Phase*Dir*Rep (p = 0.044, Figures 5.24 and 5.25) cross-effects on amplitude were found to be significant, also, by GLM univariate repeated measures ANOVA. The significance levels shown were Huynh-Feldt corrected. Table 5.6 summarizes the results.

	Amplitude	
	F	p-value
Day	F(1,7) = 0.245	0.636
Phase	F(1,7) = 5.739	0.048
Rep	F(2,14) = 0.367	0.699
Direction	F(1,7) = 8.840	0.021
Day*Phase*Rep	F(2,14) = 6.744	0.010
Phase*Dir*Rep	F(2,14) = 4.792	0.044

Table 5.6. Summary of the results of a GLM ANOVA on amplitudes.

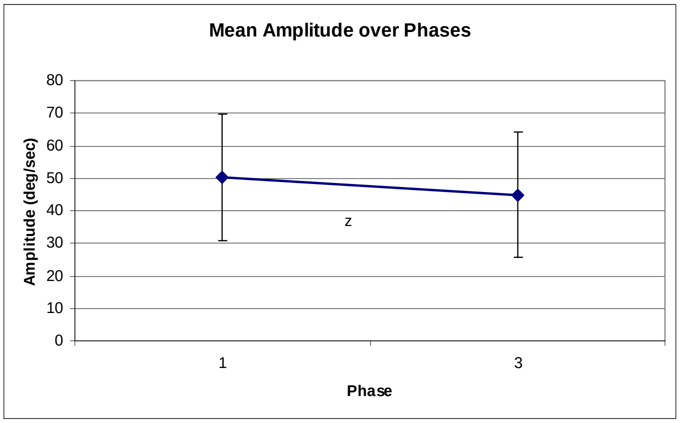


Figure 5.20. Decrease of Amplitude (deg/sec) over Phases.

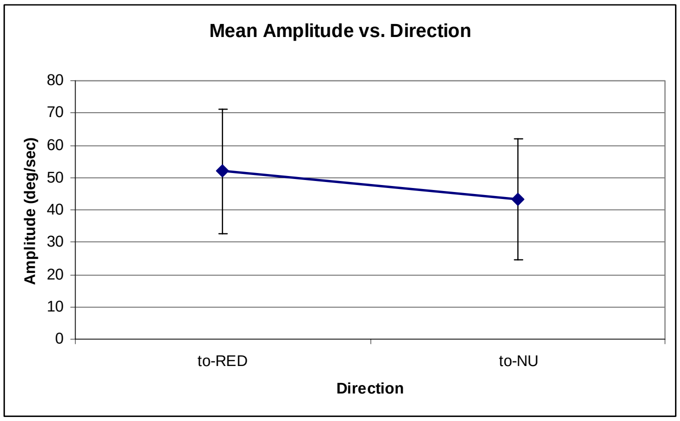


Figure 5.21. Amplitude (deg/sec) vs. Direction.

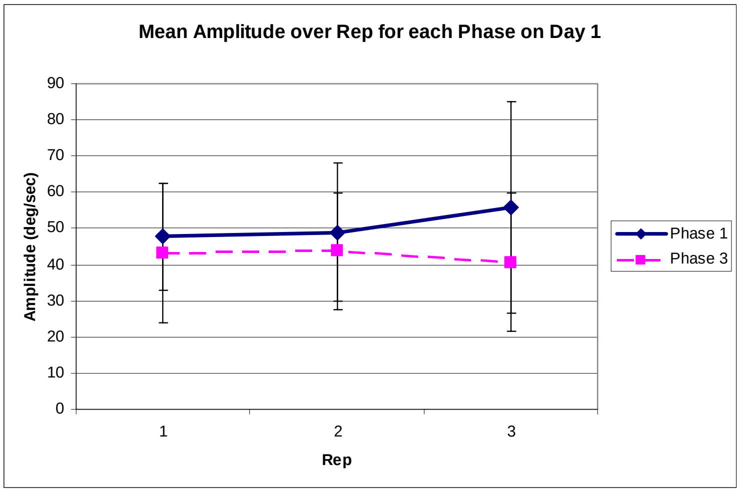


Figure 5.22. Amplitude (deg/sec) over Replication for each Phase (Day 1).

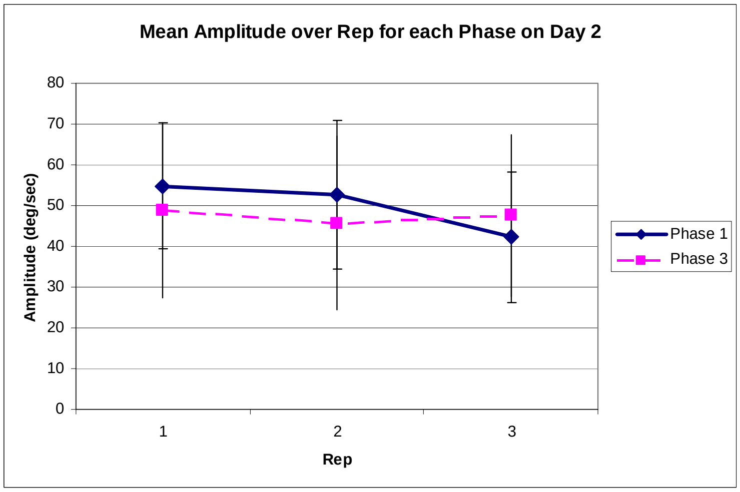


Figure 5.23. Amplitude (deg/sec) over Replication for each Phase (Day 2).

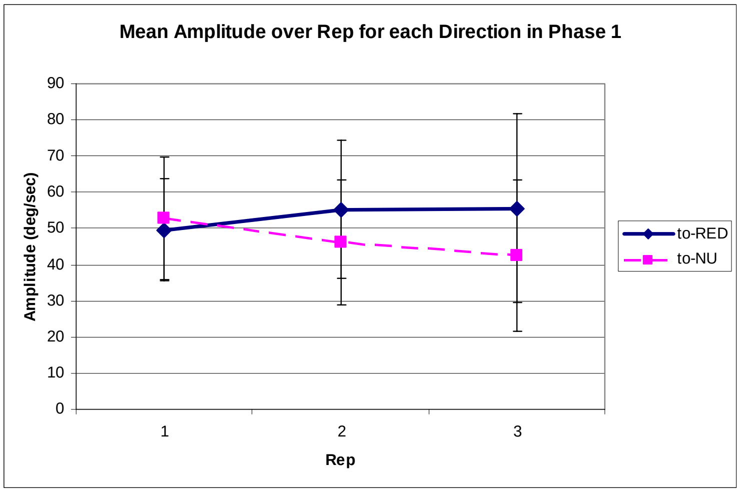


Figure 5.24. Amplitude (deg/sec) over Replication for each Direction (Phase 1).

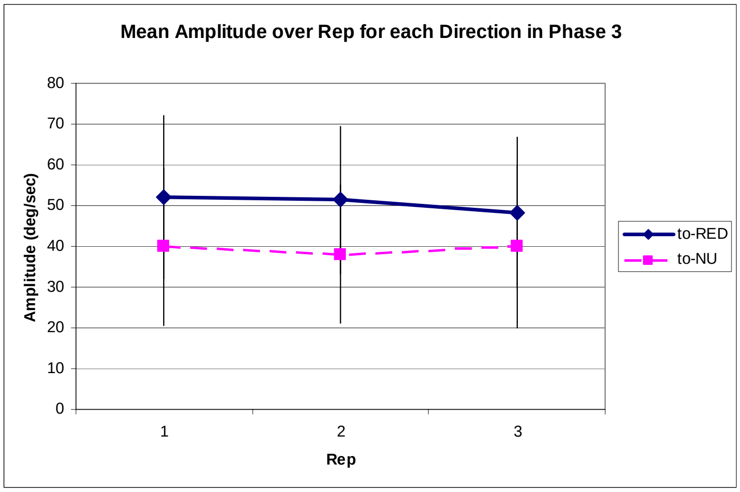


Figure 5.25. Amplitude (deg/sec) over Replication for each Direction (Phase 3).

5.4.1.2 Time Constant of SPV Decay (τ).

No significant effect was found for any variable on the time constant, under GLM repeated measures ANOVA, and none was expected. The protocol was designed to elicit as little adaptation as possible, so the protocol would not be distorted by the measurements.

5.4.2 Subjective Assessments.

As expected, motion-sickness ratings in Phase 2 (when subjects lie motionless on the centrifuge) decreased over the two days of this control experiment (p = 0.0313, Figure 5.26), but no other trend in MS values was found (Table 5.7). This decrease was expected: subjects become habituated to the experimental environment and feel more comfortable on Day 2 than on Day 1.

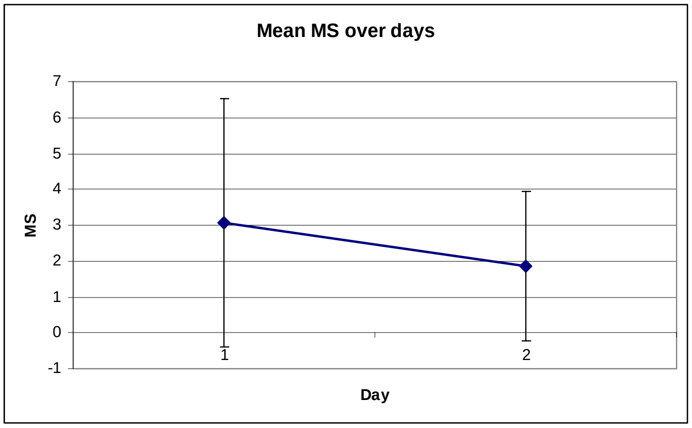


Figure 5.26. Decrease of MS over Days.

No significant effects on intensity of sensation or on illusory-tilt were found, in any of the three phases (Table 5.7). This was expected in Phase 2 because no head turn is made at all, therefore IS and IT should remain constant. It was also expected in Phases 1 and 3, as a result of the absence of adaptation.

	MS	IS	IT
Phase 1 to-RED over 2 days	p = 0.3438	p = 0.2266	p = 0.5000
Phase 1 to-NU over 2 days	p = 0.5000	p = 0.2266	p = 0.2266
Phase 2 no HT over 2 days	p = 0.0313	p = 0.1875	p = 0.1875
Phase 3 to-RED over 2 days	p = 0.1875	p = 0.1445	p = 0.5000
Phase 3 to-NU over 2 days	p = 0.1094	p = 0.1445	p = 0.5000

Table 5.7. Summary of the results of Page tests on subjective assessments.

Chapter 6

Discussion

6.1 Main Findings.

Four key findings are to be emphasized, following the results described in the previous chapter. Each of them will be explained in details in the following sections.

1) The Experimental protocol tested achieved adaptation (Section 6.2).

2) The Experimental protocol tested provoked less motion sickness than past experiments, leading to a smaller drop-out rate (Section 6.3).

3) A strong asymmetry in the head turn directions was characterized in both protocols (Section 6.4).

4) The Control Experiment did not elicit adaptation, confirming the need for head turns and the non-intrusiveness of our measurement protocol (Section 6.5).

6.2 Incremental Adaptation.

One way to validate an "adaptive protocol" to centrifugation is to characterize the fractional decrease between the pre- and post- adaptation phases (1 and 3) of the amplitude of the slow phase velocity and of the time constant of its decay during inappropriate nystagmus, as well as the decrease in motion sickness, in the intensity of illusory sensation and in the illusory tilt. Among these five measures (A, τ, MS, IS and IT), four led to the unambiguous conclusion that adaptation occurred. Even better, both habituation and adaptation were found.

Indeed, τ decreased significantly over Phases: τ was significantly larger in Phase 1 than in Phase 3. This corresponds at least to a phenomenon of habituation, as described in several previous studies: following repeated stimulus, a reduction in the physiological and psychological responses occurs, another way of saying that the responding system is less prone to react to the stimulus. In addition, τ, MS, IS and IT decreased over Days, that is between sessions. This shows that subjects did build up adaptation to the stimuli.

The habituation of a session was rolled-over to subsequent experiences. Habituation is retained from Day 1 to Day 2, and the adaptation between Day 1 and Day 2 adds to the habituation of Day 2 to carry over the next sessions. The state of adaptation is reached when the response to a specific stimulus is different than what it was in the first instance (first head turns in Phase 1 of Day 1).

Quantitatively, τ decreased of about 30% between Day 1 and Day 5 (by successive daily evolutions of -18%, +1%, -5% and -11%) both phases confounded. Independently, τ in Phase 1 decreased twice more (40% total, with daily steps of -18%, -2%, -2% and -22%) than τ in Phase 3 (20% total, with daily steps of -10%, +6%, -9%, +2%). These figures show that the different adaptation phases did not have the same, consistent effect, but that the overall trend is a significant decrease.

The fractional decrease of τ (-30%, about 1.60 sec) was slightly bigger than for previous research by Garrick-Bethell (2004, -25%, about 1.40 sec), and slightly lower than for earlier research by Sienko (2000, -33%). This suggests that the quality of the adaptive state reached with our protocol is similar to that of other protocols.

No similar results were found on Amplitudes. An explanation may come from operational issues. The calibration device for the eye-movements signals (the overhead cross mentioned in Chapter 3) was modified in the middle of the experiment, during the reconstruction of the centrifuge. Specifically, the mark that defines the height at which the cross should be placed was changed without notice, and then replaced at a position that may not have been its original position. Thus, the height of the cross may have changed between subjects. Such a modification would only affect the amplitude, and not the time constant of the SPV decay: it is a scaling factor. Therefore, it is not surprising that the effects found in τ and usually confirmed in amplitudes are not detected here.

The decrease in intensity of illusory sensation reached higher values: 62% between Phase 1 of Day 1 (average of 11.285) and Phase 3 of Day 5 (average of 4.28). Over the five Days, the fractional decrease specifically in Phase 1 was 54%, while that of Phase 3 was 61%. These results are similar to earlier experiments (Brown, 2002; Garrick-Bethell, 2004).

6.3 Motion Sickness.

The fractional decrease of motion sickness between the beginning of the protocol (Phase 1, Day 1) and its end (Phase 3, Day 5) was about 46%. Over the five days, MS decreased of about 41% in Phase 1 and 40% in Phase 3. These decreases are smaller than those in previous experiments (-67.5%, Brown, 2002).

More important, average MS ratings in the adaptation phase never exceeded 3 on any day of the experiment: 0.89 on Day 1, 0.93 on Day 2, 1.12 on Day 3, 1.77 on Day 4 and 2.62 on Day 5. In previous studies, motion sickness reports reached higher values (for example: 4, 6, 6.5 according to the protocol, for Brown, 2002, on Day 1, to be compared with our Day 5, first day at maximum speed).

These previous experiments, although achieving adaptation, suffered from huge drop-out rates. Among our seven subjects in the experimental protocol, only one dropped-out. And it is very likely that the experiment was not at the origin of this drop-out since this volunteer appeared to be overly susceptible to motion sickness: in spite of the medical screening, we failed to detect beforehand a personal history of sea/plane/car-sickness.

Therefore, we can conclude that our protocol elicited less motion sickness than previous protocols.

6.4 Direction Asymmetry.

In both experiments, it appeared that the physiological and subjective measurement differed based on the Direction to which head turns were performed. Direction was significant for the SPV measures (τ and Amplitude) in the experimental group, and Direction had significantly different effects in the Amplitude over Phases in the control experiment. Responses to to-RED head turns were larger in τ and in Amplitude than for to-NU responses. Conversely, physiological measures showed the reverse trend: head turns performed toward Nose-Up elicited more motion sickness, more intensity of illusory sensation of tumbling and more illusory tilt, than toward Right-Ear-Down.

The direction asymmetry was found in previous studies and tentatively explained by Newby (2002), as the result of otolith-canal interactions. The otolith organs, through velocity storage, can influence the nystagmic response depending on the position of the head relative to the gravity vector. The orientation of the gravity vector with respect to the canals is different in the RED and NU positions.

The difference in trend of direction asymmetry results from the dissociation between the adaptation of physiological parameters and subjective experience as explained by Brown (2002). Adaptation is very stimulus-specific and affects the two categories of measures in two different ways: this allows potentially different responses. Physiological adaptation (decrease in τ and Amplitude) is the result of the VOR being turned down to prevent retinal slip; while subjective perceptions are the result of the update of an internal model (motion sickness and subjective perceptions are triggered by the conflict between expected and experienced sensations).

6.5 Control Experiment.

As stated previously, adaptation is characterized by a reduction in the Amplitude (A) of the SPV and the time constant of its decay (τ), as well as by a decrease of discomfort (MS), and of illusory subjective sensations (IS and IT). Statistical tools were used to search for these characteristics in the control experiment's data, but failed to find any significant proof of such modifications in τ, MS, IS and IT, suggesting that we failed to find signs of adaptation in this experiment. With the knowledge of earlier research (by Guedry, Graybiel, Young, Brown, Sienko, Hecht, Cheung etc…), it is reasonable to conclude that, indeed, no adaptation was achieved in this experiment, because of the lack of stimulus to provoke it.

However, caution should be addressed: a significant decrease of the peak Amplitude of the SPV has been found over Phases, indicating that the inappropriate nystagmus diminished between the pre- and post- adaptation phases. Since no sign of such a decrease over the Days was detected, we can state that this phenomenon is just habituation and not adaptation. In addition, no similar result was found for the time constant τ, whereas the two measurements usually evolve in the same trends. As stated in Section 6.2, the data set of Amplitude is subject to caution. Therefore, this sole result is not strong enough to endanger our conclusion of an absence of adaptation.

A second sign of habituation was detected: MS significantly decreased over Days in Phase 2. Although this phenomenon was found across Days, we do not consider it as adaptation, because adaptation is triggered by a stimulus. In Phase 2, no head turn was performed; therefore no stimulus could elicit cross-coupled effects and lead to adaptation. We believe that this habituation is just the result of subjects feeling more comfortable and less stressed on Day 2 than on Day 1, as they already know the experimental environment and the protocol.

The fact that no adaptation emerged from this control experiment enables two important consequences. First, it means that the measurement protocol (6 head turns in pre- and post- adaptation phases) with the current hardware configuration can be validated for use, since it does not influence motionless subjects. Secondly, it also proves that the repeated provocation *via* head turns is the acting factor that drives adaptation in our experiment.

6.6 Limitations.

The major limitation of this work is the number of subjects. While it was easy to recruit subjects for the Control Experiment (2 sessions of one hour), finding volunteers for the Experimental Group revealed to be far harder. Even with financial retribution, very few students have a schedule that allows them to volunteer for experiments over five days. Also, due to MIT restrictions and COUHES policy, it is not permitted to spin subjects for more than one hour. That is why the experiment had to be spread over a week, allowing for enough time to make enough head turns. But several past studies investigating incremental adaptation also had few subjects: 7 for Guedry and Graybiel's (1962) first incremental protocol (64 hours at 5.4 rpm), 4 for Graybiel et al. (1969) and their adaptation to slow centrifugation (32 days at 10 rpm). In addition, although we screened the subjects for medical history, we failed to detect in advance potential problems. For example, a volunteer appeared to suffer from claustrophobia: before anything began, when the opaque canopy was put in place, he started to be panic-stricken. Therefore he could not even start one session.

Concerning the hardware used in this experiment: the stable inside light was provided by a portable flashlight, instead of the deficient on-board lighting system, that was removed. This did not appear to affect the subjects, because they are in control, which may make them more confident and in a better state during the experiment. But for further experiments, it would be better to have a stable lighting system that is really stable.

The eye movements measuring device also had a few drawbacks. While incorporating the old goggles-system into a large ski-mask enhanced the stability of the system, its need to be worn at a very low position on the face prevented some subjects from breathing correctly. Most of them indicated that it bothered them in the first minutes, but that they could bear with it for the rest of the experiment. Nevertheless, future devices should solve this problem, so as to be sure it does not add to the motion sickness of the experiment. Also, it was noticed that in the course of a session, the quality of the eye movements' signal tended to worsen. This was probably due to the heating of the camera, interfering with the electrical signal that was recorded.

Finally, the question of the accuracy of the subjective assessments is to be addressed. We have seen that past research have accredited these methods (Frankenhaeuser et al., 1962; Frankenhaeuser, 1967; Guedry et al., 1971), but our experiment presents particular situations. First, the stimulus that is assessed in subjective metrics is not the rotation of the centrifuge, but what this rotation provokes "inside" the subject. Then, the stimulus cannot be shut down (because gravity is still there) which implies that there is no real experience of "no sensation", for scaling purposes. This might introduce a bias in the sensation description. In addition, the vestibular system integrates several components that are not all fully understood, like the personal history of motion sickness, the fear / apprehension of the experiment, and other daily factors that cannot be taken into account by the experimenter since, in most cases, even the subject him/herself is not aware of them. Also, there is a hysteresis problem in all these subjective assessments: when a stimulus is approached from a direction or another, the judgment might not be the same. This is a problem of short-term history of behavior that is not easily solved. Finally, our experimental protocol stated that subjective assessments were made during and after the physiological response. This overlap might create some interference: Guedry and Lauver (1961) have shown that, in their experiment, subjective reactions end short before the physiological reaction goes back to normal. This could mean that subjective assessments may not always really match their corresponding physiological metrics.

6.7 Recommendations for Future Work.

1) One of the most affecting drawbacks of this experiment was the need to have the subjects come on five consecutive days, preferably at similar times in the day. Whereas it is likely that such a protocol could be easily implemented in astronauts training either on the ground or up in space, this particularity in the protocol makes it very time consuming, therefore limiting the number of subjects available. In this view, it would be reasonable to try to condense the experiment over a single day: for example, two sessions could be implemented in the morning and three in the afternoon. If such a protocol still satisfies the criteria (adaptation occurs with a reasonable drop-out rate), it will allow for more testings and a more rapid analysis of the data (quicker response to needs for protocol modifications).

2) This experiment satisfactorily achieved adaptation, because the fractional decreases of τ, MS, IS are comparable to those in earlier experiments, because MS was contained in an acceptable range, and finally because the proportion of subjects completing the whole experiment has significantly increased. However, other criteria to define a “better” adaptation may be considered, as the duration of exposure (time cost), linked to the number of head turns performed in the adaptation phase.

3) Several velocity increase profiles should be tested. Head turns at 3 rpm and even 5 rpm, for several subjects, did not elicit apparent motion sickness. But it is possible that some adaptation indeed occurred in these phases. We believe that exposing subjects to an initial speed higher than 10 rpm for the

adaptation phase (Phase 2) is to be avoided because it would elicit too much uncommon sensations to the subject. It is better to start with a phase that does nothing and then increase the sensations than start right away with highly provocative stimuli. In addition, doing so would create a confidence and safety climate around the subject, who would be reassured about the experiment, his/her performances and the possible sensations he/she might encounter. Subjects would then be more likely to finish the experiment. Another factor that could be worth investigating is the duration of the adaptation phase: our protocol suggests 30 head turns are enough to achieve adaptation. But can we achieve the same adaptation with fewer head turns? Can we achieve better adaptation, in terms of fractional decrease of the measures, with more head turns? Also, the frequency of both head turns (every 30 seconds) and sessions (every day) should be investigated.

4) Finally, other experiments in the Man Vehicle Laboratory showed that the use of pitch movements was more provocative, but yielded better adaptation and better eye-movement data. So far, no experiment has been implemented to adapt subjects directly to pitch movements (Garrick-Bethell, 2004). An incremental protocol using pitch movements might be worth investigation: this would first determine if the protocol is efficient in reducing motion sickness without compromising adaptation, and, second, with a comparison of both experiments, if yaw stimulation and pitch stimulation can be, in general, addressed in the same manner. It might be that movement-specific adaptation protocols are required (different intensity, duration, frequency, incremental profile…).

Chapter 7

Conclusions

The goal of this research was double: firstly, we tried to verify that an incremental exposure to centrifugation could achieve adaptation to the discomfort and inappropriate physiological responses elicited by head movements while spinning; secondly, we tried to test the measurement protocol (Phases 1 and 3: pre- and post- adaptation phase) to see if its operation does not distort the process of adaptation. Two experiments have been implemented in the Man Vehicle Laboratory at MIT to answer these questions, and the goals have been achieved.

The experimental protocol was found to be an efficient way for adaptation purposes: the drop-out rate was reduced to 14% instead of 30 to 50%, subjects felt more comfortable running the experiment, and adaptation occurred similarly to previous experiments.

The control experiment did not elicit adaptation, which is what we were looking for: 1) lying on a rotating bed without active implication of the vestibular apparatus does not modify the physiological and subjective metrics studied in adaptation experiments, and 2) our measurement protocol is not invasive.

References

Balkwill MD (1992). *Changes in the Human Horizontal VOR after the Spacelab SLS-1 Mission*. Unpublished SM Thesis, Massachusetts Institute of Technology.

Benson AJ, Viéville Th (1986). *European Vestibular Experiments on the Spacelab-1 Mission: 6. Yaw Axis VOR*. Exp. Brain Res. 64:279:283.

Benson AJ, Guedry FE, Parker DE, Reschke MF (1997) *Microgravity Vestibular Investigations: Perception of Self-Orientation and Self-Motion*. Journal of Vestibular Research, Vol. 7, No. 6, 453-457.

Bergstedt M (1965). *Stepwise Adaptation to a Velocity of 10 rpm in the Pensacola Slow Rotation Room*. In: The role of vestibular organs in the exploration of space. Washington DC: NASA, 1965; 339:45.

Berry CA (1970). *Summary of Medical Experiences in the Apollo 7 through 11 Manned Space Flights*, Aerospace Medicine 41, 500-519.

Brooks CMcC (1969). *The Nature of Adaptive Reactions and Their Initiation*. In Bajusz E, *Physiology and Pathology of Adaptation Mechanisms*. Pergamon Press.

Brown EL (2000). *Artificial Gravity: The Role of Visual Inputs in Adaptation to Short-Radius Centrifugation*. Unpublished SM Thesis, Massachusetts Institute of Technology.

Brown EL, Hecht H, Young LR (2003). *Sensorimotor Aspects of High-Speed Artificial Gravity: I. Sensory Conflict in Vestibular Adaptation*. Journal of Vestibular Research, 12 (2002/2003), 271-282.

Brubakk AO (2000). *Man in Extreme Environment*. Aviat. Space Environ. Med., 71(9, Suppl.):A126-130.

Burton RR, Mecker LJ (1992). *Physiologic Validation of a Short-Arm Centrifuge for Space Application*. Aviat. Space Environ. Med. 63:476-481.

Cheung CC (2000). *Artificial Gravity: Regulator Control of a Short-Radius Centrifuge and Subjective Responses to Head Movements in a Rotating Environment*. Unpublished SM Thesis, Massachusetts Institute of Technology.

Christenson JM, Talbot JM (1986). *A Review of the Psychological Aspects of Spaceflight.* Aviat. Space Environ. Med. 57:203-212.

Cobb, S. V. G. (1999). *Measurement of postural stability before and after immersion in a virtual environment*. Applied Ergonomics, *30*, 47-57.

Czarnik TR (1999). *Artificial Gravity: Current Concerns and Design Considerations*. WSU-Aerospace Medicine. March 1999.

Dator J (2003). *Earth Analogs for Human Space Exploration and Settlement*. International Space University. Accessed online in November 2003 at : http://www.futures.hawaii.edu/dator/space/analogs.pdf.

Diamandis PH (1988). *The Artificial Gravity Sleeper: a Deconditioning Countermeasure for Long Duration Space Habitation*. Unpublished SM Thesis, Massachusetts Institute of Technology.

DiZio P, Lackner JR (2003). *Sensorimotor Aspects of High-Speed Artificial Gravity: III. Sensorimotor Adaptation*. Journal of Vestibular Research, 12 (2002/2003), 291-299.

Draper, M.H. (1998). *The Adaptive Effects of Virtual Interfaces: Vestibulo-Ocular Reflex and Simulator Sickness*, Unpublished doctoral dissertation, University of Washington, Seattle.

DuBois-Reymond E (1848). *Untersuchungen über Thierische Elektrizität*. G. Reimer, Berlin.

Frankenhaeuser M, Sterky K and Järpe G (1962). *Psychophysiological Relations in Habituation to Gravitational Stress.* Perceptual and Motor Skills, *15*, 63-72.

Frankenhaeuser M, Fröberg J, Hagdahl R, Rissler A, Björkvall C, and Wollf B (1967). *Physiological, Behavioral, and Subjective Indices of Habituation to Psychological Stress.* Physiology and Behavior, 2, 229-237.

French AP, Ebison MG (1986) *Classical Mechanics*. Van Nostrand Reinhold [UK] Co.Ltd.

Garrick-Bethell I (2004). *Cross Plane Transfer of Vestibular Adaptation to Human Centrifugation.* Unpublished SM Thesis, Massachusetts Institute of Technology.

Gescheider GA (1985). *Psychophysics: Methods, Theory, and Application*. Hillsdale, NJ: Erlbaum Associates. 135-214.

Giurfa M, Menzel R (2003). *Biology of Adaptation and Learning.* In *Adaptivity and Learning*. Kühn R, Menzel R, Wenzel W, Ratsch U, Richter MM, Stamatescu IO (Eds.), Springer Verlag.

Graybiel A, Deane FR, Colehour JK (1969). *Prevention of Overt Motion Sickness by Incremental Exposure to Otherwise Highly Stressfull Coriolis Accelerations*. Aerosp. Med. 1969; 40:142-8.

Graybiel A (1973). *Vestibular Mechanisms Underlying Certain Problems in a Rotating Spacecraft*. In Fifth Symposium on the Role of the Vestibular Organs in Space Exploration, 1970 (pp. 35-39). NASA Report SP-314. Washington DC.

Graybiel A (1977). *Some Physiological Effects of Alternation Between Zero Gravity and One Gravity*. In J. Grey (Ed.), Space manufacturing facilities (space colonies): proceedings of the Princeton/AIAA/NASA conference, May 7-9, 1975.

Guedry FE, Lauver LS (1961). *Vestibular Reactions During Prolonged Constant Angular Acceleration*. J. Appl. Physiol. 16(2): 215-220.

Guedry FE, Graybiel A (1962). *Compensatory Nystagmus Conditioned During Adaptation to Living in a Rotating Room.* J. Appl. Physiol., Vol 17(3):398-404.

Guedry FE, Collins WE, Graybiel A (1964). *Vestibular Habituation During Repetitive Complex Stimulation: a Study of Transfer Effects*. J. Appl. Physiol. 19(5): 1005-1015.

Guedry FE (1965). *Habituation to Complex Vestibular Stimulation in Man: Transfer and Retention of Effects from 12 Days of Rotation at 10rpm*. Percept. Mot. Skills; 21:459-81.

Guedry FE, Stockwell CW, Gilson RD (1971). *Comparison of Subjective Responses to Semicircular Canal Stimulation Produced by Rotation About Different Axes*. Acta Otolaryng 72:101-106.

Guedry FE, Benson AJ (1978). *Coriolis Cross-Coupling Effects: Disorienting and Nauseogenic or Not?* Aviation, Space, and Environmental Medicine, January 1978, p.29-35.

Hecht H, Brown EL, Young LR (2002). *Adapting to Artificial Gravity at High Rotational Speeds*. Journal of Gravitational Physiology, Vol. 9(1).

Howard P (1982). *Principles and practice of Human Physiology*. Ed. Edholm OG and Weiner JS. Academic Press, London.

Howard P (1986). *The Vestibular System*. In K.R. Boff, L. Kaufman & J.P. Thomas (Eds.), *Handbook of Perception and Human Performance* (pp. 11:1 - 11:30). New York: John Wiley.

Hu S, Stern RM, Koch KL (1991). *Effects of Pre-Exposures to a Rotating Optokinetic Drum on Adaptation to Motion Sickness*. Aviat. Space Environ. Med., 62:53-6.

Jones EM, Schmitt HH (1992). *Pressure Requirements for Moon and Mars EVA's*. Los Alamos National Laboratory Report LA-UR-91-3083. Proceedings, Space 1992, American Society of Civil Engineers, Denver, CO.

Kanas N, Salnitskiy V, Grund EM, Gushin V, Marmar CR (2001). *Psychosocial Countermeasures for International Space Station Missions.* Proceedings of the 52nd International Astronautical Congress, Toulouse, France.

Kanas N, Salnitskiy V, Grund EM, Gushin V, Weiss DS, Kozerenko O, Sled A, Marmar CR (2002). *Lessons Learned from Shuttle/Mir: Psychosocial Countermeasures*. Aviation, Space and Environmental Medicine 73, 607-11.

Lackner JR, Lobovits DN (1978). *Incremental Exposure Facilitates Adaptation to Sensory Rearrangement*. Aviat. Space Environ. Med. 49(2):362-364.

Lathan CE, Clément G (1997). *Response of the Neurovestibular System to Spaceflight*. In: Fundamentals of Space Life Sciences. Vol 1, Edited by: Churchill SE, Malabar: Krieger, 65-82.

Larson WJ and Giffen RB (2004). *An Introduction to Human Spaceflight*. In: Larson WJ and Pranke LK (Eds.) Human Spaceflight, Mission Analysis and Design.

Letko W (1973). *Locomotion in a Rotating Environment.* In Fifth Symposium on the Role of the Vestibular Organs in Space Exploration, 1970 (pp. 67-72). NASA Report SP-314. Washington DC.

Lieber RL (1992). *Skeletal Muscle Structure and Function*. Baltimore: Williams & Wilkins.

Lyne LE (2000). *Artificial Gravity: Evaluation of Adaptation to Head Movements During Short-Radius Centrifugation Using Subjective Measures*. Unpublished SM Thesis, Massachusetts Institute of Technology.

Mast FW, Newby NJ, Young LR (2003). *Sensorimotor Aspects of High-Speed Artificial Gravity: II. The Effect of Head Position on Illusory Self-Motion*. Journal of Vestibular Research, 12 (2002/2003), 283-289.

McNab BK (2002). *The Physiological Ecology of Vertebrates*. Cornell University Press.

Merfeld DM, Park S, Gianna-Poulin C, Black FO, Wood S (2004). *Neural Processing of Ambiguous Sensory Cues from the Otolith Organs: Human Responses*. Submitted to Journal of Neuroscience, March 2004.

Newby NJ (2002). *Artificial Gravity: The Role of Graviceptive Information during Cross-Coupled Rotation in Context-Specific Adaptation*. Unpublished SM Thesis, Massachusetts Institute of Technology.

Newman DJ, Barratt M (1997). *Life Support and Performance Issues for Extra-Vehicular* Activities. In: Churchill SE, Fundamentals of Space Life Science, Krieger Publishing.

Newman DJ (2003). Class lectures, Space Biomedical Engineering and Life Support (16.423J), Massachusetts Institute of Technology, 2003.

Noordung H (1927). *The problem of Space Travel*.

Ohnishi T, Takahashi A, Ohnishi K (2001). *Biological Effects of Radiation*. Biol. Sci. Space. 15 Supplement: S203-210.

Oman CM (1988). *Motion Sickness: a Synthesis and Evaluation of the Sensory Conflict Theory*, Canadian Journal of Physiology and Pharmacology, Dec. 1988, 68, p.294-303.

Oman CM, Pouliot CF, Natapoff A (1996). *Horizontal Angular VOR Changes in Orbital and Parabolic Flight: Human Neurovestibular studies on SLS-2*. J. Appl. Physiol. 81(1): 69-81.

Oman CM (2003). *Vestibular Physiology*, class lecture, Space Biomedical Engineering and Life Support (16.423J), Massachusetts Institute of Technology, 2003.

Parker JF, West VR (1973). *Bioastronautics Data Book,* Second Edition, NASA SP-3006.

Pitts BM (2003). *Spacesuit: Space Craft*. Unpublished SM Thesis, Massachusetts Institute of Technology.

Reason JT, Brand JJ (1975). *Motion Sickness*. London: Academic Press.

Reason JT (1978). *Motion Sickness Adaptation: a Neural Mismatch Model*, J R Soc Med, 71:819-829.

Robinson DA (1981). *Control of Eye Movements*. In: Brooks VB (Ed.), *The Handbook of Physiology Vol II, Part 2, The Nervous System* (pp. 1275-1320), Baltimore: Williams & Wilkens.

Santy PA (1983). *The Journey Out and In: Psychiatry and Space Exploration*. Am. J. Psychiatry 140:519-527.

Santy PA (1994). *Choosing the Right Stuff: The Psychological Selection of Astronauts and Cosmonauts.* Wesport: Praeger.

Shaw JM, Hackney AC (1989). *Psychophysiology in Microgravity and the Role of Exercise*. In Workshop on Countering Space Adaptation with Exercise: Current Issues. NASA Conference Publication 3252.

Shipov A (1975). *Artificial Gravity*. In Space Biology and Medicine, Nicogossian, Mohler, Gazenko and Grigoriev, Editors, AIAA Reston VA, p359.

Sienko KH (2000). *Artificial Gravity: Adaptation of the Vestibulo-Ocular Reflex to Head Movements during Short-Radius Centrifugation*. Unpublished SM Thesis, Massachusetts Institute of Technology.

Slobodkin LB (1964). *The Strategy of Evolution*. Am. Sci. 52:342-357.

Sonnenfeld G (2002). *The Immune System in Space and Microgravity*. Med. Sci. Sports Exerc., 34(12):2021-7.

Sonnenfeld G, Shearer WT (2003). *Immune Functions During Spaceflights*, Nutrition 18, 899-903.

Stern RM, Hu S, Vasey MW, Koch KL, 1989. *Adaptation to Vection Induced Symptoms of Motion Sickness*. Aviat. Space Environ. Med. 1989; 60:566-72.

Stevens SS (1958). *Problems and Methods of Psychophysics*. Psychological Bulletin, 55, 177-196.

Stevens SS (1960). *Ratio Scales, Partition Scales and Confusing scales*. In H. Gulliksen & S. Messick (Eds.), *Psychological Scaling: Theory and Applications*. New York: Wiley.

Stevens SS (1975). *Psychophysics: Introduction to Its Perceptual, Neural and Social Aspects*. John Wiley & Sons, Inc.

Stoffregen TA, Draper MH, Kennedy RS, Compton D (1999). *Vestibular Adaptation and Aftereffects Measurements*. Chapter 44 of a *Virtual Environment handbook*. Accessed online in June 2004 at http://vehand.engr.ucf.edu/handbook/Chapters/Chapter44/Chapter_44.html

Stone RW, Letko W (1970). *Some Observations on the Stimulation of the Vestibular System of Man in a Rotating Environment*. Langley Research Center Report, NASA.

Stone RW (1973). *An Overview of Artificial Gravity*. In Fifth Symposium on the Role of the Vestibular Organs in Space Exploration. Pensacole, FL: Naval Aerospace Medical Research Laboratory, NASA SP-314, 23-33.

Stuster J (2000). *Bold Endeavors: Behavioral Lessons from Polar and Space Exploration*. Grav. Space Bio. Bulletin, 13(2).

Tomi LM, Rosskha K, Hosein J (2001). *The Role of Cross-Cultural Factors in Long Duration International Space Missions: Lessons from the SFINCSS-99 Study.* Proceedings of the 52nd International Astronautical Congress, Toulouse, France.

Tribble AC (2004). *The Space Environment – Hazards and Effects*. In: Larson WJ and Pranke LK (Eds.) Human Spaceflight, Mission Analysis and Design.

Tsiolkovsky KE (1911). *Sobr. Soch.* Collected Work. Vol.2 No1, 100-139.

Welch RB (1978). *Perceptual Modifications, Adapting to Altered Sensory Environments*. Academic Press, New-York.

Wertz JR and Larson WJ (2004). *Space Mission Analysis and Design*. Microcosm Press and Kluwer Academic Publishers.

Wilson VJ, Melvill-Jones G (1979). *Mammalian Vestibular Physiology*, Plenum Press, New-York.

Young LR, Oman CM (1969). *Model for Vestibular Adaptation to Horizontal rotation*. Aerospace Medicine, 40, 10.

Young LR, Henn VS (1974). *Selective Habituation of Vestibular Nystagmus by Visual Stimulation*. Acta Otolaryng 77:159-166.

Young LR (1983). *Perception of the Body in Space: Mechanisms*. In Brookhart JM, Mountcastle VB, Magoun HW, *Handbook of Physiology: The Nervous System III*. Bethesda, MD: American Physiological Society, 1023-1066.

Young LR, Sinha P (1998). *Spaceflight Influences on Ocular Counterrolling and Other Neurovestibular Reactions*. Otolaryngol Head Neck Surg, 118, S31-S34.

Young LR (1999). *Artificial Gravity Considerations for a Mars Exploration Mission*. Annals of the New-York Academy of Science, 871, 367-378.

Young LR (2000). *Vestibular Reactions to Spaceflight: Human Factors Issues*. Aviation, Space, and Environmental Medicine, Vol. 7, No. 9, Section II.

Young LR, Hecht H, Lyne LE, Sienko KH, Cheung CC, Kavelaars J (2001). *Artificial Gravity: Head Movements During Short-Radius Centrifugation*. Acta Astronautica, Vol. 49, No. 3-10, 215-226.

Young LR (2003)a. *Space Orientation*, in "Principle and Practice of Aviation Psychology", 2003, p.73-77.

Young LR (2003)b. *Motion Perception and the Vestibular System*, class handout, Human Factors Engineering (16.400-16.453), Massachusetts Institute of Technology, 2003.

Zhang LF (2001). *Vascular Adaptation to Microgravity: What Have We Learned?* Journal of Applied Physiology, 91, 2415-2430.

Zubrin R (2003). *Testimony to the Senate Commerce Committee*, October 29th 2003.

Appendix A

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MAN-VEHICLE LABORATORY

ARTIFICIAL GRAVITY: NEUROVESTIBULAR ADAPTION TO INCREMENTAL EXPOSURE TO CENTRIFUGATION

SUBJECT MEDICAL FORM

<u>The subject confirms not to have one of the following problems or diseases:</u>

- Frequent or severe headache
- Dizziness or fainting spells
- Paralysis
- Epilepsy
- Disturbances in consciousness
- Loss of control of nervous system functions
- Neuritis
- Loss of memory or amnesia
- Lazy eye
- Cross looking of the eyes
- High or low blood pressure
- Recent loss or gain of weight
- Moderate car, train, sea or air sickness
- Cylindrical eye lenses
- Reduced eye movements
- Astigmatisms
- Ear, nose or throat trouble
- Hearing loss
- Chronic or frequent cold
- Head injury
- Asthma
- Shortness of breath
- Pain or pressure in the chest
- Thyroid trouble
- Inability to perform certain motions
- Inability to assume certain positions
- Medication (check for sedatives, anti-dizziness, anti-depressants; birth prevention medication is allowed)
- Substance dependence or abuse (includes alcohol, and drugs like sedatives, anxiolytics,, cocaine, marijuana, opioides, amphetamines, hallucinogens or other psychoactive drugs or chemicals)
- Diagnosis of psychosis, bipolar disorder or severe personality disorders
- Hear problems (check for angina pectoris, coronary heart disease, congenital heart disease, myocardial infarction in the past, cardiac valve replacement, pacemaker)

<u>Questions:</u>

- Handedness:
- Sleep quality recent weeks before experiment:
- Vision (glasses, lenses, non):

Date:
Experimenter:
Subject :

Appendix B

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MAN-VEHICLE LABORATORY

CONTEXT-SPECIFIC ADAPTATION OF OCULOMOTOR RESPONSE TO CENTRIFUGATION

CONSENT FORM

I have been asked to participate in a study on adaptation to movement in a rotating environment. I understand that participation is voluntary and that I may end my participation at any time for any reason. I understand that I should not participate in this study if I have any medical heart conditions, respiratory conditions, if I have any medical conditions which could be triggered if I develop motion sickness, if I am under the influence of alcohol, caffeine, anti-depressants, or sedatives, if I have suffered in the past from a serious head injury (concussion), or if there is any possibility that I may be pregnant. My participation as a subject on the MIT Artificial Gravity Simulator (AGS) involves either the testing of equipment or actual experimental trials.

Prior to rotation on the AGS, I will be oriented to the rotator and data acquisition instrumentation. I understand that my height, weight, heart rate, blood pressure, and general medical history may be measured and recorded. During the experiment I will lie in either the supine, the prone position, or on the side on the rotator bed. If I am in the prone or side position my head will be supported by a pivoting, cushioned headrest. The headrest will allow me to make a free range of head movements to the left and the right, and I will be in full control of my head movement at all time. If I experience any discomfort from head movement while in either the prone or the supine position, I am free to discontinue the movements at any times. During the experiment, I will also wear eye imaging goggles. How these devices will feel has been described to me. I agree to participate in possible stationary monitoring periods before and/or after rotation.

My rotation on the AGS will not exceed the following parameters:
-acceleration no greater than 1rpm/s
-G level at my feet no greater than 1.5G
-time of rotation not exceeding 1 hour

I understand that these parameters are well within the safe limits for short-radius rotation. I can terminate rotation at any time by pressing the emergency stop button, the use of which has been demonstrated to me.

I understand that during rotation I may develop a headache or feel pressure in my legs caused by a fluid shift due to centrifugation. I may also experience nausea or motion sickness, especially as a result of the required head movements. The experimenter may terminate the experiment if I report a pre-determined degree of motion sickness symptoms. In addition, I understand that my heart rate may increase due to the rotation speed; this is no greater than that sustained during aerobic exercise, and will be measured before and after the experiment.

I understand that serious injury could result from the falling off the AGS while it is rotating. I will be closely restrained at by a safety belt, which is to be worn around the waist/chest at all times while the AGS is rotating. The restraint must be fastened in order for the AGS to rotate. If the restraint is unlatched, the AGS will stop automatically. In addition, the AGS is equipped with strong side railings similar to those on a hospital bed, and it is covered by a steel framed canopy. I will be continuously monitored by at least one experimenter in the same room. The investigators can also see me through a video camera mounted on the AGS, and in this way determine the nature of any problem that arise.

During and after the experiment I will be asked to report my subjective experience (how I feel, how I think I perceive my head movements, etc…). In addition, I will be asked to report a motion sickness rating both during the experiment. This data will be recorder anonymously.

If I am a participant in experimental trials, I tentatively agree to return for additional trials (at most 10) requested by the experimenter. I understand that a possible protocol for an actual trial will consist of a short period of supine rest in the dark, followed by a period of head movements (ranging from 90 degrees to the left, to vertical, to 90 degrees to the right) in the dark, followed by a period of similar head movements in the light, and that this trial could be repeated many times. During these head movements, my head will move at approximately a speed of 0.25 meter per second.

In the unlikely event of physical injury resulting from participation in this research, I understand that medical treatment will be available from the MIT Medical Department, including first aid emergency treatment and follow-up care as needed, and that my insurance carrier may be billed for the cost of such a treatment. However, no compensation can be provided for medical care apart from the foregoing. I further understand that making such medical treatment available, or providing it, does not imply that such injury is the investigator's fault. I also understand that by my participation in this study I am not waiving any of my legal rights (further information may be obtained by calling the Institute's Insurance and Legal Affairs Office at 253-2822).

Monetary compensation for those who are not members of the Man-Vehicle Laboratory will be $10 per hour. Subjects from the Man-Vehicle Lab will be taken on a voluntary basis and will not be paid.

I understand that I may also contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, Leigh Firn, M.D. (MIT E23-389, 253-6787), if I feel I have been treated unfairly as a subject.

I have been informed as to the nature of and the purpose of this experiment and the risks involved, and agree to participate in the experiment. In case I experience any discomfort, I am free to discontinue the head-movements any time I wish to do so. I understand that I will receive a copy of this consent form.

Subject Date Experimenter

Appendix C

Pre-Experiment Subject Briefing.

General Instructions.

During this experiment, while spinning on the centrifuge, you will be asked to make head movements. These head movements will consist in yaw turns to the right (RED, or right ear down head turn) and to the left (NU, or nose up head turn). These head movements will be demonstrated to you prior to the experiment, and you will be allowed a period of practice before the centrifuge starts spinning. Head turns should be 90° amplitude and about 1 second duration.

Protocol.

The experiment will consist of 5 sessions on 5 consecutive days. Each session will be divided into 3 phases.

Phase 1	Phase 2	Phase 3
Speed = 23 rpm 3 sets of 2 head turns (RED, NU) In the dark.	Speed = speed[day] 15 sets of 2 head turns (RED, NU) In stable light.	Speed = 23 rpm 3 sets of 2 head turns (RED, NU) In the dark.

Day	speed[day]
1	3 rpm
2	5 rpm
3	8.5 rpm
4	14 rpm
5	23 rpm

Phase 1 and 3 are identical. During these phases, your eyes movements will be recorded through the ISCSAN goggles you will wear. During phase 2, you will turn on the flashlight, in order to have a stable light surrounding you. Eyes movements won't be recorded during this phase. Phase 2 will change over the days: the speed will progressively increase so as to reach maximum speed on Day 5.

Eyes Recordings.

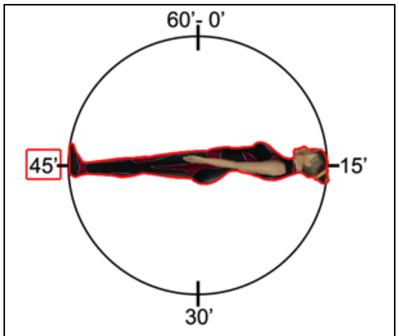
During the whole experiment, you will wear a ski-mask equipped with two infrared cameras that will record your eyes movement. You will also wear a blindfold during phases 1 and 3, to prevent any light from reaching your eyes. **It is VERY important that you keep your eyes wide open and avoid blinking during and after each movement**.

Subjective Assessments.

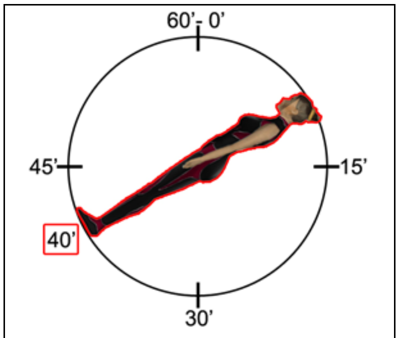
While spinning and making head movements, you will experience an illusory sensation of your body rotating or tumbling. This might cause motion sickness and a general feeling of discomfort. You will be asked after each head movement during phases 1 and 3, and after them every other set of head turns during phase 2, to report your subjective sensations. There are of three types:

> *MS: Report of Motion Sickness Score*
> Symptoms of motion sickness are similar to those experienced during sea-sickness (cold, heat, sweat…). This is an estimation of how *bad* you feel. MS is rated on a 0 to 20 scale to represent the overall feeling of discomfort. A score of 0 is for "I am fine" and a score of 20 is for "I am about to vomit". The operator will ask: "What is your motion sickness now?". You will have to answer by the number that you think best assesses your motion sickness.
>
> *IS: Report of Subjective Intensity of Sensations*
> Head turns made while the bed is rotating often elicit novel sensations one would not expect to experience if the bed were still. It is of primary concern to know how different the sensation is compared to making a head turn while stationary. The feelings you experiences during the first head turn you make while the bed is spinning in phase 1 will be assigned an arbitrary baseline value of 10. Every time the operator will ask "What is your sensation?", you will have to respond with a number from 0 to infinity, that is a relative value for the subjective intensity of the sensation experienced as a result of head turns, compared to the very first head turn (Day 1, Phase 1). For instance, a turn twice the intensity of the sensation of the first turn will be called a 20, and a turn with half the intensity will be called a 5. If the turn feels identical to a turn made while not spinning on the centrifuge, it will have a subjective intensity of 0.
>
> *IT: Report of Illusory Tilt*
> The specificity of the required head turns (right ear down and nose up) generates an illusory sensation of pitching forward or backward. You will be asked to report this sensation, based on an analogy with a clock dial. At rest, the body is lying on the

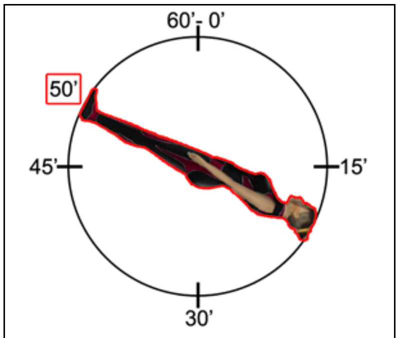
45-15 minutes axis (feet at 45', head at 15'). If you feel that you are pitching forward, then your feet will move between 30 and 45 minutes. If you feel that you are pitching backward, then your feet will move between 45 and 60 minutes. You will have to report your perceived feet position, when the operator asks "What is your feet/body position?".



Position at rest.



Pitching forward.



Pitching backward.

Final Question.

Do you have any question? You also have the possibility to ask anytime!

Appendix D

Raw Experimental Data.

Subjects for the control experiment are CS1 to CS8 (contex=0).
Subjects for the experimental group are INC1 to INC7 (contex=1).
Values in bold italic are inserts (see Section 4.3).
Question marks signal missing data.

SUBJECT	CONTEX	DAY	PHASE	DIR	REP	MS	IS	IT	TAU	AMP
CS1	0	1	1	0	1	2	10	40	6.3338	36.3681
CS1	0	1	1	1	1	2	10	45	5.1137	42.9557
CS1	0	1	1	0	2	1	7	40	7.5055	40.3352
CS1	0	1	1	1	2	1	9	45	5.9455	51.4471
CS1	0	1	1	0	3	2	8	40	6.4409	34.0109
CS1	0	1	1	1	3	4	11	40	6.3678	42.3416
CS1	0	1	2			1	5	47		
CS1	0	1	2			3	4	40		
CS1	0	1	2			1	7	40		
CS1	0	1	2			5	7	45		
CS1	0	1	2			4	6	45		
CS1	0	1	2			3	5	45		
CS1	0	1	2			3	5	45		
CS1	0	1	2			4	7	40		
CS1	0	1	3	0	1	2	8	40	6.4122	30.9652
CS1	0	1	3	1	1	4	11	35	6.6620	20.8382
CS1	0	1	3	0	2	6	11	40	7.4269	31.7594
CS1	0	1	3	1	2	6	10	40	7.7411	15.9049
CS1	0	1	3	0	3	6	11	40	8.9540	29.2800
CS1	0	1	3	1	3	7	12	40	7.3657	19.0976
CS1	0	2	1	0	1	1	5	40	5.2289	28.5229
CS1	0	2	1	1	1	1	5	35	6.0511	27.3144
CS1	0	2	1	0	2	1	5	40	8.4463	40.2524
CS1	0	2	1	1	2	1	6	40	4.7940	28.6560
CS1	0	2	1	0	3	2	7	35	5.7059	50.3106
CS1	0	2	1	1	3	1	5	35	5.5645	25.2448
CS1	0	2	2			1	5	35		
CS1	0	2	2			2	7	45		
CS1	0	2	2			1	6	35		

CS1	0	2	2			2	7	35		
CS1	0	2	2			1	6	45		
CS1	0	2	2			2	5	40		
CS1	0	2	2			1	4	45		
CS1	0	2	2			2	6	45		
CS1	0	2	3	0	1	1	10	35	7.4337	46.1051
CS1	0	2	3	1	1	2	10	35	7.5580	21.8928
CS1	0	2	3	0	2	2	7	35	8.4873	29.2851
CS1	0	2	3	1	2	2	6	30	4.3768	34.6058
CS1	0	2	3	0	3	3	7	35	8.9860	36.4922
CS1	0	2	3	1	3	2	7	35	5.7342	10.9927
CS2	0	1	1	0	1	0	10	44	7.0891	38.1265
CS2	0	1	1	1	1	0	9	43	3.5138	39.3850
CS2	0	1	1	0	2	0	10	45	5.8909	15.1382
CS2	0	1	1	1	2	0	5	45	4.7304	29.9450
CS2	0	1	1	0	3	3	10	45	5.5586	26.9450
CS2	0	1	1	1	3	0	10	45	3.2688	7.5570
CS2	0	1	2			0	0	45		
CS2	0	1	2			0	0	44		
CS2	0	1	2			1	1	42		
CS2	0	1	2			0	0	44		
CS2	0	1	2			0	0	45		
CS2	0	1	2			0	0	45		
CS2	0	1	2			0	0	43		
CS2	0	1	2			0	0	45		
CS2	0	1	3	0	1	0	10	45	3.0644	6.3250
CS2	0	1	3	1	1	0	10	43	1.8282	9.4895
CS2	0	1	3	0	2	0	10	45	1.1387	27.4367
CS2	0	1	3	1	2	0	12	45	1.0765	26.6870
CS2	0	1	3	0	3	0	11	45	1.3899	20.2995
CS2	0	1	3	1	3	0	10	45	3.3893	2.7354
CS2	0	2	1	0	1	0	15	45	5.8180	65.8505
CS2	0	2	1	1	1	0	20	45	3.6193	85.8581
CS2	0	2	1	0	2	0	15	45	4.5663	45.9493
CS2	0	2	1	1	2	0	19	43	1.9542	37.1409
CS2	0	2	1	0	3	0	15	44	2.6718	32.1701
CS2	0	2	1	1	3	0	20	45	1.6642	36.7509
CS2	0	2	2			0	0	45		
CS2	0	2	2			0	0	45		
CS2	0	2	2			0	0	45		
CS2	0	2	2			0	0	45		

CS2	0	2	2			0	0	45		
CS2	0	2	2			0	0	45		
CS2	0	2	2			0	0	45		
CS2	0	2	2			0	0	45		
CS2	0	2	3	0	1	0	17	45	4.8477	33.1358
CS2	0	2	3	1	1	0	20	45	0.9476	48.4840
CS2	0	2	3	0	2	0	16	45	3.5997	53.1933
CS2	0	2	3	1	2	0	20	45	2.0221	11.7020
CS2	0	2	3	0	3	0	16	45	2.1339	62.5695
CS2	0	2	3	1	3	0	20	43	2.6203	30.3399
CS3	0	1	1	0	1	1	10	40	5.8079	33.2946
CS3	0	1	1	1	1	5	14	30	5.4405	68.3648
CS3	0	1	1	0	2	1	10	45	8.4128	46.8750
CS3	0	1	1	1	2	3	12	40	5.3635	53.1204
CS3	0	1	1	0	3	1	10	45	5.8689	68.9131
CS3	0	1	1	1	3	1	11	10	4.1777	91.7671
CS3	0	1	2			0	6	45		
CS3	0	1	2			0	3	45		
CS3	0	1	2			0	4	45		
CS3	0	1	2			0	0	45		
CS3	0	1	2			0	2	40		
CS3	0	1	2			0	1	45		
CS3	0	1	2			0	0	45		
CS3	0	1	2			0	0	45		
CS3	0	1	3	0	1	3	10	40	4.3344	56.5488
CS3	0	1	3	1	1	3	14	30	4.2889	45.0116
CS3	0	1	3	0	2	1	9	35	5.7457	56.5524
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CS3	0	1	3	0	3	0	2	45	5.6354	43.3615
CS3	0	1	3	1	3	3	5	35	4.4969	77.9644
CS3	0	2	1	0	1	2	10	45	5.1134	68.8221
CS3	0	2	1	1	1	5	11	40	4.4330	66.3054
CS3	0	2	1	0	2	2	10	40	6.7204	52.5926
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CS3	0	2	1	0	3	1	6	45	6.7204	19.0699
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CS3	0	2	2			0	0	45		
CS3	0	2	2			0	0	45		

CS3	0	2	2			0	0	45		
CS3	0	2	2			0	0	45		
CS3	0	2	2			0	0	45		
CS3	0	2	3	0	1	2	4	40	3.6630	75.1485
CS3	0	2	3	1	1	6	8	45	1.6772	72.8419
CS3	0	2	3	0	2	1	1	45	4.9631	51.6779
CS3	0	2	3	1	2	4	6	40	5.0449	45.5132
CS3	0	2	3	0	3	1	2	45	5.5855	48.8004
CS3	0	2	3	1	3	3	3	45	2.6409	46.7250
CS4	0	1	1	0	1	0	10	45	5.8299	67.4328
CS4	0	1	1	1	1	0	20	35	8.7070	47.8585
CS4	0	1	1	0	2	0	10	50	7.1513	47.0250
CS4	0	1	1	1	2	0	30	25	7.0580	77.5169
CS4	0	1	1	0	3	0	15	55	6.3034	51.6111
CS4	0	1	1	1	3	0	20	25	5.5372	63.6718
CS4	0	1	2			0	0	45		
CS4	0	1	2			0	0	43		
CS4	0	1	2			0	2	43		
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CS4	0	1	2			0	0	43		
CS4	0	1	2			0	0	44		
CS4	0	1	2			0	0	44		
CS4	0	1	2			0	0	45		
CS4	0	1	3	0	1	0	8	50	6.2801	50.6559
CS4	0	1	3	1	1	0	25	20	5.5813	70.1659
CS4	0	1	3	0	2	0	10	48	5.7484	59.9266
CS4	0	1	3	1	2	0	30	15	4.4061	52.7092
CS4	0	1	3	0	3	0	10	48	5.2533	52.0778
CS4	0	1	3	1	3	0	30	20	5.0042	46.4504
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CS4	0	2	1	1	1	0	10	30	6.5280	65.0334
CS4	0	2	1	0	2	0	3	48	6.6057	68.2234
CS4	0	2	1	1	2	0	15	30	7.1818	37.6082
CS4	0	2	1	0	3	0	4	50	5.8014	57.6197
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CS4	0	2	2			0	0	45		
CS4	0	2	2			0	0	45		

CS4	0	2	2			0	0	45		
CS4	0	2	2			0	0	45		
CS4	0	2	3	0	1	0	4	48	6.7743	54.6050
CS4	0	2	3	1	1	0	15	20	4.2453	25.7230
CS4	0	2	3	0	2	0	6	50	5.0648	56.9257
CS4	0	2	3	1	2	0	20	20	7.0371	35.1199
CS4	0	2	3	0	3	0	6	46	6.4361	57.8829
CS4	0	2	3	1	3	0	25	30	5.4510	53.1694
CS5	0	1	1	0	1	0	10	45	6.4081	37.8702
CS5	0	1	1	1	1	0	7	45	5.3118	24.4373
CS5	0	1	1	0	2	1	5	45	7.8691	36.2808
CS5	0	1	1	1	2	1	9	45	6.2172	23.2808
CS5	0	1	1	0	3	2	9	45	7.8630	34.6420
CS5	0	1	1	1	3	2	10	45	6.6819	37.7186
CS5	0	1	2			1	4	43		
CS5	0	1	2			2	3	42		
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CS5	0	1	2			3	5	42		
CS5	0	1	2			5	6	42		
CS5	0	1	2			5	6	42		
CS5	0	1	2			5	7	42		
CS5	0	1	2			6	7	42		
CS5	0	1	3	0	1	5	10	42	3.8565	50.2980
CS5	0	1	3	1	1	5	12	42	4.8458	42.3164
CS5	0	1	3	0	2	5	10	42	10.0825	46.9819
CS5	0	1	3	1	2	5	14	42	4.2030	39.1488
CS5	0	1	3	0	3	5	10	42	9.2580	35.9500
CS5	0	1	3	1	3	5	14	42	4.5170	43.5321
CS5	0	2	1	0	1	0	5	44	8.1243	39.0279
CS5	0	2	1	1	1	0	10	44	5.8059	52.1833
CS5	0	2	1	0	2	0	6	44	7.6224	67.3820
CS5	0	2	1	1	2	1	10	44	4.7404	58.7278
CS5	0	2	1	0	3	1	10	44	7.7793	37.8841
CS5	0	2	1	1	3	1	10	44	9.6656	17.8670
CS5	0	2	2			1	2	44		
CS5	0	2	2			1	2	44		
CS5	0	2	2			0	2	44		
CS5	0	2	2			2	2	44		
CS5	0	2	2			2	2	44		
CS5	0	2	2			2	3	44		
CS5	0	2	2			2	3	44		

CS5	0	2	2			2	3	44		
CS5	0	2	3	0	1	2	6	44	7.8621	49.1309
CS5	0	2	3	1	1	2	10	44	5.4468	17.9146
CS5	0	2	3	0	2	3	5	44	6.2330	69.3481
CS5	0	2	3	1	2	3	10	44	5.7565	38.0454
CS5	0	2	3	0	3	3	10	44	9.5478	46.4397
CS5	0	2	3	1	3	4	12	44	4.7486	40.5537
CS6	0	1	1	0	1	0	10	42	5.7784	36.4757
CS6	0	1	1	1	1	2	10	41	7.9207	40.4100
CS6	0	1	1	0	2	1	10	44	4.8120	54.2926
CS6	0	1	1	1	2	1	10	44	8.0024	46.3282
CS6	0	1	1	0	3	1	9	44	5.2285	63.0896
CS6	0	1	1	1	3	2	10	44	5.7692	46.8258
CS6	0	1	2			0	8	45		
CS6	0	1	2			0	7	44		
CS6	0	1	2			2	10	45		
CS6	0	1	2			2	10	45		
CS6	0	1	2			1	9	45		
CS6	0	1	2			1	9	45		
CS6	0	1	2			1	9	45		
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CS6	0	1	3	0	1	1	11	44	5.3621	58.2228
CS6	0	1	3	1	1	2	11	44	8.0182	46.8258
CS6	0	1	3	0	2	1	10	46	5.0129	42.6317
CS6	0	1	3	1	2	2	12	43	8.4232	41.7845
CS6	0	1	3	0	3	1	12	46	4.8931	44.5638
CS6	0	1	3	1	3	2	11	44	5.5588	32.0685
CS6	0	2	1	0	1	0	8	45	5.5156	63.9567
CS6	0	2	1	1	1	4	10	43	5.7805	49.3643
CS6	0	2	1	0	2	2	10	46	5.1944	67.5613
CS6	0	2	1	1	2	3	9	45	6.7544	39.2126
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CS6	0	2	1	1	3	4	10	43	7.9685	31.5080
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CS6	0	2	2			0	8	45		
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CS6	0	2	2			1	8	45		
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CS6	0	2	2			0	8	45		
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CS6	0	2	3	0	1	0	10	45	5.9838	67.0016
CS6	0	2	3	1	1	1	11	44	3.8759	36.5843
CS6	0	2	3	0	2	1	10	46	5.5152	58.5949
CS6	0	2	3	1	2	2	10	43	7.9577	31.1444
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CS7	0	1	1	0	1	2	10	40	3.7046	50.6303
CS7	0	1	1	1	1	6	15	50	3.7273	74.6955
CS7	0	1	1	0	2	5	12	20	2.8845	88.6255
CS7	0	1	1	1	2	7	20	60	3.8261	56.6110
CS7	0	1	1	0	3	7	18	20	4.1103	116.7538
CS7	0	1	1	1	3	13	20	50	3.3940	75.1829
CS7	0	1	2			3	15	45		
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CS7	0	1	2			7	17	50		
CS7	0	1	2			8	17	50		
CS7	0	1	2			9	15	52		
CS7	0	1	2			7	15	50		
CS7	0	1	2			5	15	50		
CS7	0	1	3	0	1	5	30	55	5.2569	62.8527
CS7	0	1	3	1	1	10	35	30	4.5063	64.4330
CS7	0	1	3	0	2	7	25	30	6.2385	55.7133
CS7	0	1	3	1	2	13	30	40	4.6105	75.2064
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CS7	0	2	1	1	3	5	20	30	3.1217	50.9658
CS7	0	2	2			2	15	51		
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CS7	0	2	2			3	15	50		
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CS7	0	2	2			5	15	50		
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CS7	0	2	3	0	1	5	35	52	4.0263	97.2587

CS7	0	2	3	1	1	7	40	35	2.5073	56.2721
CS7	0	2	3	0	2	7	45	30	5.4791	95.5416
CS7	0	2	3	1	2	8	45	30	4.6587	70.1073
CS7	0	2	3	0	3	8	40	15	5.4692	100.6996
CS7	0	2	3	1	3	10	45	35	4.9385	71.3844
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CS8	0	1	1	1	1	5	10	30	5.6665	63.1239
CS8	0	1	1	0	2	5	15	50	7.5061	71.9983
CS8	0	1	1	1	2	8	15	30	2.3018	44.4565
CS8	0	1	1	0	3	10	15	30	7.5061	99.6695
CS8	0	1	1	1	3	10	15	50	2.4251	32.2732
CS8	0	1	2			8	2	50		
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CS8	0	1	2			6	5	40		
CS8	0	1	2			8	5	35		
CS8	0	1	2			10	8	50		
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CS8	0	1	3	0	1	12	15	20	5.3319	47.7878
CS8	0	1	3	1	1	12	16	30	6.9774	26.7532
CS8	0	1	3	0	2	10	14	20	4.9508	63.2080
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CS8	0	2	1	1	3	5	8	20	6.6158	32.4082
CS8	0	2	2			3	4	35		
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CS8	0	2	2			5	4	55		
CS8	0	2	2			3	4	50		
CS8	0	2	2			4	4	50		
CS8	0	2	2			4	3	50		
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CS8	0	2	3	0	1	5	10	37	4.5060	44.7175
CS8	0	2	3	1	1	5	10	40	7.2380	33.3335

CS8	0	2	3	0	2	5	8	25	4.9400	23.6984
CS8	0	2	3	1	2	5	6	60	4.8440	26.6984
CS8	0	2	3	0	3	5	6	25	4.3139	32.3033
CS8	0	2	3	1	3	5	8	50	4.2988	40.6068
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INC1	1	1	1	1	1	2	14	40	7.6906	52.8044
INC1	1	1	1	0	2	2	12	46	6.1344	25.1139
INC1	1	1	1	1	2	2	14	41	4.9831	56.9117
INC1	1	1	1	0	3	2	11	46	4.6767	35.6513
INC1	1	1	1	1	3	2	15	40	6.0858	37.9054
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INC1	1	1	2	1	2					
INC1	1	1	2	0	3	0	6	45		
INC1	1	1	2	1	3	1	8	45		
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INC1	1	1	2	1	1					
INC1	1	1	2	0	2	1	7	45		
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INC1	1	1	2	1	3	0	6	45		
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INC1	1	1	2	0	2	1	6	45		
INC1	1	1	2	1	2	1	7	45		
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INC1	1	1	2	1	2					
INC1	1	1	2	0	3	1	6	45		
INC1	1	1	2	1	3	2	7	45		
INC1	1	1	3	0	1	2	11	46	3.6340	22.0757

INC1	1	1	3	1	1	2	16	39	5.5073	53.6257
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INC1	1	1	3	1	2	2	17	40	5.2202	49.4954
INC1	1	1	3	0	3	2	12	46	5.8981	34.1713
INC1	1	1	3	1	3	2	17	39	5.3365	43.8682
INC1	1	2	1	0	1	2	9	46	5.2635	30.1078
INC1	1	2	1	1	1	2	16	41	7.9458	45.2934
INC1	1	2	1	0	2	2	9	46	4.4482	35.3586
INC1	1	2	1	1	2	2	17	39	5.9947	41.9751
INC1	1	2	1	0	3	2	9	46	3.1189	38.0592
INC1	1	2	1	1	3	2	17	39	7.1830	24.7752
INC1	1	2	2	0	1	0	7	45		
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INC1	1	2	2	1	2					
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INC1	1	2	2	0	1	0	6	45		
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INC1	1	2	3	1	1	2	18	39	5.4374	31.2443
INC1	1	2	3	0	2	2	13	46	5.8323	24.0696
INC1	1	2	3	1	2	2	17	46	5.4262	37.3788
INC1	1	2	3	0	3	2	13	46	3.8497	30.0728
INC1	1	2	3	1	3	2	17	40	3.6310	14.1394
INC1	1	3	1	0	1	2	10	46	***3.9800***	***34.9500***
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INC1	1	3	1	0	2	2	10	46	4.2461	32.9694
INC1	1	3	1	1	2	2	17	39	5.1468	31.1355
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INC1	1	3	2	0	3	1	6	45		
INC1	1	3	2	1	3	2	7	44		
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INC1	1	3	2	0	3	1	6	45		

INC1	1	3	2	1	3	1	7	45		
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INC1	1	3	3	1	3	2	17	40	5.2246	40.2221
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INC1	1	4	1	1	1	2	16	42	7.0294	49.0469
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INC1	1	4	1	1	2	2	14	43	6.6903	27.9230
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INC1	1	4	2	1	1	2	12	43		
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INC1	1	4	2	0	3	2	7	45		
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INC1	1	5	2	0	3	2	11	45		
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INC1	1	5	2	0	2	2	11	45		
INC1	1	5	2	1	2	2	14	44		
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INC1	1	5	2	1	3					
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INC1	1	5	2	1	3	2	16	44		
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