Analysis and conceptual development of an EEG laboratory for mobile applications: An interdisciplinary user-centered approach

By

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ABSTRACT

This research aims to improve the overall user experience as well as the overall performance of a modern Electroencephalogram (EEG) laboratory. An analysis of the workflow of activities undertaken in the EEG laboratory was conducted in order to develop a conceptual interior design of a mobile laboratory to be used for community-based research. Rather than taking a pre-existing laboratory interior configuration and simply placing it within a sufficiently large vehicle, this research project is focused on creating a purpose-built environment more suitable to the activities of conducting EEG experiments.

This thesis follows a user-centered design approach to the research, analysis, and conceptual development of an interior laboratory environment, and applying design research methods to the understanding of user needs and activities. Working closely with professionals in the field of psycholinguistics and neuroscience, an interdisciplinary collaboration was maintained throughout this research.

The conceptual design of the mobile laboratory includes better equipment integration in the environment, enhanced workflow, and improvements for laboratory data collection efficiency. Vehicle studies of floor plan compatibility and equipment integration capabilities were compared and analyzed. Based on the activities evaluated through prototyping, the findings suggest that a Class C vehicle platform offers a better solution for the mobile laboratory.

Key words: Design research, interdisciplinary collaboration, mobile EEG laboratory, purpose-built environment, user-centered design

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Thanks to my sisters and their families for always making sure I was heading in the right direction. A special thanks to my girlfriend, Brianne Perron, for being patient and extremely supportive during this thesis.

Un gros merci à mes parents, Victor et Thérèse, pour leur soutien continu pendant mes études académiques. À ma mere, merci de m'avoir montré comment être fructueux. À mon père, merci de m'avoir enseigné ton métier. Je m'excuse de « te faire honte. »

PREFACE

The proposal for a mobile laboratory originated with the Ottawa Cluster for Excellence in Advanced Neurosensing (OCEAN). OCEAN is a Carleton University based interdisciplinary research team whose goals in the short term are to build a vehicle prototype featuring an innovative wireless mobile Electroencephalography (EEG) lab that allows for community-based research in various remote rural and urban populations.

The initial OCEAN research was conceived as three one-year cycles that would realize a low fidelity remote prototype (Cycle 1), followed by a temporary mobile prototype based on a vehicle package (Cycle 2) that would be used to predict the laboratory's performance in a mobile setting. The final outcome (Cycle 3) would be the completion of a mobile laboratory vehicle. This linear progression would allow for comparative analyses, while fine-tuning the design process and prototypes throughout. The current thesis research was planned to initiate and contribute to the development of Cycle 1.

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1. INTRODUCTION

1.1. Scope of Thesis

The purpose of this research is to improve the overall user experience as well as the overall performance of a modern Electroencephalogram (EEG) laboratory. An analysis of the workflow of activities undertaken in the EEG laboratory was conducted in order to develop a conceptual interior design of a mobile laboratory to be used for community-based research. Rather than taking a pre-existing laboratory interior configuration and simply placing it within a sufficiently large vehicle, this research project is focused on creating a purpose-built environment more suitable to the activities of conducting EEG experiments.

An EEG records electrical activity through the scalp and is used to measure neuronal activity in the brain (Rugg & Coles 1995; Luck 2005; Handy 2005). Besides their widespread use in clinical diagnostics, EEG methods have been used in research experiments to examine the processes involved in various aspects of cognition, including attention, memory, language, and emotion.

This thesis follows a user-centered design approach to the research, analysis, and conceptual development of an interior laboratory environment, and to applying design research methods to the understanding of user needs and activities. Working closely with professionals in the field of psycholinguistics and neuroscience, an interdisciplinary collaboration was maintained throughout this research. Such collaboration enabled the sharing of knowledge effectively and made resources widely accessible to ensure that any conceptual solutions met the specific needs of the users of EEG laboratories.

Having identified early objectives for the research, an in-depth review of current literature was conducted. While doing so, multiple challenges as well as theories for the effective design of a mobile laboratory were reviewed. The following are the key theories as further presented in the literature review.

- In common practice, on the creation of an environment, Frank Lloyd Wright proposed that form follows function (1969).

- Robert Sommers, a specialist of human spatial behaviors, argued that, traditionally, most of the effort concerned with functionalism in the field of architecture has been focused on form rather than function (Sommers 1969). This school of thought at the time maintained that the building structure itself becomes its function based on how well it fits harmoniously within the landscape rather than how well it supports the user (Sommers 1969).
- In order to meet user expectations, existing interior spaces are often modified, sometimes dramatically, to allow particular activities to be performed, resulting in an inconvenient, time consuming and costly practice. To avoid the issue of the cost, modern design practices often include user studies to propose design solutions that are appropriate over the long term.
- Amos Rapoport, an architect who contributed to environment behavior studies (EBS) and helped define the built environment, suggested an anthropological approach in the understanding of the user and the purpose of a built environment, which plays an important role in the creation of rich environmental experiences (Rapoport 1982).
- The incorporation of ethnographic methods in the design process allows for a better understanding of the particular needs and behaviors attributed to a user environment (Wasson 2000). Designers apply ethnography differently than anthropologists, employing less theoretical contextualization and focusing on shorter time periods (Wasson 2000).

A user-centered approach was chosen as the best fit for the research because a laboratory should be designed according to the activities to be undertaken in the provided space. When one considers researchers and the participants in a laboratory as the central focus in the design of products, services, and environments, efforts are shifted towards an understanding of the user expectations, human factors, workflow, and environmental affordances and constraints that come into play. The goal of this research is to analyze the user activities and expectations in a set environment through the use of design research methods and to design environment interior proposals in scenarios that simulate realistic operating conditions.

1.2. Conceptual Framework and Research Questions

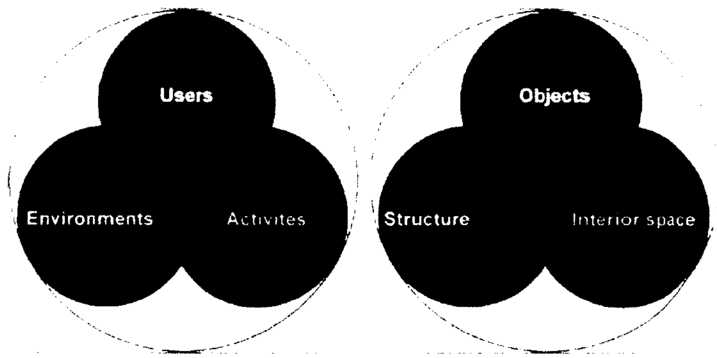


Figure 1. Conceptual Framework of Thesis

The conceptual framework of this thesis in Figure 1 illustrates the key elements involved in designing a mobile laboratory environment. Working closely alongside researchers at Carleton University fostered a deeper understanding of the user needs and expectations regarding the activities taking place in an EEG laboratory. This research investigates the integration of a modern EEG data collection environment into a potentially mobile environmental setting, by identifying critical issues involved in creating such an environment and focusing on the constraints and attributes which have a bearing on the physical environment.

This research was envisioned as the first cycle of three cycles over a number of years. The progression starts with a remote prototype (Cycle 1) with the objective to create a full-scale low-fidelity model of the interior environment of a laboratory, followed by a temporary mobile prototype based on a vehicle package (Cycle 2) that would be used to predict the laboratory's performance in a mobile setting. The final cycle would consist of a final mobile laboratory (Cycle 3) that is perfected, with the least amount of error compared to its predecessors. This linear progression would allow for comparative analysis, while fine-tuning the design and prototype. This thesis focused mainly on the first cycle and the following research questions.

- How can an environment for mobile laboratory data collection be more supportive to the needs and activities of the researchers and participants engaged in an EEG study?
- What are the environmental features and affordances, which contribute to a better integration of an EEG testing laboratory into a precisely defined and limited spatial mobile environment?

1.3. Structure of Thesis

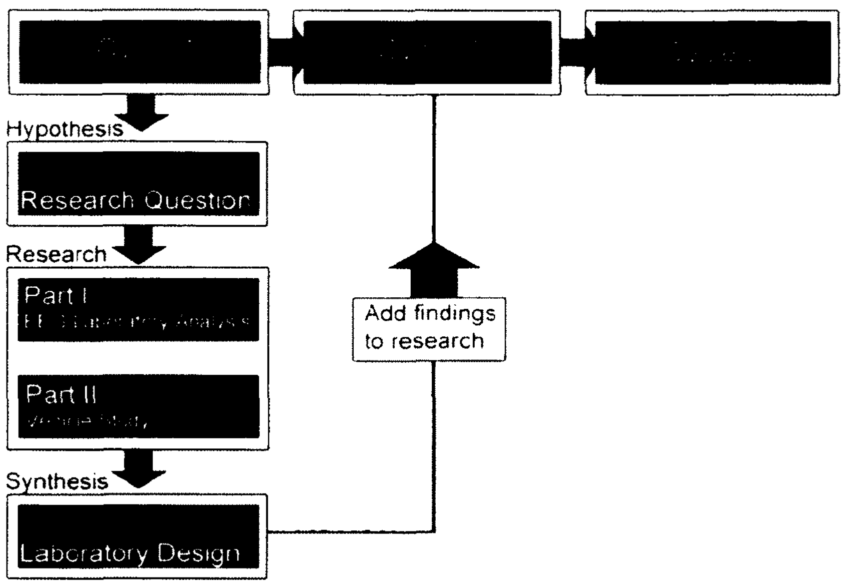


Figure 2. Thesis Structure

In the first chapter, the design of a mobile laboratory as the objective of the current thesis is presented. The research questions and the scope of the research are defined. User-centered design is proposed as an essential element of the interior design that aims to emphasize the importance of understanding the user and the activities to be undertaken in the interior built environment.

The second chapter is the literature review that provides the theoretical framework for this thesis. Theories about the built environment and its components, which play a key role in the overall user experience, are presented in detail. In addition, the suitability of design approaches currently utilized to design environments are reviewed and assessed in the context of the work. The third chapter presents the methods used in this thesis. Chapter 3 is divided into two parts. Part I is composed of the design research methods of observation and participation, as well as a pilot project conducted to understand the general context of the users, their activities, and environment. These three processes are the methodological triangulation necessary to establish criteria upon which the design of the interior environment can be based. Part II is a vehicle study conducted to determine the spatial envelope requirements for the design, and to provide guidance for selecting a vehicle package necessary for the design concept. A low-fidelity representation of the interior environment is created to evaluate the floor plan configuration and the equipment integration into the interior envelope of the vehicle.

The fourth chapter is comprised of findings presented in two parts as such to follow the structure of Chapter 3. Beginning with an overview of the EEG laboratory and its activities, Part I covers the connection between the objects needed to perform EEG experiments and its integration into the environment. User groups are defined and their needs are presented and specified. Design criteria are established and explained. The second part of this chapter comprises the results from the vehicle study. The results of the vehicle packages are presented and an overall spatial envelope is determined for an ideal package for the mobile laboratory design.

In the fifth and final chapter, the results of the research conducted are discussed and conclusions are drawn. The proposed design of the interior of the laboratory is intended to further refine the design criteria so as to create the ideal mobile laboratory for EEG experimentation. Recommendations for future design practice and research are also made.

1.4. Contribution of Thesis

- Firstly, this research affectively completes Cycle 1 of the continuing three-cycle progression originally envisioned.
- Secondly, using a detailed knowledge of the activities and the contributing factors involved in carrying out an EEG experiment, this thesis indicates a thorough understanding of how user experiences can be greatly improved through the choice of configuration and design of the interior environment.
- Thirdly, by following a user-centered approach, this work makes clear recommendations to enhance the interior laboratory performance.
- Furthermore, the analysis of this work suggests new directions for future EEG laboratory designs and other laboratories with similar challenges and parameters.

2. LITERATURE REVIEW

2.1. Introduction to the Literature Review

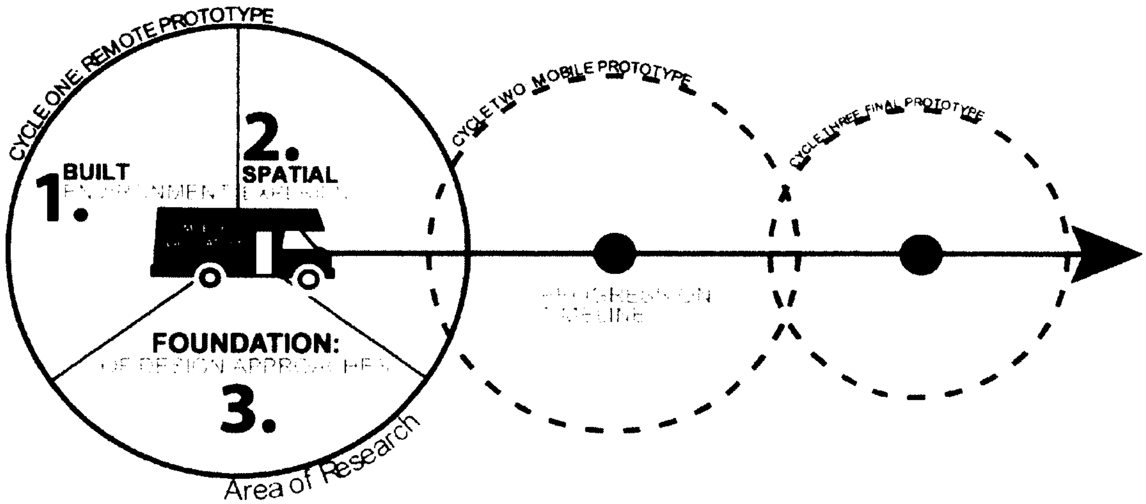


Figure 3. Theoretical Background

In this chapter, the fields of knowledge from which the research questions of this work have evolved are outlined and described. The main arguments, which were gathered from a wide range of fields, were summarized and categorized into one of the following three topics: the built environment, the spatial experience, and the foundation of design approaches.

Considering the built environment, with which people interact, it is only logical to start with a general discussion regarding how the interior environment has been viewed by scholars, since opinions have evolved throughout time. The concepts in this section stem from architecture, graphic design, interior design, industrial design, psychology, and anthropology. Having learned a great deal from viewing sources in other disciplines, some interior environments are considered to be more successful than others in terms of supporting certain activities.

The spatial experience of an individual, or a user expectation of an interior environment when a certain activity is performed, is also strongly relevant to this work. As in the second topic, the attributes and elements contributing to the user experience of the interior environment are explored. This topic incorporates concepts developed by anthropologists, psychologists, and architects.

The third topic of discussion deals with the design approaches, which have been used to create interior environments and an overall experience for the user, both on the product scale as well as the interior environment scale.

2.2. The Built Environment

The built environment is defined by the human-made surrounding environment that provides the setting for human activity, ranging in scale from personal shelters and buildings, to neighborhoods and cities that can often include supporting infrastructure, such as water, energy and networks. The built environment is a material, spatial and cultural product of human labor that combines physical elements. The built environment can be further defined by four interrelated characteristics, which follow (Habraken 2000).

- It is everywhere; it provides the context for all human endeavors, i.e., everything created or built by humans.
- It is intended to serve human needs, wants, and values.
- Much of it is created to help users deal with the overall environment by mediating or changing it to raise user levels of personal comfort.
- Every component of the built environment is defined and shaped by context; each and all of the individual elements contribute either positively or negatively to the overall quality of the environment.

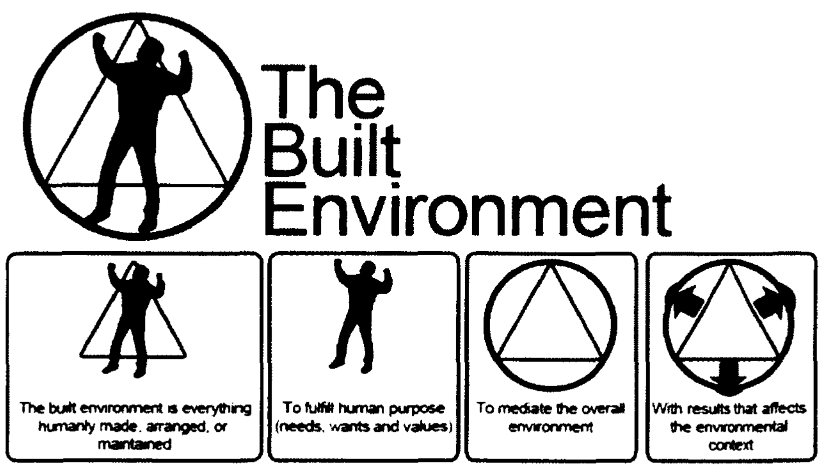


Figure 4. Definition of the Built Environment and Four Characteristics

The built environment is comprised of seven components: products, interiors, structures, landscape, cities, regions, and earth. With the scope of this work, products, interiors and structures are the most relevant components to be reviewed and discussed. The interconnections of these components are relevant, as they serve to support each other to create the built environment (Bartuska 2007).

- Products: This component includes materials and commodities that are created generally to extend the human capacity to perform specific tasks.
- Interiors: This component is defined by an arranged grouping of products and generally enclosed within a structure. They are often arranged to enhance the level of activities to take place.
- Structures: This component includes planned groups of spaces defined by and constructed of products, related to activities, which are combined into composite structures. Structures consist of an internal and external space.

Figure 5. Components of the Built Environment by Bartuska 2007

2.2.1. User and Environment Relationship

Many scholars agree that a better understanding of the built environment will allow the space to be effective for the user. This means taking corrective measures to creating positive qualities that facilitate the user enjoyment and enriches productivity. A poor quality creates apathy and has a negative impact on user health.

According to several authors specializing in spatial behavior and the built environment, such as Amos Rapoport, Robert Sommer and Tom J Bartuska, better environments are created when people work together in a cooperative way and to understand the user behaviors in a set environment. The best way to create a better environment is to actively engage with that environment. Active participation in the environment will greatly increase awareness of the activities carried out by the user and will result in a better solution for interior spatial interaction. The relevant proposal will be further presented in the following sections of this chapter.

2.3. Spatial Experience

The spatial experience refers to what a user experiences when entering, or interacting with, an environment. This experience can be enjoyable or painful depending on whether the environment satisfies the user needs and values. Also, multiple physical attributes can affect a user behavior when he or she is trying to perform a certain activity within an environment. This way of thinking can provide some understanding of why humans build or transform the environment in which they live or work. Designers are often accused of being preoccupied with making a visual statement with their design than with making environments that meet the needs of the users (Korobkin 1976).

To additionally aid in this understanding, it is useful to explore the nature of human needs, wants, and values. According to Abraham Maslow, a psychologist, all organisms must satisfy certain basic needs in order to survive. He proposes that humans concentrate on the most basic needs until those needs are met with some degree of certainty and satisfaction. Afterwards, we turn our attention to those needs not strictly essential to bodily function and survival. The same transition occurs at each level of hierarchy shown in Figure 6. This hierarchy is useful and underlines the fact that elements of the built environment do correspond, often directly, to expressions of human needs and wants. Figure 6 illustrates the general types of physical and psychological needs (on the left), the hierarchy of six levels of human needs (in the center), and the ways in which these needs are expressed in the built environment (on the right). Beyond the realm of needs is that of wants, those material goods that are not required at any level, and they emerge from the desire for self-gratification (Maslow 1971). The conceptual development of the mobile laboratory reflects this understanding of the nature of human needs.

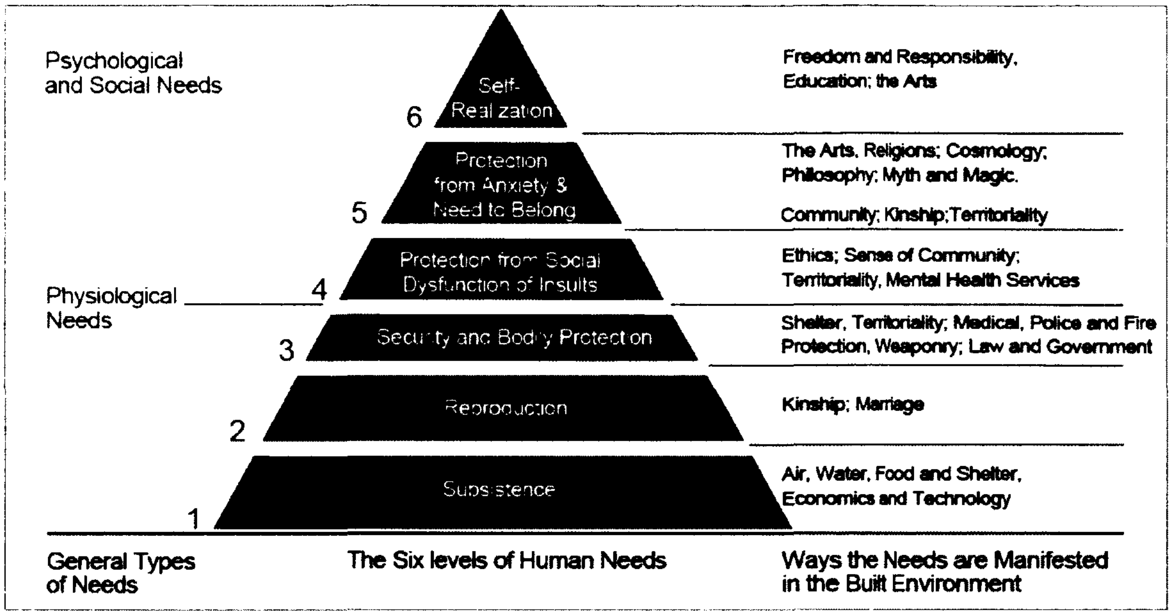


Figure 6. Human Needs Manifested in the Built Environment by Maslow 1971

2.3.1. Physical Attributes

Physical attributes found in the built environment, can be linked to human behavior. The physical attributes of the environment will have an immediate impact on the user experience. The following attributes are described in terms of how they influence the user experience when an activity in an environment is performed.

Accessibility

Accessibility is defined as access to a building, room, and objects for all users in an environment. A user ability to function autonomously within an environment is compromised by barriers, such as narrow hallways, high countertops, and stairs (Windley 1980).

Adaptability

Adaptability is defined as the attribute that enables an environment to be modified to fit changing human activities. Because of the increasing complexity of human activities, it is advantageous for spaces or buildings to be able to change rapidly to accommodate changing activities (Windley 1980).

Proxemics

Proxemics refers to social interaction and privacy. Social interaction is defined as the interaction between two users (Hall 1969). Buildings and communities are often arranged to encourage informal contact between residences. Airport seating layouts often hinder social interaction, while restaurants are purposely designed for social interaction. Privacy in the built environment refers to the way in which the environment controls the input and output levels of the user (Altman 1975). Ensuring privacy of the patient is common practice in hospitals.

Density

Density is the number of individuals per unit area. Density can have both a negative and positive impact on the user, depending on the situation. In hospitals, for example, a high density will create spatial efficiency, but at the same time may be attributed health risks (Stokols 1972).

Legibility

Legibility concerns the level at which a user identifies the environmental configuration of the components to form a functional internal representation or mental image (Sommar 1969). Legibility plays an important role in promoting orientation and way finding within the environment. These are especially important for public buildings such as hospitals.

The attribute of legibility can also be referred to as wayfinding. Wayfinding enables one to know where they are within the built environment and how to reach a destination without getting lost. Wayfinding has a significant contribution in user behavior studies because it enables the user to predict the consequences of their actions, thus reducing anxiety associated with getting lost, and makes it easier for the user to adjust to a new environment (Weisman, 1987).

2.3.2. Environmental Affordances

The term 'affordance' was originally defined by James J Gibson, a psychologist who wrote an article *The Theory of Affordances* in 1977. He defined affordances as all possible actions latent in the environment, objectively measurable and independent of the user ability to recognize them, but always independent on their capabilities. Later, Donald Norman reinterpreted the term affordances in terms of levels of interaction. According to Norman, affordances refer to user interactions with parts of a system, product or environment, such as doors, windows, lights, and blinds, etc. Simply, anything that a user can interact with can provide affordances. Following Norman, there are four levels of affordance constraints that will impact the user interaction.

- Physical constraints are physical limitations that constrain possible course of actions, such as a car that can't start unless it is in neutral gear.
- Cultural constraints rely on accepted cultural conventions. For example, western society can associate the color red with stop, danger and alert; and the color yellow to warnings, slow and caution; while in other societies, the color red and yellow might take on other meanings.
- Logical constraints refer to the use of logic to constrain actions. Examples of logical constraints can be found in mapping, and particularly in what is termed natural mapping. This refers to doing things in a logically obvious order. For example, moving a switch up can cause an object to move up.
- Semantic constraints refer to the constraints when the meaning of a situation controls the possible action. The term semantics will be further clarified in the literature review.

To give clarification to the term semantics, it is further discussed in what follows. By definition, the term product semantics refers to how the aesthetic treatment provides messages to the user about its function. Non-verbal signs make it clear how the product should be handled. The significance of this idea to this thesis indicates that product design-based theoretical knowledge can be transferred to the design purpose-built environment since it deals with similar parameters and criteria.

2.4. Foundation of Design Approaches

This subsection provides an overview of the design approaches for designing built environments. Based on the findings presented earlier in the chapter, the key things to be incorporated into the design approach for creating a built environment are summarized as follows.

- A better understanding of the built environment will enable the space to be more effective for the user.

- Better environments are created when people work together in a cooperative manner and the understanding of the user behaviors in a set environment.
- An exploration of the nature of human needs, wants, and values will result in better design outcomes.
- The physical attributes of the environment will have an immediate impact on the user experience.
- Affordance constraints will impact user interactions with the environment.

2.4.1. Design Research Methods

Design research methods relate to the ability to understand the user needs and values, and to apply them to design solutions. Design researchers incorporate ethnographic research methods in their design process. However designers have a narrower and somewhat different meaning of ethnography in the field of design than most anthropologists (Wasson 2000). Since anthropology is the study of humanity, it brings up new areas of understanding of cultural backgrounds, thus creating new meanings with the use of symbolism in design. Design and anthropology both have interests in social settings and gathering data.

The E-lab framework is one of the approaches used by design researchers for analysis and understanding a situation or context. The E-lab framework focuses on the understanding of five elements and the interactions between them (Wasson). The five elements of the E-lab framework are as follows.

- Activities: These are goal-directed sets of actions for things that individuals want to accomplish, such as learning.
- Environments: This is where activities take place.
- Interactions: These take place between a person and someone else.
- Objects: These are the items found in the environment.
- Users: People have behaviors, preferences, and needs.

2.4.2. User-centered Design

User-centered design represents a design philosophy, which describes a design approach in which end-users influence the design outcome for products, services and environments. In design applications, there are multiple ways in which users are involved in user-centered design. The key criteria of this concept are that users must be involved during all stages of the design process. In some cases, design researchers consult with users about their needs and involve them at specific times during the design process. In other cases, the user will have a key influence on the design outcome by being actively involved with designers as partners throughout the design process. What differentiates this design philosophy from others is that the user-centered design is aimed to optimize the product around how users can use, want to use, or need to use the product, rather than forcing the user to change their behavior to accommodate the product, service or environment (Norman 1986).

Donald Norman was the first to use the term user-centered design. The term became widely used after the publication of a co-authored book titled User-centered System Design: New Perspectives on Human-Computer Interaction (Norman & Draper 1986). Afterward, Norman further developed the user-centered design concept in his seminal book The Design of Everyday Things (Norman 1988).

In The Design of Everyday Things (Norman 1988) he identifies the needs and the interests of the user and focuses on the usability aspect of the design. Norman put forward four basic suggestions on how a design should be.

- Make it easy to determine what actions are possible at any moment.
- Make things visible, including the conceptual model of the system, the alternative actions, and the results of actions.
- Make it easy to evaluate the current state of the system.
- Follow natural mappings between intentions and the required actions, between actions and the resulting effect, and between the information that is visible and the interpretation of the system state (Norman 1988).

These recommendations place the user at the center of the design. The role of the designer is to facilitate the task for the user and to make sure that the user is able to make use of the product as intended and with a minimum effort to learn how to use it. Telling designers that products should be intuitive is not enough. Design principles are needed to guide the design (Norman, 1988). Norman's work stressed the need to fully explore the needs and desires of the users and the intended uses of the product. To involve actual users, often in the environment in which they would use the product designed, was a natural evolution in the field of user-centered design. Users became a central part of the development process. Their involvement led to more effective, efficient, and safer products, and contributed to the acceptance and success of products (Preece, Rogers, & Sharp, 2002).

2.4.3. Participatory Design

In North America, user-centered design evolved from the Scandinavian approach of participatory design which was developed in the early 1970s. Participatory design is a design approach that aims to have all users as well as other stakeholders actively involved in the design process who may be affected by the product. This design approach helps the product service or environment designed outcome meet their needs (Bødker, S 1987). Due to the cultural difference between the users and designers, the users were unable to understand the language of the designers and vice versa. Prototypes and mock-ups were used as a central form of communication tool between users and designers.

2.4.4. Participatory Design in the Built Environment

Participatory design provides many applications in development and enhancement of the built environment. It offers architects and interior designers a foundation to environmental space organization such as purpose built facilities. An advantageous feature of participatory design is that it can involve many different democratic users in the design process since it involves more than one stakeholder. By incorporating a variety of users, it likely increases the number of opportunities for successful outcomes. A good example can be found in a project with students from Colombia University, University of Sydney, and Sapienza University of Rome, who provided design solutions for Vancouver's downtown eastside, which was suffering from drug and alcohol related problems. The process allowed cross-discipline participation from planners, architects and industrial designers and focused on collaboration and the sharing of ideas and stories, as opposed to simply producing ridged and singular design outcomes (Kuiper 2007). In addition, participatory design is becoming popular in hospitals. It is a method for designers creating environments that are more responsive and appropriate to the user practical needs (Ehn & Kyng 1991).

Environmental-behavior studies and participatory design promote a more inclusive and systematic design process by identifying and solving design problems within a holistic human or societal framework. Human behavioral objectives emerge from these frameworks and can be defended by documented research. However, the main issue with research in design is that the findings are generally difficult to translate into design criteria because they are established by non-designers, often with other objectives in mind. Therefore a four-stage design process is created to propose a guide for design decision making to achieve behavioral objectives.

2.5. Framing of Research

A system of proper integration between the objects, the interior environment and the structure supporting the environment, can enhance the user experience. The idea for creating a mobile laboratory is not about how to take what is already found in a laboratory and placing it in a vehicle package but is one of improving the process and experience of conducting EEG experiences with environmental features that promote EEG activities.

The combination of a user-centered design approach and design research methods is the ideal process. The design research methods attempt to recognize the knowledge gained from the literature review to establish the conceptual development a mobile laboratory. Participatory design requires the involvement of stakeholders. Given the considerable time required and the limited access to these stakeholders, maintaining a constant interdisciplinary collaboration throughout the research will greatly increase the field of knowledge.

3. METHODS

3.1. Introduction to the Methods

This chapter describes the methods used to address the research questions put forward in the current thesis. As previously mentioned, this thesis uses a user-centered approach and design research methods combined. Such an approach allowed the information needed to contextualize designs solutions for a mobile EEG laboratory to be collected successfully. This section is organized in two parts. Part I is called EEG Laboratory Analysis and Part II is called Vehicle Study. Both Part I and II use interdisciplinary means of sharing knowledge and resources. This ensured the collection of the information needed to establish the design criteria for creating the effective mobile laboratory.

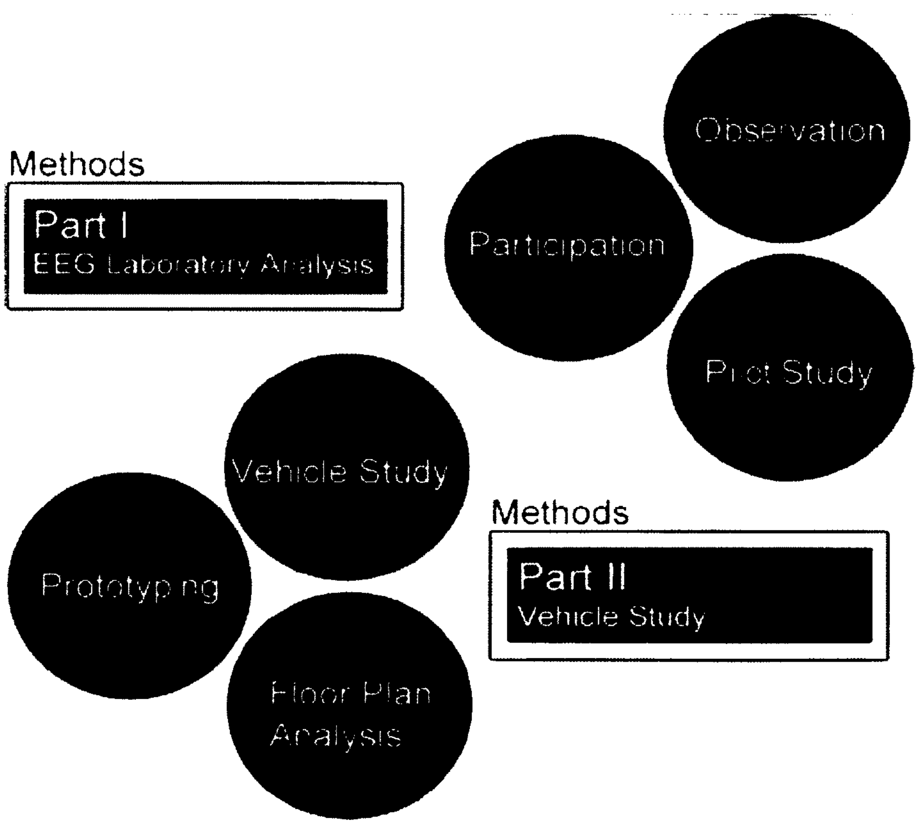


Figure 7. Methods Framework

3.2. Research Methods

3.2.1. Part I: EEG Laboratory Analysis

The EEG laboratory analysis was conducted in two EEG laboratories located at Carleton University. The first laboratory is under the supervision of Dr. D'Angiulli. The second laboratory is under the supervision of Dr. Hirotani. The purpose of Part I was to establish the connection between the users (e.g., researchers, participants), the activities taking place in the EEG laboratories, and the laboratory environment. The research objectives are summarized as follows.

- Identify the users, their needs, and goals.
- Determine the activities conducted by the users.
- Determine how user goals are achieved.
- Identify the environment in which the activities are taking place.
- Evaluate the physical environment, factors affecting workflow effectiveness, and equipment usage.

The final stage of the project was to draw connections between the results of the methods used and to begin establishing design criteria for designing a mobile laboratory environment.

Method 1: Observation

EEG experiments conducted in two different laboratories were observed. As participants entered the laboratory, their actions were observed throughout the experiments. The actions of the researchers were also observed and noted throughout the experiments.

Method 2: Participation

The second method required the participation in EEG experiments as a researcher and as a participant. The participation took place in the same laboratories as mentioned above. The participation activities included the preparation of EEG equipment, conducting, an EEG experiment on a volunteer participant, and the author being a participant in the EEG experiment.

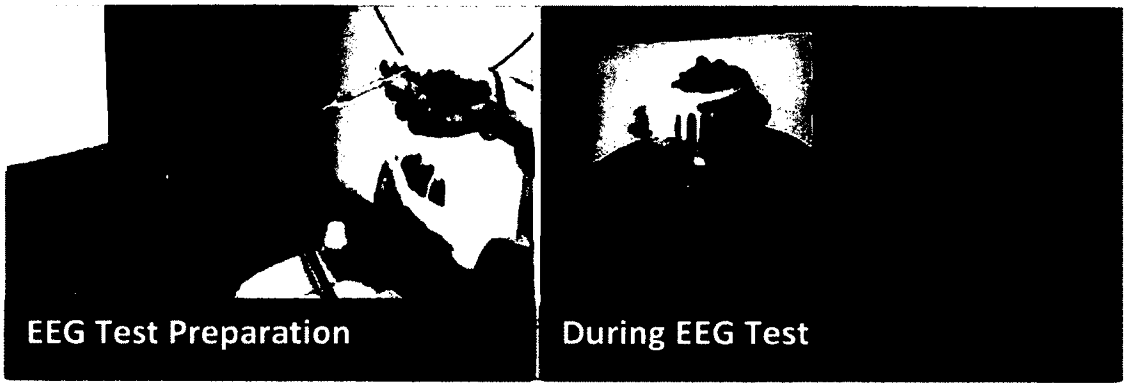


Figure 8. Participation and Observation of the EEG Laboratory

Video cameras were installed in the laboratory to record the author's behavior when performing EEG related activities. The recordings were used for further analysis, which revealed additional information, not identified during the actual participation of the experiment.

Method 3: Pilot Project

A pilot project involved a third year Carleton University Industrial Design studio class. The pilot project was carried out as part of Dr. WonJoon Chung's studio class. It was a 4-week, team-based project. The project began on January 3 2012. Students observed and participated in Dr. Hirotani's EEG laboratory and prepared design concepts of either products that could improve the overall experience of EEG testing or floor plan layouts which could possibly improve the laboratory performance.

3.2.2. Part II: Vehicle Study

Part I identified the users of EEG laboratories and clarified the activities performed in the laboratories. Part II analyzed the results obtained in Part I and determined the vehicle platform most appropriate to support the EEG laboratory activities and the equipment in a confined spatial environment. Part II dealt with technical data such as spatial volumes, human factors and ergonomics. The objectives of Part II are as follows.

- Address the mobility versus deployability elements of the laboratory.
- Analyze the current EEG laboratory floor plan layout.
- Conduct a vehicle floor plan analysis.

- Determine the floor plan compatibility between the current laboratory and a mobile vehicle platform.
- Evaluate the equipment integration.
- Validate the floor plan arrangement.

Method 1: Floor Plan Analysis

A floor plan analysis of Dr. Hirotani's EEG laboratory was conducted. The purpose of the analysis was to determine the physical constraints and the arrangement of the equipment suited for the EEG laboratory activities. The analysis was carried out using diagrams illustrating the movement envelops of the users within the laboratory. Such a method led to identify key patterns in the user movement within the space. In addition, the maximum and minimum dimensions of the interior space suitable to support the activities were established through anthropometric and basic interior space design standards.

Method 2: Vehicle Analysis

Vehicles samples were studied and analyzed based on the degree of their mobility, availability, floor plan compatibility, road efficiency and usability. A wide range of vehicle packages including deployable medical environments, commercial service vehicles for trades, and personal recreation vehicles, were considered for this work. The objective of the Vehicle Analysis was to determine and validate the floor plan layout based on the appropriate vehicle packages. This was done by analyzing the current EEG laboratory floor plan located on the Carleton University campus.

Method 3: Prototyping

A low-fidelity prototype of the designed floor plan layout of the EEG laboratory was built to determine the floor plan compatibility of the vehicle platform. Additionally, movement envelope mock-ups were created to evaluate the floor plan arrangement and to verify if the equipment could be integrated into the interior without affecting the user performance. The prototype was built in a studio space located on campus. It took approximately three weeks to construct the prototype, using lumber, plywood, colored tapes and cardboards.

The low-fidelity prototype was intended for the first stage of a validation process. It was not possible to run real EEG experiments in the low-fidelity prototype due to the lack of access to power, lighting and running water. In order to test the functionality of the laboratory, it would require a refined and complete replica constructed with the proper material finishes, real acoustic chambers, all EGG equipment and functional collapsible furniture installed.

3.3. Research Ethics

After consulting personnel at the Carleton University Research Office responsible for Research Ethics applications, it was concluded that this thesis work required no ethics approval. As described above, the methods used were all based on the author's informal observation of the laboratories and the activities that took place at the time of observation. No real participants were tested or involved in any part of the analyses presented in this thesis.

4. RESULTS

In this chapter, the results from the methods used to address the research thesis question are outlined and described. The research results are organized in two parts. Part I is called EEG Laboratory Analysis Results and Part II is called Vehicle Study Results.

4.1. Part I: EEG Laboratory Analysis Results

4.1.1. Introduction

The data analysis for Part I was performed using elements of the E-lab framework, also known as AEIOU framework. As mentioned in the literature review, the E-lab framework is one approach being used by designers that is influenced by ethnographic research for analysis and understanding a situation or context. The E-lab framework focuses on the understanding of five elements and the interactions between them (Wasson). The five elements of the E-lab framework are.

- Activities: These are goal-directed sets of actions for things that individuals want to accomplish, such as learning as an example.
- Environments: This is where activities take place.
- Interactions: These take place between a person and someone, or something else.
- Objects: These are the items found in the environment.
- Users: People have behaviors, preferences, and needs.

For the purpose of outlining the results, the user groups will be presented first, followed by the activities. To add context and to help describe the activities, it was necessary to introduce the user groups first. Within the activities subsections the descriptions will incorporate the other three elements of the E-lab framework to describe the interaction between them.

4.1.2. User Groups

Two main user groups were identified during the observations and participation. Figure 9 shows a hierarchic level of each user groups

Participants

The participants consist mainly of adults. However, when children or adolescents and elderly participate in an experiment, a family member or caregiver usually accompanies them.

Researchers

The researchers consist of both professor and students. Professors are the most knowledgeable and experienced in EEG studies and are responsible for overseeing the experiment and guiding the students through the EEG process. Senior students are more experienced in conducting EEG experiments and are often engaged as role models for the junior students, who generally don't have much experience in conducting EEG experiments in the laboratory environment.

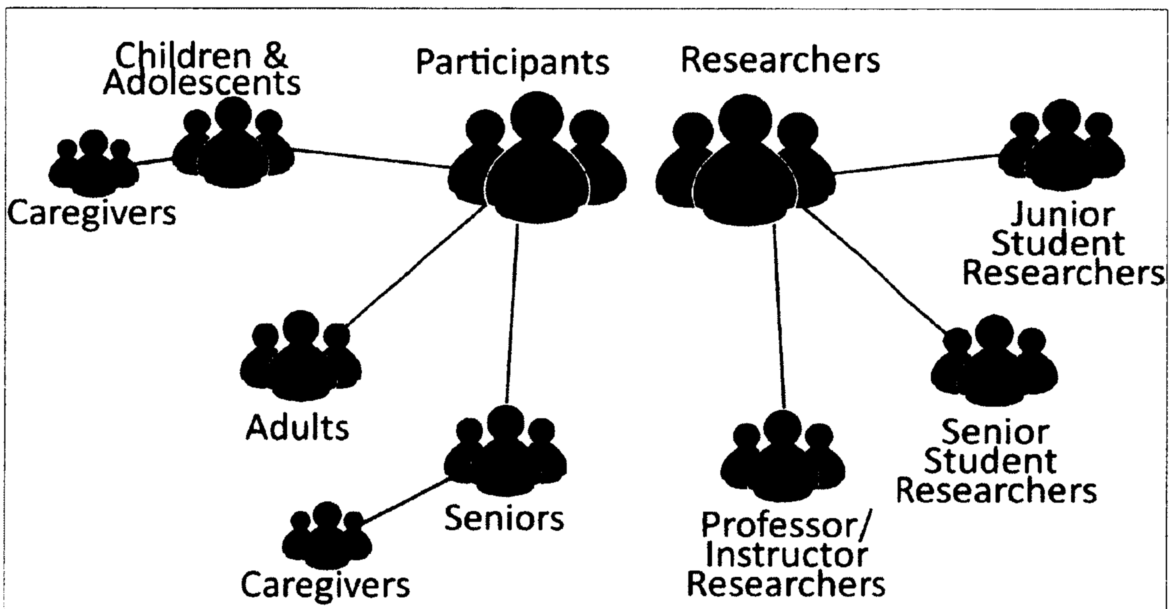


Figure 9. User Groups

4.1.3. Activities

Based on the E-lab framework analysis, a cycle of four major activity stages was identified during the EEG experiment (Figure 10).

- Introduction stage
- Equipment preparation stage
- EEG testing stage
- Data analysis stage

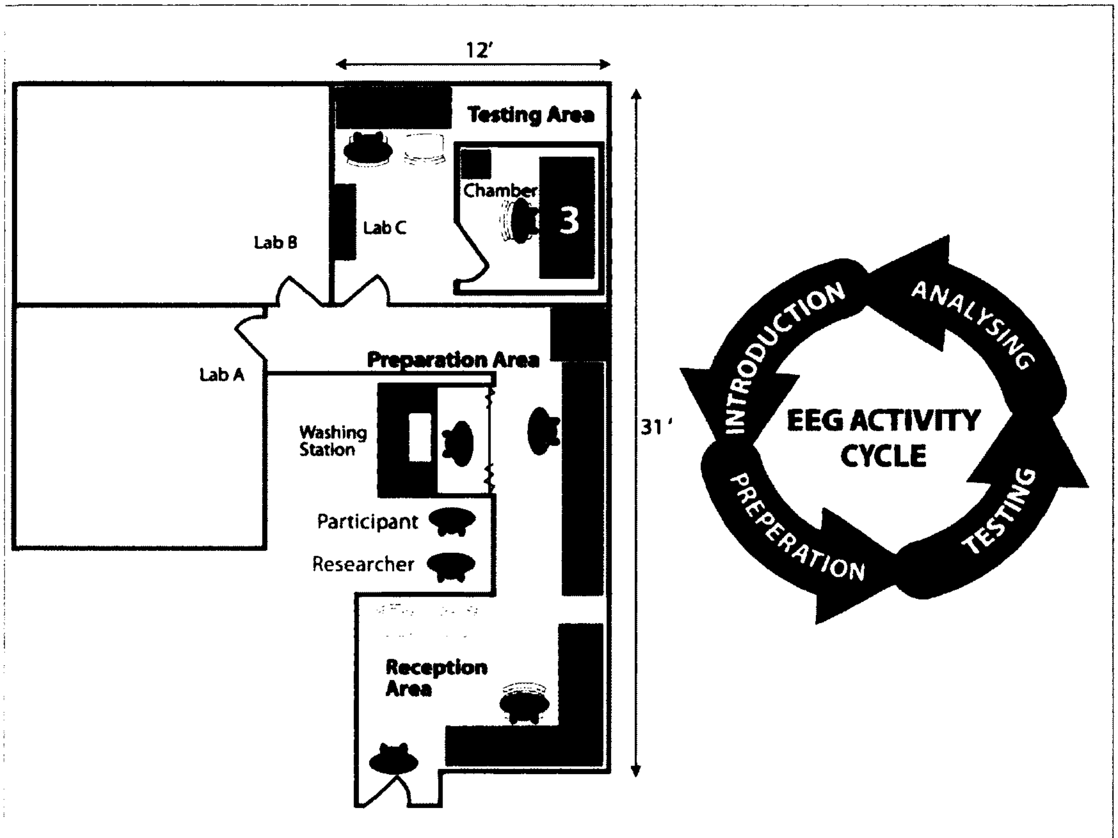


Figure 10. Current EEG Laboratory and Activity Cycle

Activity 1: The introduction stage

The introduction stage of the experiment occurs in the reception area of the laboratory (Figure 11). During this stage, the researchers formally introduce themselves to the participants involved in an experiment, since a majority of the participants often experience high anxiety due to the laboratory environment and the equipment within it. The researchers give a sense of reassurance and comfort to the participants by explaining the procedure and their roles and participation, all to minimize their levels of discomfort. Any legal documents, such as consent forms, are filled out during this stage. Participant heads are measured and their data is entered into a database. The participants are then asked to leave behind any electronic and personal items at the reception area. In the event of multiple experiments happening simultaneously, researchers will take on the role of a receptionist to welcome and process new arriving participants.

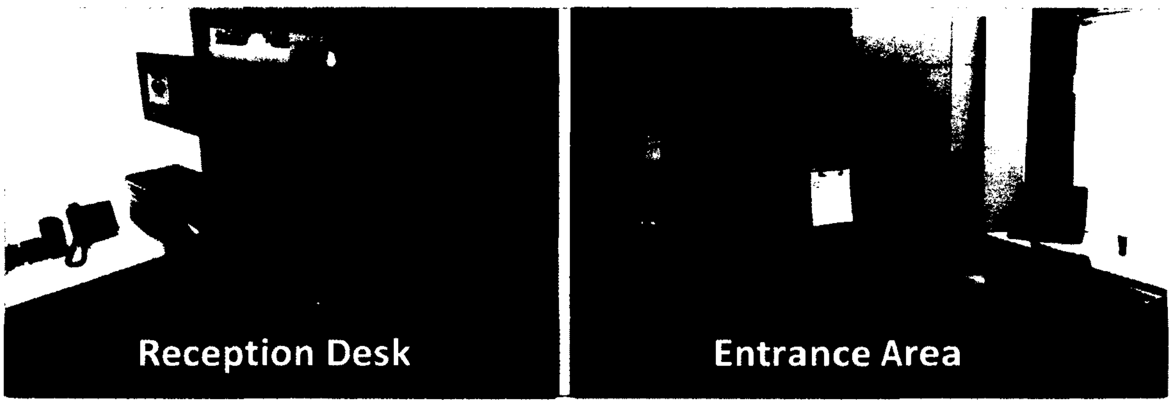


Figure 11. Entrance Reception Areas

Some of the key objects in the environment found in the reception area are listed below.

- Researchers are equipped with a desk and a computer to keep track of the daily schedule.
- Waiting chairs are clearly visible when first entering the area, signaling to the participants that they may sit while waiting to be attended.

The natural light coming into the reception area is both welcoming and illuminates the room, making it a better working environment for the user. The layout of the entrance is designed to immediately allow an interaction between participants and researchers, upon arrival, and provides the space necessary to accommodate both participants and guardians.

Activity 2: The equipment preparation stage

Prior to starting the EEG testing, both the researchers and participants must prepare themselves and the equipment. The majority of the preparation takes place in the hallway section of the laboratory, between the reception area and the testing laboratory rooms. This area is called the preparation area (Figure 12).

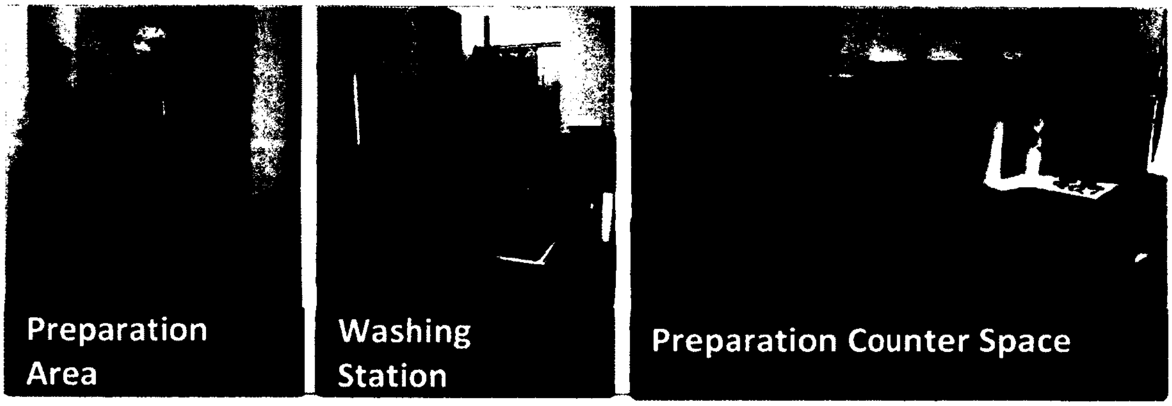


Figure 12. Preparation Areas

Some of the key objects found in the preparation area are listed below.

- A single sink is available for both researchers and participants. To save on time, both individuals prepare themselves simultaneously. The participants normally have priority over use of the sink, which is equipped with storage for shampoo, towels, and hair dryer.
- There is a curtain separating the researchers and participants to provide some privacy to the individual using the sink.
- The participants are instructed to dampen their hair to ensure sufficient electrical conductivity to record accurate EEG data.
- During this time, the researchers prepare the head cap for the experiment. Once ready, the head cap is placed upon a participant's head.
- To prepare the head cap, the researchers must clean the ends of the electrodes and the head cap itself.
- Since there is only one sink available, researchers have multiple water-filled bowls on hand. Washing the electrodes can prove difficult since the electrodes are connected to a junction box that cannot get wet.
- Afterwards, the researchers must individually insert the prepared electrodes into the head cap in the correct positions; otherwise the system will not function correctly. This stage of preparation is done on the adjacent counter facing the sink.
- The counter unit contains storage for the equipment such as a refrigerator for gels, towels, and gel syringes. The counter top is long and provides space for the researchers to spread the equipment out for drying.

The flow of work in the current spatial environment of the hallway is less than optimal. Because of the heavy traffic in the hallway, it is possible to damage the equipment that is drying on the counter by knocking things over accidently while passing by. Additionally, the lone sink reduces the efficiency, since the researchers are required to move from the sink to their own counter. It was also noted that newer research students performing an experiment would often go through the storage units, opening cabinet doors to find the equipment they need. In effect, the newer researchers waste experiment time searching for equipment. Labeling of the equipment storage units is a possible solution to improve the workflow efficiency and reduce the stress level of the new researchers. This solution is incorporated into the set of design criteria.

Activity 3: The EEG testing stage

The EEG testing stage is the core of the experiment. During this stage, the researchers collect the needed data from the participants. The testing is done in one of the three laboratory testing areas available (Figure 13). When participants first come into the lab, they are guided into the noise-dampening chamber, where they sit on a chair, facing a monitor on a table while waiting to begin. The purpose of the chamber is to minimize the external sounds and signals that interfere with the EEG signals captured by the electrodes. The researchers begin by connecting the head cap and the amplifier, and proceed to injecting gel onto the individual electrodes to ensure electrical conductivity. Afterwards, the experiment can begin.

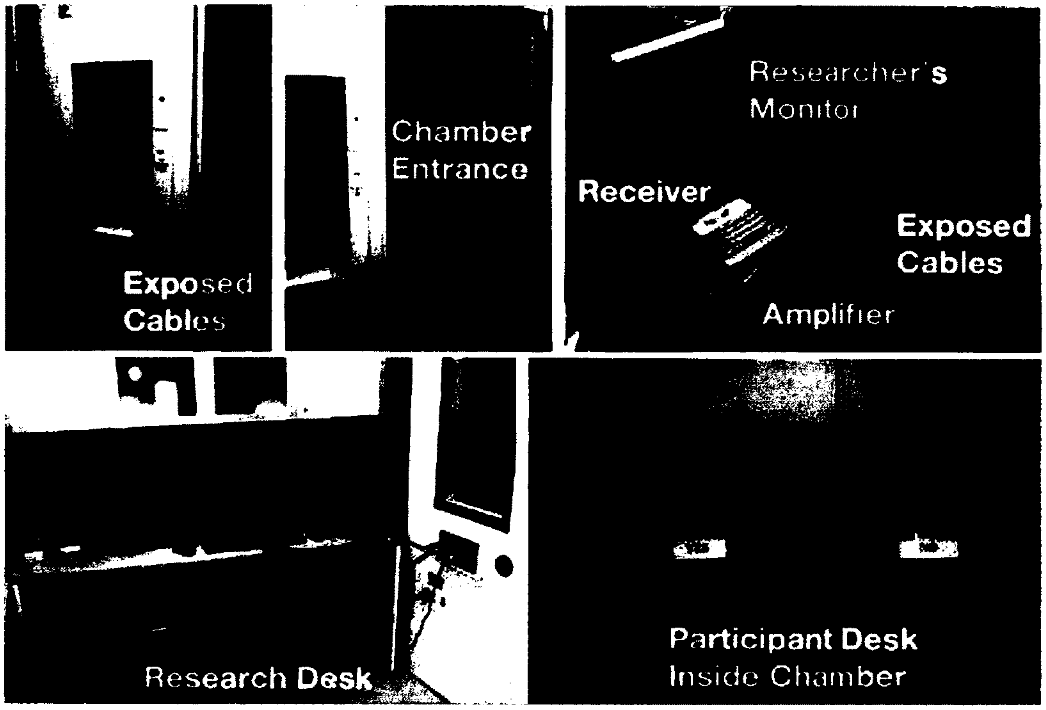


Figure 13. Laboratory Interior

Some of the keys objects found in the laboratory testing area are listed below.

- Each of the EEG laboratory station's walls is painted a different color, not only to create an aesthetically pleasing environment, but also to help Dr. Hirotani coordinate with her student researchers conducting experiments. It was observed that Dr. Hirotani's researchers would remember the laboratory rooms not by number, but by wall color.
- Each laboratory room is equipped with a researcher desk containing four monitors, two computers, and storage for equipment. An additional smaller desk is used to fill the syringes with gel.
- Many cables create tripping hazards and are visually obstructive. The cables attached to the head cap that are suspended behind the participants create tension on their necks due to their weight.
- It is crucial that the chambers are equipped with proper lighting. The ideal lighting source would be halogen light, since it does not flicker like florescent tube lights. Flickering reduces the concentration level of the participants. For this same reason, any windows in the chamber must be located outside the peripheral view of the participants.

An important observation was made regarding the layout of the chamber and the presence of the equipment within it. It is difficult for the researchers to complete their tasks and navigate around the participants.

Activity 4: the analysis of data stage

This stage is done behind the scenes. After collecting data from multiple experiments, researchers must now analyze the data. This is either carried out in an unoccupied laboratory or any other available desk space. The researchers often do their analysis and write up their reports on their personal laptops. In one case, a researcher was working awkwardly on a desk that was near a power outlet so that they could keep their laptop charged.

4.1.4. Discussion of Analysis

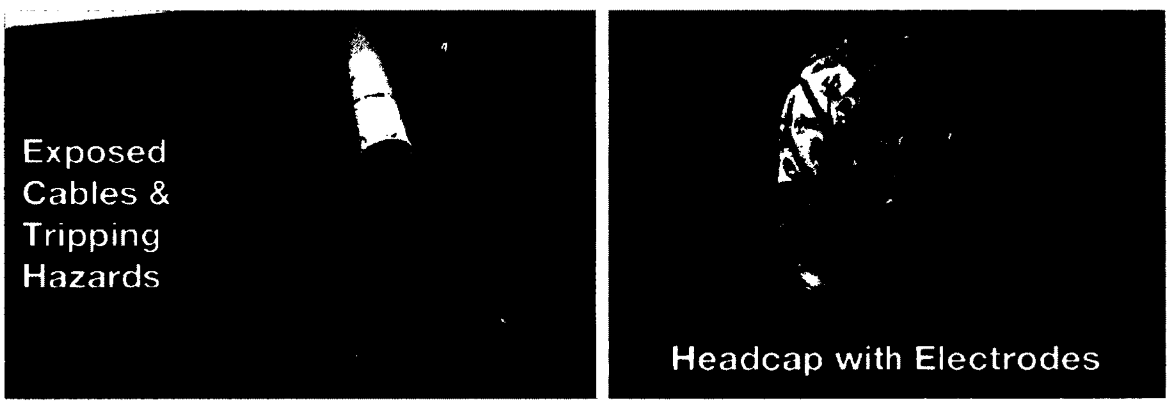


Figure 14. Exposed Cable and Head Cap Configuration

It is evident that the challenges imposed on researchers and participants originate not only from the location of the laboratory, but also from the technical issues related to systems integration of the equipment into the laboratory environment. The current EEG systems consist of three independent pieces of equipment; an amplifier, a set of electrodes, and a head cap to which electrodes are attached. These components are all connected with wires and cables; the electrodes are wired to the amplifier, which is in turn wired to an EEG recording computer. This makes it challenging and hazardous for both researchers and participants to navigate and accomplish tasks during the experimental session. Both the researchers and participants must constantly watch out for wires and other obstacles while they are interacting with the equipment. Not only is this an unsafe practice, but the sight of the exposed wires can have a negative emotional effect on the participants. Since most of the EEG testing is performed in a noise-cancelling chamber to reduce outside sounds, the space inside the chamber is limited and difficult to organize.

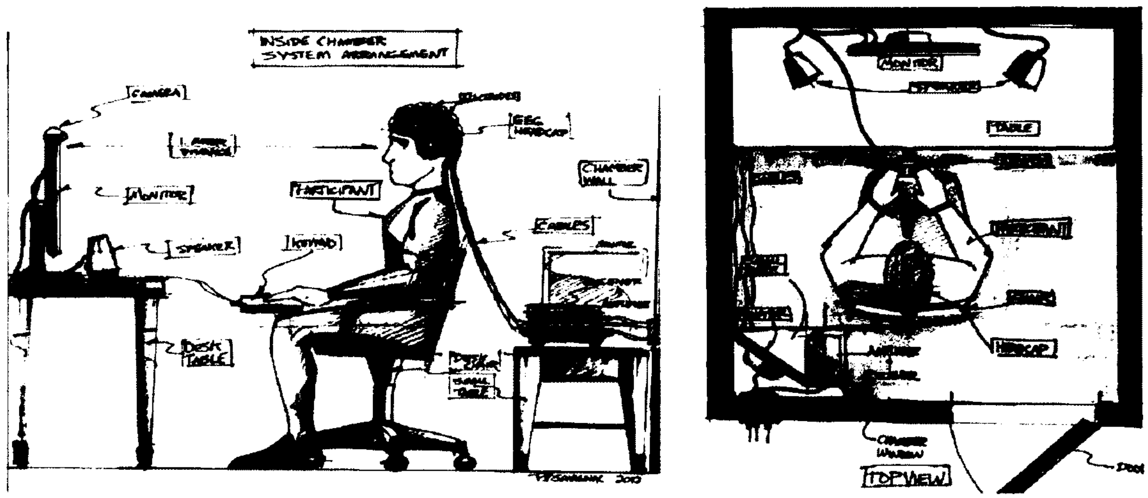


Figure 15. Illustration of Current Chamber Configuration

The main objective of the EEG researchers is to obtain quality data. The quality can be contaminated by environmental factors such as sudden outside noises and electrical interference with other equipment, the lighting system, as well as from head motion. In order to minimize these effects, it is imperative that the participants are comfortable and relaxed. This reduces the amount of discomfort-driven shifting motion that may disrupt EEG data. Another area of improvement is in the preparation area. Multiple washing stations for participants to wash their hair following experiments and for researchers to clean EEG caps and electrodes are incorporated. This design addition can be a challenge if lab space is limited. It should also be noted that researchers are almost always working under a strict time frame. Since the preparation stage can take up to half an hour, delays can negatively affect the ability of the participants and the researchers to remain focused, making it more difficult to successfully complete the experimental session. Figure 16 indicates the average duration of each activity during one EEG cycle.

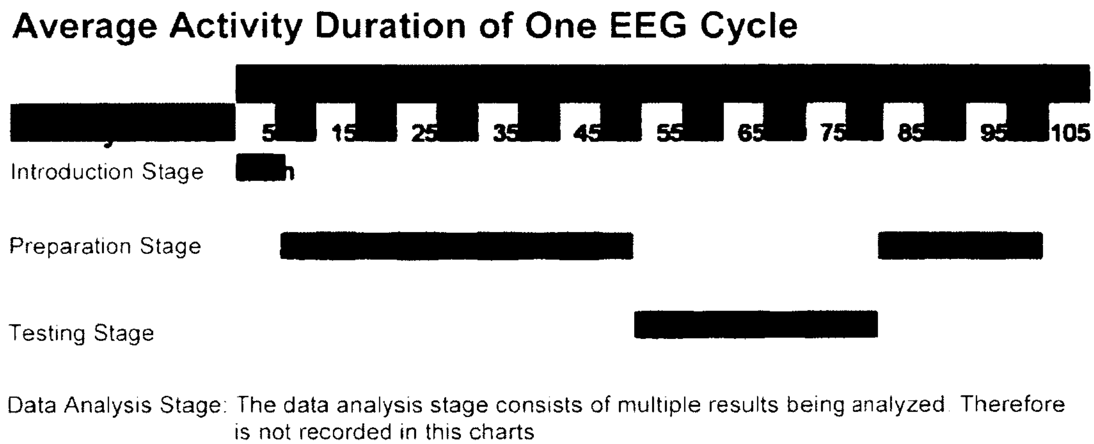


Figure 16. Activity Duration

4.2. Part II: Vehicle Study Results

4.2.1. Vehicle Definition

One of the unique aspects of bringing the EEG research to remote communities is to obtain data from participants who would not normally travel to Carleton University's campus EEG laboratory. Part II of this research involves the evaluation of a suitable vehicle package to support the EEG activities and to involve the user needs.

Identifying the anthropometrics of the user groups, as well as establishing the standard interior dimensions and the associated limitations, would set the physical requirements of a vehicle package and narrow the search. Therefore, the first steps were to identify possible vehicle platforms to transport a laboratory to isolated communities and to base the design concept on the selected vehicle platform. During the investigation, there were the two possible vehicle scenarios that emerged from this discussion.

Should the laboratory be deployable or mobile? To further clarify the terms 'deployable' and 'mobile', a definition of each is provided. Deployable is a military term meaning to arrange in a position of readiness or to move equipment strategically or appropriately. Mobility is the capability of moving, which is permanently equipped with a vehicle for transport. The following two examples are vehicles that are categorized as a modular deployable unit and a mobile unit, respectively. The purpose of these examples is to gain further insight into possible system arrangements to be applied to the initiative.

Deployable example

A great example of a purpose built deployable vehicle is the ZMS (Zeppelin Mobile Facility). ZMS is one of Germany's leading manufacturers of shelter systems in the world and is one of the first manufacturers of lightweight containers in an aluminum-sandwich-structure.

- The multifunctional shelter varies from 10' shelters for emergency and disaster management to large modular hospital arrangements based on the extendable 20' shelters.
- The extendable containers are ideal for deployment since only a fixed enclosed volume is transported, tripling in interior volume once deployed on location.
- In addition, this feature gives greater flexibility for the arrangement of the interior in terms of movement envelopes and equipment storage.
- The Zeppelin Modular System's uniqueness is due to the modular and multi-functional character of the shelters, since they offer solutions to nearly all demands for functional plants or camps. This includes the necessary infrastructure and system integration to guarantee a smooth and proper working facility.

Figure 17. Modular Multi-function Shelters

The ZMS falls under the deployable system category, since the containers are not self-mobile. They require to be transported on site by another vehicle, such as a truck, a train or a helicopter. However, the level of implication and flexibility for such a system is greater in the sense that multiple units can be deployed to a single isolated area to create a whole research facility.

Mobile example

Examples of a purpose built mobile vehicles are the Nissan NV2500 and NV200 commercial vehicles built by Nissan. The NV2500 is a contracting vehicle that serves as a 'wall-less' mobile office/workspace.

- It includes a computer workstation, fold-down conference table, numerous storage compartments, cargo/tool tie-down racks, nearly six feet of interior height and an awning-style side panel that opens to create a standing outside workshop table.
- Unlike the modular container from ZMS, which can be extended to provide more interior and equipment space, the NV2500's design features an integration of the equipment in the wall cavities of the vehicle. All elements of the interior are designed to be multi-functional and highly durable, and able to stand up to the rigors of heavy use at a construction site.

Figure 18. The Nissan NV2500 and NV200 Vehicles

The NV200 Concept, originally shown at the 2007 Tokyo Motor Show, has these features.

- Equipment integration into the vehicle structure and an extendable unit gives greater interior volume for its users.
- The NV200 concept is a fuel-efficient, delivery-type van and mobile office all-in-one.

- The NV200 concept is a cab-forward design with a unique sliding cargo 'pod' that extends from the rear to reveal a workspace and living quarters.

4.2.2. Vehicle Package Analysis

Prior to identifying a suitable vehicle package, the user groups and activity stages identified in Part I suggest that the interior volume needs do the following.

- Accommodate two major human dimensions; child dimensions and adult dimensions.
- Accommodate the necessary equipment use to support the four activity stages of an EEG experiment.
- Because of the sensitivity of the electrodes, the vehicle platform must be sufficiently stable to minimize electrode signal interference from the motion of individuals within the interior of the vehicle.

Five vehicle packages were evaluated as candidates for the mobile laboratory. As follows, they are Class A, Class C, cargo van, RV trailer and cargo container. The platforms were chosen based on their availability in our geographic area and the fact that these could be licensed to be on the road.

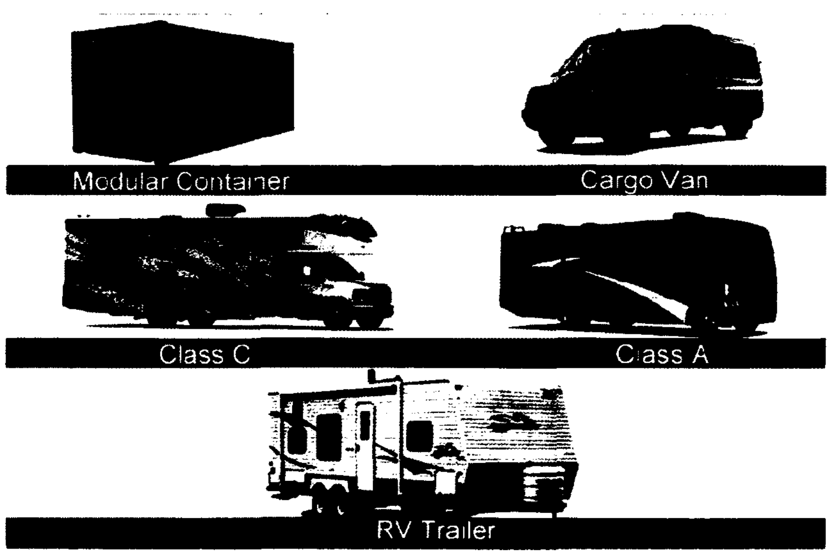


Figure 19. Vehicle Packages

In order to determine the most appropriate platform available for the mobile laboratory, the vehicle samples were studied and analyzed in a five-point matrix and given a numeric score. The ratings are from 0-4, 0 being non-applicable, 1 being low and 4 being the highest rating (Figure 20) based on the following.

- Availability based on geographic location
- Mobility for traveling from one location to another independently
- Floor plan compatibility for interior space affordances
- Road efficiency
- Operational usability

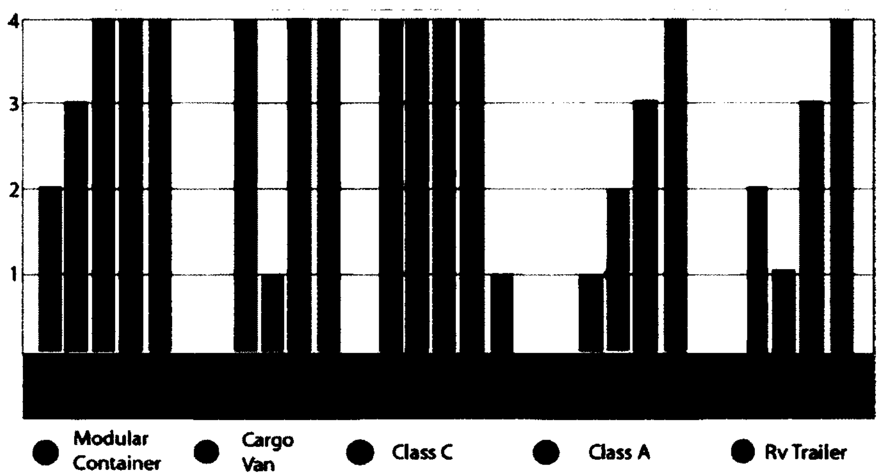


Figure 20. Vehicle Evaluation Chart

Considering that all vehicles are available, the most important criteria in this scenario are mobility and usability. Class A, Class C and cargo van rank the highest. Because of the short duration of the experiment and their relatively large interior volumes, the Class A and Class C vehicles allow more equipment to be brought on location, allowing multiple experiments to be conducted at the same time. Two chambers can potentially be installed in these vehicles. The cargo van lacks the interior space for two running EEG chambers.

4.2.3. Vehicle Study Discussion

It was determined that for early studies the Class C motorhome vehicle type met most of the criteria. Consideration was given to both the total complete unit appropriation and the possibility of acquiring components separately. The former option gives greater flexibility in terms of assembly options. Additionally, the interior dimensions of the vehicle closely matches that of the A class motorhome and the modular container. Therefore, in the event of future research where a deployable modular unit is most appropriate, the design could be transferred from one vehicle package to the next.

The total fixed available interior volume of the vehicle is 1344 cubic feet (24' length, 8' width, and 7' height). Considering the option to add an extendable compartment, the volume can be tripled, depending on the design. Additionally, the floor cavity between the floor and vehicle chassis houses multiple compartments that can accommodate extra equipment, such as generators to power the equipment and multiple water tanks required for the sinks. A drawback to having extendable compartments is the increased weight of the vehicle, which has a negative effect on the vehicle road efficiency. Extendable compartments also reduce the amount of storage space between the floor and vehicle chassis.

4.2.4. Laboratory Floor Plan Analysis

Figure 21 illustrates a representative traveling path taken by the researchers and participants in Dr. Hirotani's EEG laboratory. The illustration was used to objectively find ways to reduce the length of travel between laboratory areas, thereby strategically organizing the layout of the equipment to increasing the work flow efficiency. As mentioned in Part I of the results, the pathway connecting the laboratory room and the entrance area is also the area where the EEG equipment is prepared. When there is a high volume of participant and researcher traffic, this area often causes problems for the researcher attempting to prepare the head cap and electrodes, decreasing the overall workflow effectiveness. The location of the equipment in the laboratory also creates workflow issues. Having the preparation station located in a centralized location in the laboratory is ideal for accessibility. However its location is also the area with the highest flow of traffic.

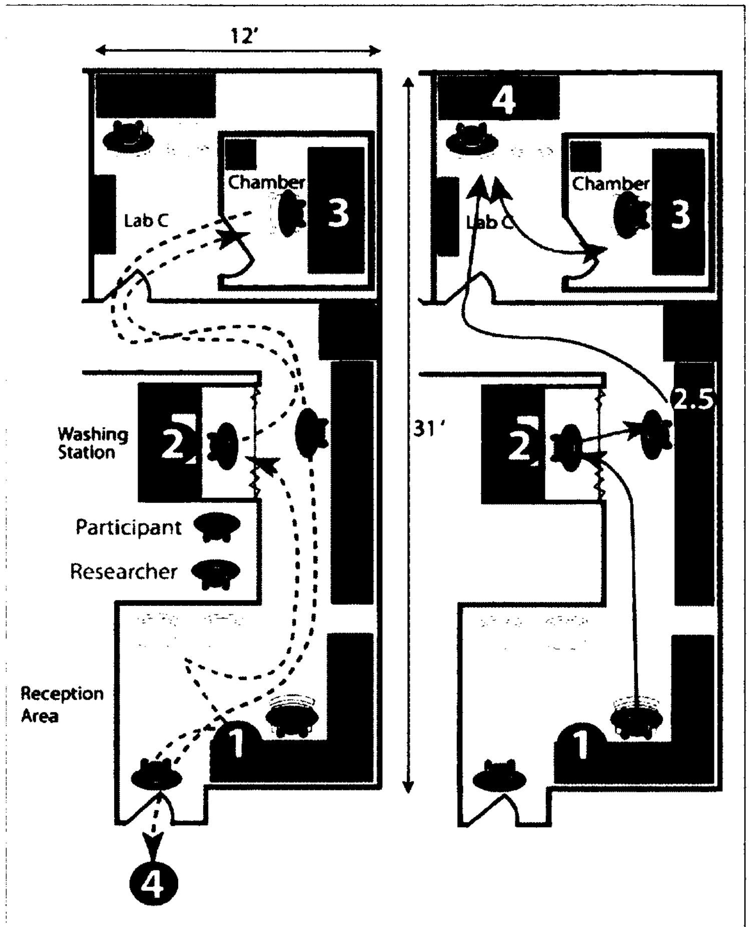


Figure 21. Current Participant and Researcher Movements

The layout of the testing laboratory room also provides opportunity for workflow improvement. The physical dimensions of the sound chamber and its configuration makes it less than ideal for researchers to perform their task efficiently. The interior dimension of the chamber is limited and must accommodate equipment such as the table and desks, in addition to both the researcher and participant to navigate. The small chamber entrance also negatively affects the workflow of the researcher who is traveling in and out of the chamber during the preparation stage of the experiment.

With exception to the adjustable desk chairs located in the current EEG laboratory, the height, reach limits and clearance of the desks, tables, and workable surface areas are not adjustable, meaning that the users below the average height percentile will have limited to no reach. Individuals above the average height percentile will have clearance issues.

4.3. Conceptual Development

Four different types of users with specific needs were identified. Each researcher has a particular protocol to be carried out, while the participants have individual expectations of the environment and the experiments, and in many cases are accompanied by family members or caregivers with particular needs. Secondly, there are well-defined technological requirements that must be integrated to facilitate the workflow during the experiments, while remaining as visually unobtrusive as possible. Finally, the restricted spatial envelope of the mobile environment provides limitations that should ideally enhance the efficiency of any design specifications because it reduces the user movement from workstation to work station.

The design criteria were established based on the data collected during the research phases of Part I and Part II. The following bullet points list combinations that represent important issues to the researchers and participants, as well as the vehicle environment. They are combined to reflect the natural thought process required to be successfully integrated in the design development. The following are the design criteria in order of priority.

- Increase in workflow efficiency while minimizing the researcher movement envelopes by organizing and integrating the equipment in the environment such way that they can be used in closer proximity
- Increase in researcher collaboration to promote discussion in a side-by-side work arrangement
- Increase in research control of the laboratory environment by restricting subject movement, travel distance, and distractions
- Safe transport of the equipment

The following concept is based on the dimensions of a Class C vehicle platform. In discussion with Dr. D'Angiulli and Dr. Hirotani, it was suggested that the vehicle concept should support two testing chambers to allow more testing of participants in any given time. From a selection of concept drawings, the design that best fulfilled the design criteria and requirements based on the findings of this thesis is illustrated below (Figure 22 - 26). The concept proposal for the interior of the mobile lab makes use of the entire 1344 cubic feet interior volume and features the following.

- Integration of equipment storage and EEG preparation station

- Integration of sound absorbing material in wall cavities to reduce outside interferences
- Space to facilitate three researchers to promote teamwork in a confined environment
- Two separate entrances to keep subjects isolated from one another during testing and to maintain privacy
- Two change rooms with hair cleaning stations to improve workflow efficiency
- Integration of monitors and EEG equipment in chamber wall cavities to reduce clutter and minimize tripping hazards
- Collapsible furniture in change room for subject to use as required
- Rounded corner edges on furniture and walls to reduce potential impact injuries
- Adjustable seating and monitors inside chamber to ensure the highest level of comfort and thus the most accurate data collection

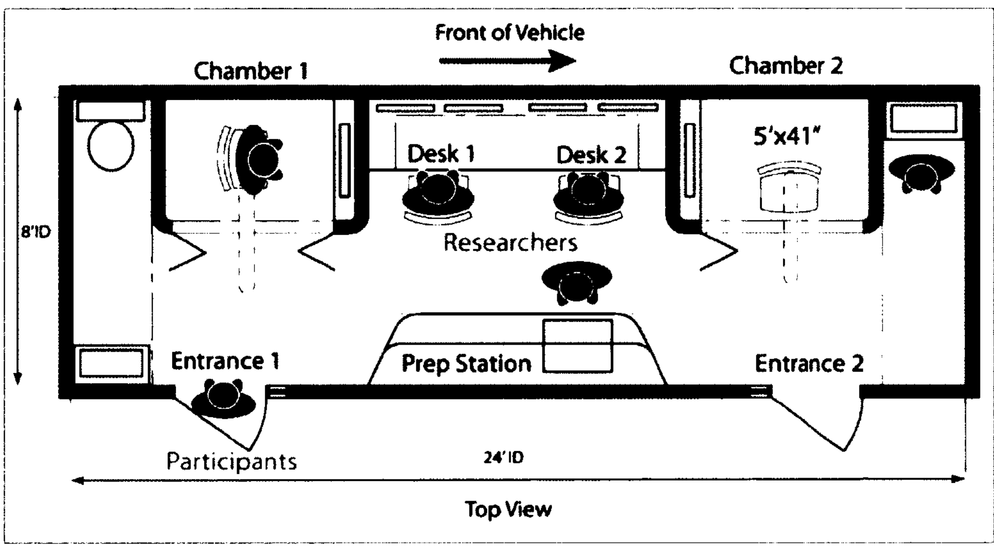


Figure 22. Vehicle Floor Plan Arrangements

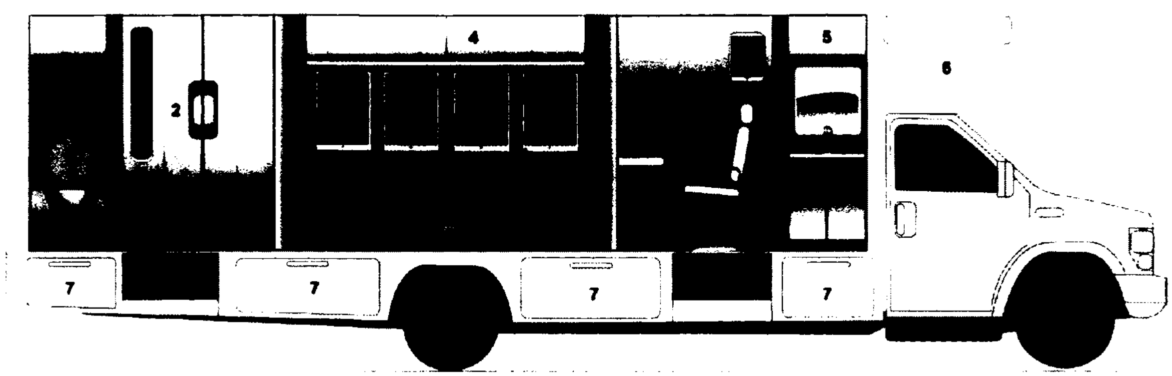
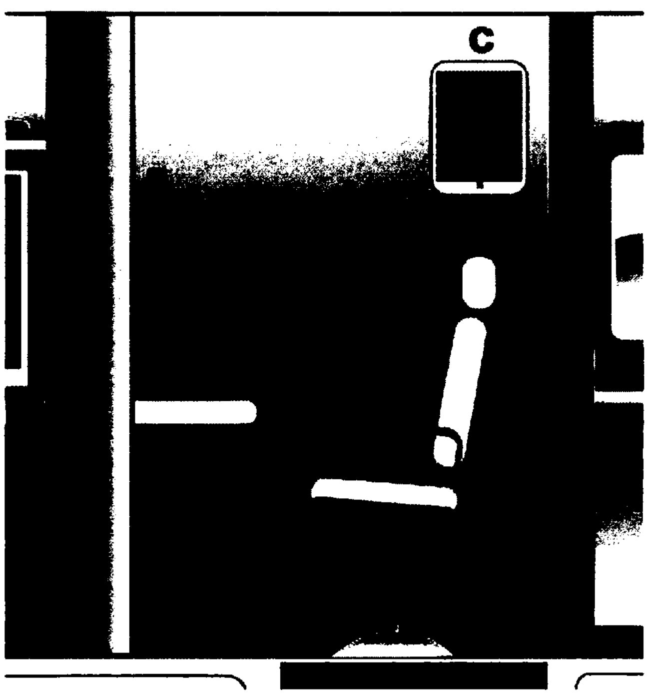


Figure 23. Vehicle Design Elevation View Starboard Side



Laboratory Configuration

1- Washroom/changing room
2- Testing chambers
3- Researcher work station
4- Overhead equipment storage
5- Washing station/changing room
6- Additional equipment storage
7- Sub-frame external storage

Chamber Configuration

a- Adjustable monitor station
b- Wall build desk unit
c- Electrode monitor
d- EEG wireless amplifier/receiver unit
e- Adjustable participant seating

Figure 24. Chamber Configuration Design

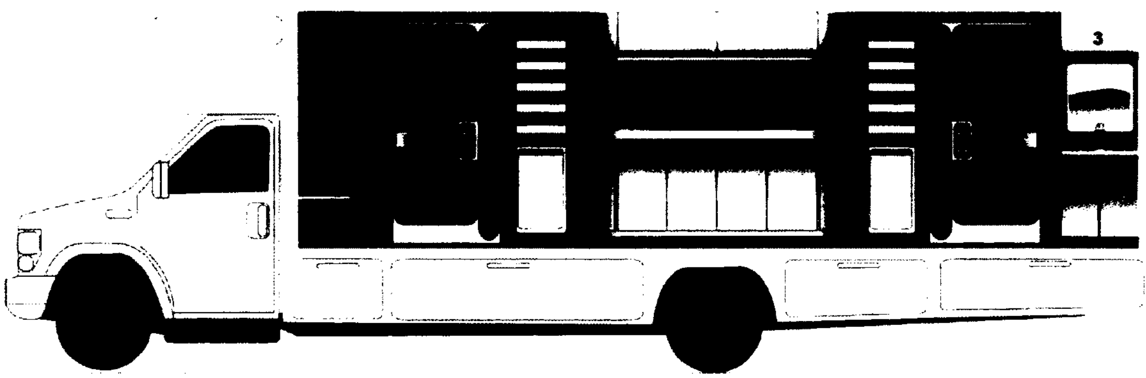


Figure 25. Vehicle Design Elevation View Port Side

Laboratory Configuration

1- Integrated wall furniture (changing room)
2- Participant lab entrance
3- Washing station/changing room
4- Preparation station

Preparation Station Configuration

a- Wall integrated document organizer
b- Overhead equipment storage
c- Washing station
d- Counter space
e- Head cap drying system
f- Equipment storage
g- Wall integrated table

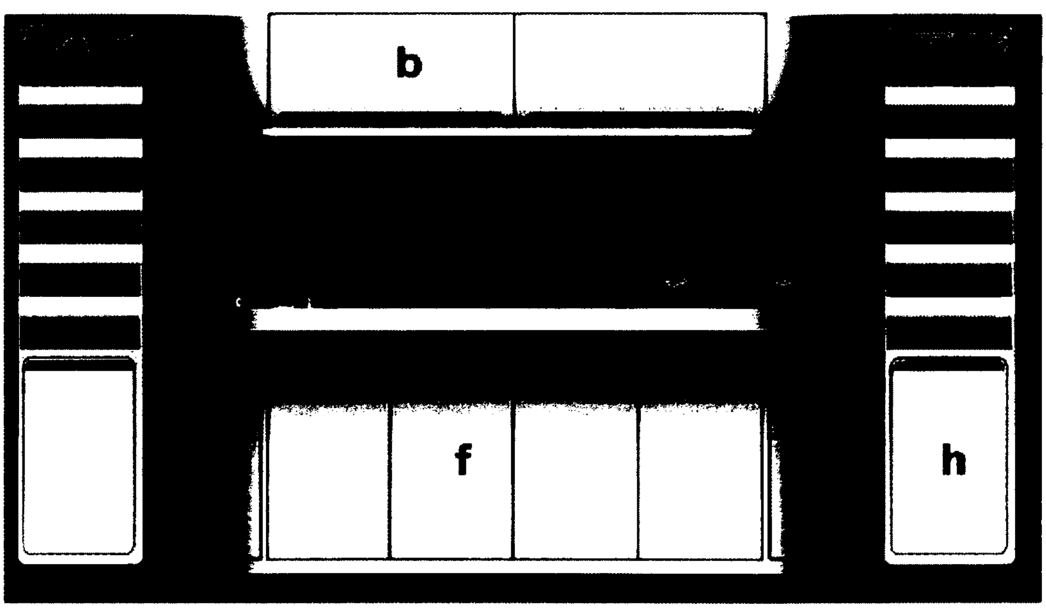


Figure 26. Preparation Station

4.3.1. Prototyping for Concept Validation

A full-scale low-fidelity model of the interior of the Class C vehicle was produced to evaluate the vehicle package based on the physical requirements. These requirements include the spatial movement envelopes of the users, according to the activities, and the integration of the equipment into the interior in a manner not affecting the user performance.

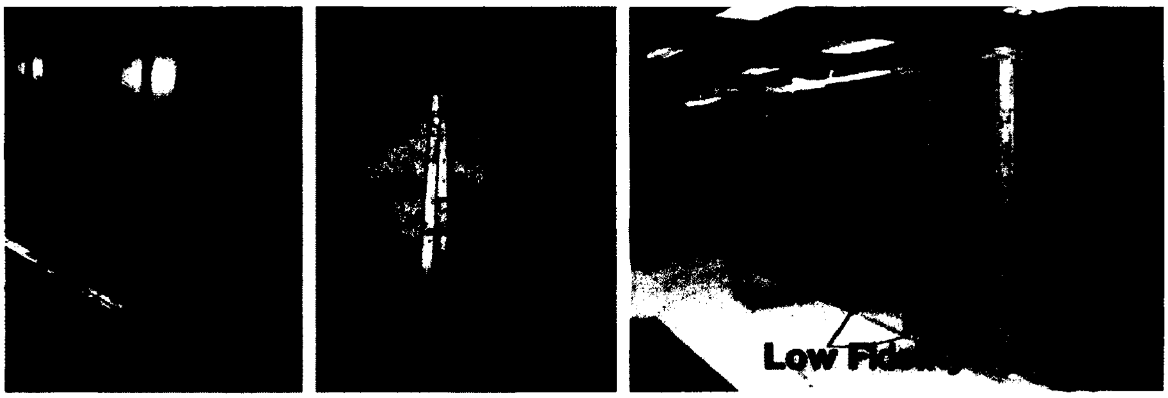


Figure 23. Prototype Images 1

Figure 24. Prototype Images 2

The main purpose of a full-scale model was to create a realistic representation of the interior and to give a sense of scale (Figure 27-28). The interior volume of the vehicle was somewhat successfully able to accommodate the four activities (the introduction, preparation, testing and data analysis) while greatly reducing the spatial movement envelops of the researchers and participants. Unlike the current EEG laboratory in which each activity is performed in a specific location, the design of the layout allows all activities to take place within a confined area of the mobile laboratory. This means that the testing chamber also serves as a waiting area for the initial introduction stage of the experiment, as required. The centralized preparation station reduces the travel distance required to prepare the equipment as compared to the current lab.

Additionally, the participants do not need to enter the preparation area, since they have their own changing rooms at both ends of the vehicle. The vehicle package also accommodates two testing chambers while permitting the safe navigation of both researchers and participants. The equipment is stored within the wall cavities and tape drawings were done to indicate the locations of the cables and wires, as they would be passed within the interior of the walls. Although the changing room configuration is a bit confined, it is manageable.

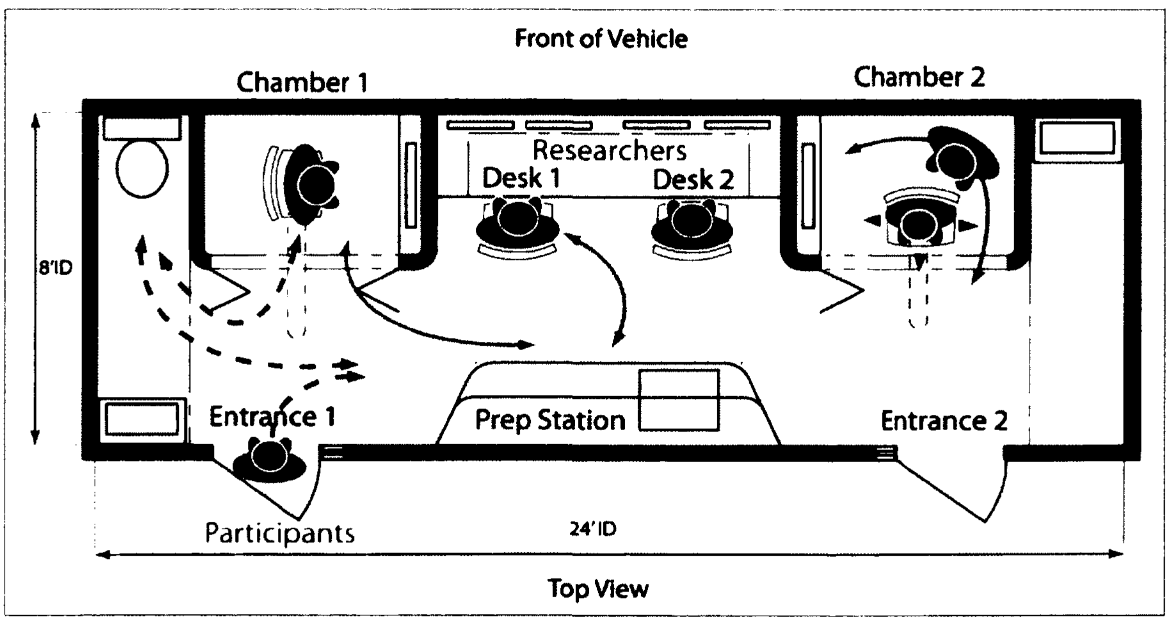


Figure 25. User Movements in Prototype

One drawback of the design is that it did not allow a waiting area for participants. The advantage of having a reception area is that it creates a more inviting environment for participants. The disadvantage however, lies in the technological restraints of the electrode sensors used for testing and the stability of the vehicle. Because the electrodes are so sensitive to outside noise and disturbance, the movement of participants in the vehicle reception area would affect its readings.

5. DISCUSSIONS AND CONCLUSIONS

In this final chapter, the conclusions answering the research questions of this work are outlined and described. As identified in Chapter 1, the purpose of this work was to improve the overall user experience and performance of an EEG laboratory and to produce a conceptual interior design of a mobile laboratory used for community-based research. The goal of this research was to thoroughly analyze the user activities and expectations through design research methods and to conceptually develop an interior environment in realistic scenarios in order to answer the following questions.

- How can the environment for mobile laboratory data collection be more supportive to the needs and activities of the researchers and participants engaged in an EEG study?
- What are the environmental features and affordances, which contribute to a better integration of an EEG testing laboratory into a precisely defined and limited spatial mobile environment?

5.1. Discussions

5.1.1. Discussion 1: Lack of Integration

It was established that some of the challenges imposed on the researchers and the participants come not only from the interior structure and layout of the laboratory but also from the system integration of the equipment into the laboratory environment. As mentioned in Chapter 4, the current EEG systems consist of three independent pieces of equipment: an amplifier, a set of electrodes, and a head cap to which electrodes are attached. This system is connected through wires and cables; the electrodes are wired to the amplifier, which is in turn wired to an EEG recording computer. This arrangement makes it challenging for both the researchers and the participants to navigate and accomplish the required tasks during experimental sessions. Both researchers and the participants must constantly watch out for wires and other equipment while they are interacting with each other or the equipment. Not only are these objects tripping hazards, but the sight of the exposed wires also has a negative emotional effect on the participants.

5.1.2. Discussion 2: Chamber Design Limitations

Due to the fact that most of the EEG testing is done in a noise cancelling chamber to reduce outside sounds, the space inside the chamber is limited and difficult to organize due to the wall thickness of the chamber. The chamber took fifty percent of the volume space in each laboratory room. For the researchers, obtaining quality data is the main objective. The quality of the data can be compromised by environmental factors such as sudden outside noises and electrical interference with other equipment, the lighting system, as well as from movements of the participant head while connected to the EEG equipment. In order to reduce these factors, it is imperative that the participant be comfortable and relaxed such that shifting movements or disruptive signs of discomfort are minimized. The slightest head movement or facial artifact will be recorded, contaminating the researcher results.

Additionally, the current chamber arrangement is limited in its ability to adapt and accommodate participants who are below or above the average height percentile. The chamber serves to suppress any outside signals and noises. However they are not designed to effectively accommodate the equipment. They lack internal compartments, which could allow the wiring to be concealed alongside in the walls, rather than being exposed on the exterior. Furthermore, the layout of the chamber itself could be greatly improved to provide increased accessibility for both researchers and participants.

5.1.3. Discussion 3: Floor Plan Configuration

Another identified area for improvement was in the preparation area layout and arrangement. Multiple washing stations should be incorporated to allow the participants to wash their hair in privacy following experiments. This addition is a challenge due to the limited available space. It should also be noted that researchers are almost always working under a strict time frame. Since the preparation can take up to half an hour, delays can negatively affect the ability of the participants and the researchers to remain focused, making it more difficult to successfully complete the experimental session.

5.1.4. Discussion 4: User Expectations

In observing and participating in the EGG experiment, we are dealing with four differentiated types of users that all have specific needs. Both the senior and junior research students and the instructor researchers have particular protocols to be completed, the participants have individual expectations of the environment and the experiments, and in many cases accompanying family members or caregivers also need consideration. There are specific technological requirements that must be integrated in a way to enhance workflow during experiments while remaining as unobtrusive as possible. Finally the restricted spatial envelope of the mobile environment will provide limitation that has been proven to ideally enhance the efficiency of any design specifications.

5.1.5. Discussion 5: Vehicle Selection

The Class C motorhome vehicle type met most of the criteria. Consideration was given to both the complete unit appropriation and the possibility of acquiring components separately, the latter granting greater flexibility in the assembly phase. The evaluation of the full-scale low-fidelity model of the vehicle suggested that the interior dimensions of the Class C motorhome were sufficient to integrate the EEG equipment without negatively affecting the user activities, and to allow the spatial movement envelops of the users. Additionally, the interior dimensions of the vehicle closely match the Class A motorhome and the modular container. Therefore, in the event of future research where a deployable modular unit is more appropriate than a mobile unit, the design could be transferred from one vehicle package to the next. In considering the addition of an extendable compartment to the vehicle, it was found that the interior volume tripled. However, this feature increases the weight of the vehicle, which affects the vehicle's road efficiency and reduces the available storage space between the floor and vehicle chassis. The cavity between the floor and vehicle chassis houses multiple compartments to accommodate extra equipment storage, such as generators to power the laboratory, and the multiple water tanks required for the sinks inside the laboratory.

5.2. Conclusions

5.2.1. Design Criteria Conclusions

To address the opportunities in the previous discussions, the design criteria were developed over the course of the research. The following are combinations that represent challenges important to two types of users, the researchers and the participants. They are combined to reflect the natural thought process required to be successfully integrated in the design development process. The criteria for the mobile laboratory are listed in order of increasing priority.

- Increase in workflow efficiency, while minimizing the researcher movement envelopes by organizing and integrating the equipment in the environment such that they can be used in close proximity
- Enhancements in researcher collaboration to promote discussion in a side-by-side work arrangement
- Increase in researcher control of the laboratory environment by restricting subject movement, travel distance and distractions
- Provide legible features to facilitate task accomplishment
- Safe transport of the equipment

5.2.2. Design Feature Conclusions

The conceptual design outcome of the laboratory met the design criteria by having features based on driving scenarios. The final design to conclude this thesis is based on the Class C vehicle platform. The features have been categorized in eight different groups to give clarification to the conceptual design of the mobile laboratory and to explain how these features met the design criteria.

Accommodation – The space accommodates a minimum of three researchers. Having the research desks located next to one other provided the ideal solution for social interaction between researchers and promoted more opportunities for collaboration, and the minimization of research errors.

Accessibility - Accessibility to the equipment and space for the preparation of the equipment is located in a centralized area of the laboratory, located directly across from the research desks, and away from heavy traffic.

Centralization - The centralization of the equipment increases the workflow efficiency, while minimizing the movement envelopes, and minimizes obstructions. This location is safe, since the equipment is not near the participants.

Laboratory control - Two separate entrances for the participants to enter the laboratory are recommended. This allows participants to be separated, not only ensuring confidentiality, but also helping increase researcher control of the laboratory environment by restricting participant movement and travel distance. As participants enter the laboratory they are immediately led to private changing rooms and testing chamber.

Adaptability – The interior environment is made adaptable through the use of collapsible features. The chamber can be converted into a private one-on-one reception area, where the researchers can introduce themselves to the participants and proceed with any documentation that needs to be filled out. This feature is achieved with collapsible pieces of furniture, which are integrated into the structure of the vehicle.

Integration - The wiring and other electronic equipment are integrated into the wall cavities of the structure to ensure no tripping hazards or visual distractions. The added benefit is that it also protects the equipment when the vehicle is in motion. Rather than putting an existing testing chamber in the vehicle, which will take up a lot of volume, the vehicle's wall cavities are insulated with the same noise dampening material found in the testing chambers.

Adjustability - Testing chambers are arranged to ensure quality control, and adjustable seating is featured in the testing chambers to minimize participant movement and to increase their comfort level during testing.

Legibility- Rounded corner edge furniture and walls will reduce the likelihood of injuries and additional overhead storage for personal objects and consumable materials. To provide better legibility for researchers, a customizable labeling system is included throughout the laboratory. This feature will allow new researchers to quickly locate and prepare the equipment, reducing the time lost in the preparation stages of the experiment.

5.3. Contribution and Implication for Future Research

As identified at the end of Chapter 1, the following contributions have been made and have the following implications for future research.

- Firstly, this research affectively completes Cycle 1 of the continuing three-cycle progression originally envisioned. This clearly provides the foundation for the design of a final mobile laboratory vehicle.
- Secondly, using a detailed knowledge of the activities and the contributing factors involved in carrying out an EEG experiment, this thesis indicates a thorough understanding of how user experiences can be greatly improved through the choice of configuration and design of the interior environment.
- Thirdly, by following a user-centered approach, this work makes clear recommendations to enhance the interior laboratory performance. The user-centered approach indicates future implications for other interior environments.
- Furthermore, the analysis of this work suggests new directions for future EEG laboratory designs and other laboratories with similar challenges and parameters, such as laboratory facilities in hospitals, universities, and other research institutes.

The proposed design can be implemented into a fully functional prototype that can be compared and evaluated by the experts in the field of EEG studies. The time taken by both laboratories to perform one EEG test can be used to compare the prototype and the current laboratory in terms of floor plan arrangement, equipment configuration, and overall workflow efficiency. Additionally, experts can evaluate the quality of the data from each EEG test to identify any significant improvement. This future research will generate further design implications for the Cycle 2 advancement.

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