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Investigation of the Stroop Effect in a Virtual Reality Environment

Master's Thesis

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Declaration of Originality

Declaration: I hereby declare that this thesis, my original investigation and achievement, submitted for the Master's degree at Tallinn University of Technology, has not been submitted for any degree or examination.

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Date: January 19, 2020

Signature: ....

Abstract

Human cognitive behavior is an exciting subject to study. In this work, the Stroop effect is investigated. The classical Stroop effect arises as a consequence of cognitive interference due to mismatch of the written color name and the actual text color. The purpose of this study is to investigate the Stroop effect and Reverse Stroop in the virtual reality environment by considering response, error, and subjective selection. An interactive application using virtual reality technology with Unreal Engine implemented using instruction-based Stroop and reversed Stroop tasks. In the designed test, participants need to throw a cube-shaped object into three specific zones according to instructions. The instructions depend on the color (represents Stroop Test) or the meaning of the words (represents reversed Stroop test). The instructions using either congruent or incongruent ("blue" displayed in red or green) color stimuli. Participants took more time to respond to the Stroop test than the reverse Stroop test. The result shows that Stroop and reversed Stroop replicates in virtual reality. Moreover, the result shows that subjective difficulty may affect the Stroop phenomenon in Virtual Reality.

List of abbreviations and terms

HMD	Head-mounted display
UE	Unreal Engine
RSE	Reverse Stroop Effects
EQS	Environment Query System
BP	Blueprint
fMRI	Functional Magnetic Resonance Imaging
HIV	Human Immunodeficiency Virus
VRST	Virtual Reality Stroop Task

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1. Introduction

Inhibitory control or response inhibition is one of the essential components of executive function [1]. Clinical neuropsychologists often use assessment of executive function by using the Stroop effect for this assessment. A paper pencil-based Stroop test is widespread in this case [2]. Though this type of research for executive function is already proven, there are many possibilities to use new technologies like Virtual Reality, which is already gaining interest in different fields of research. Virtual Reality(VR) can provide a realistic environment than a typical paper-pencil based Stroop test, which can provide more interesting results for cognitive assessment. Simultaneously, it is also challenging to create an environment that suits testing the executive functioning using the Stroop test. This test is about showing the Stroop words and recording the user response time. In order to get more information about user performance and the relation with the subjective difficulty, we created a VR based application. It uses Stroop based instruction to provide instruction to perform specific tasks in the virtual environment, reaction time, and the result of the task is recorded.
The existing researches for the Stroop test are using a single color-word. For example, the word "Red" is written in blue text color, and the user needs to respond to the color. The approach for this Stroop test is different from the existing research because Stroop based instruction is used instead of the single-color based word. For example, "Throw Red Cube to Blue Well" where the text color of the word "Red" and "Blue" is either congruent or incongruent. Using an instruction with Stroop words created substantial user confusion in response, therefore, proves the Stroop effect's existence in virtual reality. The reverse Stroop effect is also replicated in VR.

1.1. Card-Based Stroop Test to Current Technology Support

The phenomenon for the Stroop was first introduced in 1935 by John Ridley Stroop and proved that people usually take a longer time to visualize the color by name when the meaning of the world is incongruent (for example, the user needs to tell "yellow" where the word yellow uses blue or green color) than tell the color of natural stimulus. After then, a tremendous amount of research has been done based on the Stroop effect [3], and it has much evidence and proof of reliability. In the original Stroop test, multiple Stroop color cards were used, and the performance was measured using the time gap of the user's first and last response. After then the computerized version of the Stroop task discovered, the required time is measured by the time duration taken for processing each item. Often this is measured by the corresponding keypress. Instead of providing a large Stroop effect, it seems that typewritten responses are used less [4]. The Stroop effect is less for the arbitrary keypress compared to the voice record method [3]. There are many computerized version of the Stroop task required response by pointing [5, 6, 7]. It is found less reliability and more validity reported by research on the Stroop effect from the last few decades. Stroop test is started growing attention for using different experiments. Virtual reality(VR) is getting more and more attention among the researcher, and it is being used for different types of training for surgeons, athletes, and pilots, and many more [8]. VR is getting attention as a medium to test the Stroop Effect among researchers. Parsons et al. compared the regular paper-based Stroop test and VARST(virtual reality Stroop task) [9]. It is found that the effect replicated in VR, no significant difference found.

1.2. Project Goal and Research Questions

There is a lot of research on Stroop effecting using conventional card-based Stroop with the computerized like ANAM [10]. A few research found those are using Virtual reality environments. There still lots of possibilities to research the Stroop effect in VR for analysis of the different aspects of human psychology and cognitive abilities. Inspired with this possibility, we used Virtual Reality for this research. The goal of this research is to develop a platform in Virtual Reality and investigate the Stroop effect. The investigation includes recording objective performance (response time, error rate, or the number of errors) and comparing the different subject groups. A modified version of standard Stroop task and reverse Stroop task is used in VR to record response based on user reaction. Where participants need to react either based on the color of the word or meaning of it, depending on the instruction user needs to perform a task (throw a cube-shaped object into well). The instruction is either based on the color of the word or meaning of it. In the VR environment, there are three wells with three different colors. These three-color wells corresponded with the color of the instruction stimuli. The stimuli are presented as an instruction using a specific time gap between the instructions with the congruent or incongruent color of the word. For example, "Throw red cube in blue well" where blue is written in red color. Participants guided to react to the color of the word or meaning of the color. The response calculation assed with touching and throwing the cube into the well. As indicated, the goal of the research is the investigation of the Stroop Effect in Virtual Reality. As a part of the goal, the research will proceed further to find out the answers to the following research questions.

1. Which one has strong replication between Stroop and Reverse Stroop tests in VR?
2. Is there any influence of subjective difficulty for the Stroop Test in VR

1.3. Structure of the Thesis

The research paper is consisting of five sections. In the beginning, section1 the reader gets the introduction with some ideas about various technology supports for the base topic of the research. The research continuation of the base topic Stroop effect with different technology supports. The project goal and research question are also described in the introduction section. In section 2, the reader gets a review of all technologies used during the research. The brief explanation of the base topic Stroop effect, previous psychological research behind it, possible reason behind the Stroop effect, a different version of the Stroop effect are some of the topics of literature review section. As the game design is one of the parts of research and the Enreal Engine is used for developing the game, the reader will get a short description of how Unreal Engine works and the procedure of developing the game in an Unreal Engine. The section 3 is all about the methodology of the research, including system design, system development, game design participants and data collection, data, and the result analysis. Discussion and future works are described in section 4 . Finally, the last section is the conclusion.

2. Literature Review

2.1. Review of VR Technologies

The idea of Virtual Reality(VR) exists from the 1950s. Morton Heilig [11] was an American born cinematographer who is called the father of virtual reality. He developed Sensorama in the 1960s, which was an entertainment console for the single user. It brought together some sensor output. Stereo speakers, Stereoscopic display, fans, a vibrating chair, and odor emitters are the output name. With the combination of those sensor outputs, users could get an immersive experience like a riding bike through the road of Brooklyn. It was a straightforward immersive system for the user with lots of limitations, but as starting, it was a great initiative. After that, many innovative companies and individuals worked for developing their unique VR devices. It seems that the head-mounted display(HMD) is a recent innovation for the mission of virtual reality, but it is not correct. The very first version of this device was developed in 1961 by Philco Corporation. Iva Sutherland, one of the famous computer scientists, created the ultimate display in 1968; it also called "Sword of Damocles." It was a primitive type considering the UI (user interface) and realism. By taking the output from the computer program, the system displayed with the stereoscopic display. As soon as the user moved their head, tracking of the head can change the perspective of the user. The device was so heavy that there was a mechanical arm hanged from the ceiling to hold it with the user's head. During the 1989 virtual reality term enters our everyday life, Jason Lanier, who was a computer philosophy writer, has a contribution to make this term available to our everyday vernacular. However, the concept was the same; computer technology created the virtual reality environment, which was manipulated and explored by individuals. Now a day's virtual reality is used in many fields. Mostly using fields are entertainment, medicine, sports, and architecture. Defense authorities also using this to train their military and aviation.

Nevertheless, the fields are not limited; it is increasing. VR apps are using for some exciting and beneficial aspects. For example, VR can be used for decreasing work-related depression and stress [12]. However, VR is usually a simulation of a real-life environment, which can be said artificial simulations. It enhances an imagery situation or reality. For example (e.g., impersonating a character in a Minecraft game adventure) [13]. One of the typical definition of VR is "artificial simulations, usually recreation of a real-life environment, that enhance an imagery reality or situation" [14]. A more explicit definition is by Burdea and Coiffet, "a simulation in which computer graphics are used to create a realistic-looking world."

Types of Virtual Reality Devices

Most of the available systems for Virtual Entertainment in the market require a computer to provide power. HMD is also needed to help this system to provide an immersive virtual world. There are many HMD available nowadays. Some of those are affordable, and others are expensive. In terms of accessibility, some of those are great for almost all people. Google Cardboard is not only cheap but also works with smartphones. So, anyone with a smartphone can take the experience of virtual reality with Google Cardboard. The following section provides a short description of some devices starting with this. Table1 shows a comparison among the most popular HMD.

Oculus Rift

Facebook purchased Oculus VR in 2014. Oculus rift is one of the most gold standard VR headsets, specially designed for video games. With the high field view, this can provide high quality immersive visual experience. Oculus rift includes two OLED displays, both stonking up at a resolution of 1080 by 1200 for each eye. So, the total resolution is 2160 by 1200. The controllers are very natural to use. The position of the trigger on the handgrip is excellent. The device has two sensors included, but it needs at least three sensors for the full room-scale experience. That means moving around the room and interact with the objects. However, for the straightforward games, i. e. racing games, two sensors are enough.

HTC Vive

HTC's VR system has a partnership with the Valve, and this is driven by Stream VR, which is the leading VR controller combo and headset in the present market. The powerful technology and design made this innovative, sleek, and powerful Kit.

It is providing the full immersive experience for gaming and advanced room-scale technology.

Samsung Gear VR

Samsung developed Gear VR. It is affordable than the Oculus Rift and some other available VR headset in the market. Samsung has a collaboration with Oculus for this device. It needs a Samsung Smartphone to run. Some of the Samsung phones that compatible with Gear VR are Galaxy S9, S9+, Note9*, Note5, Note8 S8, S8+, S7, S7 edge, S6 edge+, S6 edge, S6, A8, A8 Star, A8+.

Google Cardboard

After enabling VR in mobile devices, it started to enter into our daily life [15]. Google Cardboard VR is suitable for passive entertainment using a smartphone device by viewing the 360-degree media view. Though this is not ideally suited for actual virtual exploration but still an excellent option for the new users to start experiencing VR.

Haptic Gloves and Treadmills

Many additional devices help to improve the VR experience and level of immersion when the user starts the VR environment. For example, the Virtuix Omni Treadmill can provide the user with VR experience at a different level. Using this user can jump, run, and explore the virtual world in a 360-degree view. One of the most valuable questions in VR is mimicking the essential sense of touch. Manus VR already developed Haptic gloves that track movement using sensors and provide touch sense using vibration when users navigate through the game.

Table 1. Virtual Reality Device Comparison

	Oculus Rift	**HTC Vive**	**Samsung Gear VR**	**Google Card-board**
Type Platform	Tethered PC	Tethered PC	Mobile Samsung phones	Mobile Most Smart-phones
Positional Tracking	Laser Towers	Camera	None	None
Controller	Xbox One gamepad or Touch motion controllers	Primarilly motion controllers	Trackpad	Single Button
Operating System	Windows 7 SP1 or newer	Windows 7 SP1 or newe	Android	Android, iOS
Ram	8 Gigabites or more	4 Gigabites or more	2 Gigabites or more	2 Gigabites or more

Types of Virtual Reality

Though different types of VR devices described above can come together to create a complete set of VR hardware, there are still different types of virtual reality systems. We can distinguish between different virtual reality depending on the mode that users interact with it. Table2 shows the Characteristics comparison of different types of virtual reality.

Window on World

Window on World VR is suitable for the medical industry. There are numerous training sessions created using the window on world VR [16]. In normal VR, we experience the virtual world using HMD, but for the window on the world, we use a desktop monitor.

Immersive System

The immersive system is entirely different from the window on world VR. HMD is used to create an illusion to the user so that they feel their presence in the virtual world by hiding the real-world view. With this VR system, the user can get the exact feeling of virtual reality.

Mixed Reality

Mixed reality is the coexistence of physical word and virtual world. It is merging the virtual world and the real world in order to create a new environment.

Telepresence

Telepresence is one kind of remote control using virtual reality. Examples of this type of virtual reality are bombing disposal robots operated using VR, and virtual reality operated drones.

Table 2. Virtual Reality Type Comparison

Characteristics	**Window on World**	**Immersive System**	**Mixed Reality**	**Telepresence**
Is the user aware of the real world?	Yes	No	Yes	Yes
Can user interact with the real and virtual world in real time?	Yes	No	Yes	Yes
Can Real and virtual content interact with each other in real time?	Yes	No	Yes	Yes

2.2. Stroop Effect and Background Research

Stroop is a phenomenon that first described by John Ridley Stroop [17]. It provides us much information about how the human brain works for information processing. It is a tendency to feel difficulty in telling the color name, ignoring the word itself. Though it seems, it is simple, but it plays a tremendous role in clinical and psychological research. In Stroop's original study, there were some elements, and the experiment was in two parts. The elements were the name of some colors written in black color, the name of the color written in different colors than the color name itself. In the first step, the participants got the instruction to read the color name printed in black ink. For the second step, the participants had to read the color, not the word meaning. For example, "Blue" might be written in red color, then the participants would have to tell the name of the color that means "Red."

Stroop Test and Explanation

Stroop test is the simplified version of the original Stroop experiment done by Ridley Stroop. This test can be used for many perspectives, for example, information processing speed, selection skills of a person. However, the question in hand why this Stroop effect exists? There are many proposals for this phenomenon, but there is no universal agreement exists. The following section describes some of the ideas behind it.

Causes of Stroop Phenomenon

Though the Stroop test is old, still there are lots of interest among researcher about this. Researchers are still trying to find out the causes of this phenomenon. Many discovered factors affect the result; for example, the Stroop test result can vary between man and woman [18]. John Ridley Stroop himself found that women feel fewer destructions than men. Older people usually take a longer time than young [19].

Theory of Selective Attention

It needs more attention and awareness for processing the information that needs to be ignored [20]. So, the relation of this theory with the Stroop effect is that when a person needs to tell the color name instead of the word itself, it takes more attention. Therefore, this theory suggests the human brain process written information faster than the colors.

Automaticity Theory

Automatic and controlled thinking are two types of cognitive processes. There are some relations to the Stroop effect with the above two cognitive processes. The reason is that reading a word is an automated process. So when people need to identify the colors of the word, then the automated process happens, and it distracts from the actual goal of the user.

Speed of Processing Theory

Processing color is slower than processing words for humans. In the case of the Stroop test, as we need to process color and words both, so naturally faster process, which is processing words come first. Thus, it becomes difficult to tell the color name once we already processed the word.

Parallel Distributed Processing

According to this theory, when we do multitask out brain creates separate pathways for various tasks. Based on the importance, the brain processes the pathways. The easiest between naming the word meaning or the color of the text is processed first.

Reverse Stroop Test

The reverse Stroop test is the opposite of the Stroop test. Participants need to respond to the word name by ignoring the incongruent or congruent color of the word. Usually, word interferes with the naming the color. However, there is a situation where color interferes with reading of the word. This instance is known as the reverse Stroop effect. The idea behind the reverse Stroop effect depends on the relative speed of processing. The inventor of Stroop effect Ridley Stroop first found this effect, indicated in his third experiment in 1995. After a considerable amount of training, this effect started, and it was quite transient. There are many research works done for the reverse Stroop effect afterward, and they successfully proved the existence of the reverse Stroop effect. The success usually depended on the changes in the Stroop task and making it difficult, which made it difficult to compare the result with the standard Stroop test. The reverse Stroop effect is still not a widely accepted phenomenon. An example reversed Stroop study [21]. Participants respond with above and below Stroop words or specific location of the screen. For the first experiment, it was easy to process the spatial position than the word meaning. Here participants got confusion about word meaning with the interference of incongruent spatial position while deciding by pressing the key. There was no interference from the incongruent word meaning about decision making for the spatial position. In experiment two, the method of the interference was altered, where the spatial position was harder to process. It was obvious that the faster dimension got interference from the lower dimension but not the opposite. There are some other studies found based on the reverse Stroop effect [22, 23, 24, 25, 26]. Many of these researches used nonverbal responses, and there is an of the question of how critical the response mode because the original Stroop test used a different method for recording the responses. Two studies [27, 28] are cited as for the illustrative Stroop effect. They found the reverse Stroop effect, which introduced with the ink color. It was hard to read the words because of color interference. However, it is unfortunate that, like many of the other research for the reverse Stroop effect, these two did not experiment with both direction interference in the same experiment.

The Consequence of Practice on Stroop Effect

There is a critical question, does practice changes the Stroop effect result? If it does, then how and what information we get about the causes of the Stroop phenomenon? The importance of this question realized by Stroop and his predecessors. Extensive reading habit is one of the views for the words interference when naming the color. Therefore, Stroop interference has a direct relation to differential practice. The practice should have a consequence for the Stroop effect is found by the Stroop (1935) with the third experiment. However, he claimed that considerable practice needed to alter the response tendencies when performing the Stroop test. Unfortunately, the studies related to the Stroop effect hardly considered the consequence of the practice. Very few studies indicated the practice issue with the Stroop effect. However, their final claim shows the practice is not a critical variable for the Stroop effect. Jensen and Rower [29] showed that the practice effect occurs within the first five trials, which is very much arguable. Intuitively, by performing extreme practice, users can develop a strategy to get more success in the Stroop test, proved by several other researchers. However, some research showed that it is not apparent [30]. It depends on the difficulty level of the test. Easy test interference reduces with practice.

Psychology Research Behind the Stroop Effect and Reverse Stroop Effect

The Stroop effect has been examined from time to time where changing evidence or methodologies in order to find the response strength and processing speed is also counted [31, 5, 32]. For example, response time is affected by the word meaning than the font color [24], which is also reported by Stroop (1935) first time in history. It was observed that when Stroop asked people to read printed words instead of visualizing the color, the reliability of the interference was not excellent. This phenomenon is called Reverse Stroop Effect(RSE), and the interference behind it would increase by practicing some days [Stroop experiment 3, 1935]. The modification of the conventional Stroop task provides more reliability and strong RSE. RSE was found by another research [33] where they used small fonts, and it was also challenging to identify. Some other researchers observed reverse Stroop effect, for example, [24] experimented RSE when they asked participants to read the printed words backward and upside down. RSE observations got theoretical interests because it suggests that due to a couple of information processing, cognitive interference happens.

In the standard Stroop effect, color information processing speed is less than the word meaning processing. Therefore the interference happens with responding. However, when modifying the Stroop task by rendering the word meaning reading, word stimuli being RSE. In some studies, RSE is observed by giving small tasks to the participants. For example, [34] reported reverse Stroop effect when they asked the participants to press a key on a response box according to the meaning of the word. The same type of RSE reported by Durgin when the participants point a location of the computer screen according to the color match [6, 7]. It is assumed that when participants identify the color by using the name, there happens an internal process where the transition of the lexical code to the visual code needed. It is supported by the dual coding theory found in research [35]. This research supported that the exiting stimuli structure, which means ink code and "logogen code," which is phonological code extracted first and then translated to the response. Depending on the instruction, the transformation can happen in both ways, phonological code to image code or image code to the phonological code. Though this is one of the processing behind the RSE, [5] reported that there is no need for the translation of the image code to phonological or vice versa to get RSE. In this research, the author used a pointing task where the user needs to point their responses at some specific zone labeled with the name of the color. Autor used stimulus-response strength for this proposal.

Though there is a tremendous amount of research happed for the Stroop task in different environments and processes, the dependent variables of the research are limited to error rate and response time. The subjective difficulty was considered for very few research [36]. It is unknown whether Stroop and RSE are biased with the subjective evaluation of the difficulty of the task. Subjective evaluation is the evaluation or assessment of any tasks that are biased. Subjective evaluation is a fascinating subject to research because people consciously or unconsciously tend to do that. Almost every phenomenon is subjective, as people used to make some subjective evaluation for every task in the unconscious mind. For this possibility of subjective evaluation, there may influence on the response time and error rate for the Stroop task. Primarily when it is implemented with the Stroop task in-game environment with the new technology, for example, Virtual Reality.

Uses of Stroop Effect in Different Field of Research

Stroop effect is one of the most popular research topics of the last 50 years. The Stroop original test intention was measuring cognitive flexibility and selective attention [37]. Later, researchers are not only interested in experimenting with the effect but also find a relation with different aspects of human life, for example, psychology and brain health. BMI (Brain Machine Interface) is a direct interface between machine and brain, which is used in ECG.

Stroop effect can be used for the development of BMI [38]. Typically there are eight electrodes used for measuring BMI. However, according to the author's claim, it is possible to use only three electrodes using the Stroop effect. Using the ECG signal can be used for measuring human stress and relaxed state. To create a stress state Stroop test is used [39], and the classification of the states was 96.41%. Mental illness diagnosis is necessary to check the mental health of people. fNIRS (functional near-infrared spectroscopy) is used for detecting mental illness. The reason behind that is the average pattern changes in cerebral blood flow of that type of patient is different from the mentally healthy people. In order to classify patients, the Stroop effect can be used according to fNIRS data [40]. Supervisory attention processing (selective attention, inhibitory control, planning, problem-solving, and some aspects of short-term memory) is an exciting topic to research.

Using supervisory attention, we can know much information about human cognitive behavior. Stroop effect is used for researching about supervisory attention processing. Parsons et al. [41] showed a novel approach for processing supervisory attention in virtual reality using VRST (virtual reality Stroop test). VRST is also used to detect traumatic brain injury detection in active duty military [42]. Neuro Oncologist uses paper and pencil based Stroop test in the military to identify cognitive deficits related to traumatic brain injury. They measure attention processes and executive functioning using the Stroop Color-Word Interference Test. The participants may need extra cognitive demands compared to the traditional neurotological test. It happens because of the divination of the attention for interacting with virtual reality. Depending on this hypothesis mean response time of the VRTS was more than the traditional one. Virtual reality may better replicate natural conditions for cognitive tasks than the traditional paper pencil-based test settings.

As traumatic brain injury detection among military people, the Stroop task used to test is there any different reactions among HIV positive people [43]. Response inhibition, Controlled processing, and set adoption were examined among HIV positive and HIV negative people. The result shows that the HIV positive persons had a slower response for both vocal reaction time version or the computerized version of the Stroop task.

Stroop test is used for how the human brain works [44]. Using fMRI(functional magnetic resonance imaging), they found an interference related activation in left inferior frontal gyrus among older adults comparing with the young adults.

Stroop effect is used to research on autistic children to detect whether any different reaction comes from them. The result suggests that autistic children learn only from the root memory [45]. Furthermore, the Stroop test is used for measuring age-related deterioration in inhibitory processing [46]. There are lots of other research where the Stroop effect used, and still, researches are ongoing based on the Stroop effect.

Stroop Test Variation

Since the Stroop effect is a concept, there are different version of the Stroop test exists. The different authors translated the Stroop test in various languages. For example Chinese [47], Swedish [48], Japanese [49], Hebrew [50], German, Czechoslovakia. One of the challenges of the Stroop test is that there are numerous versions of the Stroop test literature. Though there is no standard version of the Stroop test, there are three versions published commercially. Two of those are Trenerry's Stroop, Charles golden's Stroop(1978). The last one is peter, published by Peter Comalli et al. [19]. The Stroop test variation exists in different aspects, i. e. include dot or XXXX in the Stroop test, the number of choice of colors, including extra task with congruent color words, excluding some colors or words.

Individual differences in Stroop test

There are many studies found discussing the individual differences for the Stroop effect. Unfortunately, most of those did not show the exact reason why this difference affects the phenomenon. However, in the following section, the sex and age difference for the Stroop effect is explained.

Sex Differences in Stroop Effect

Sex is the most apparent difference between individuals. So, lots of efforts found to find the sex difference effect for the Stroop test. Even before the Stroop effect discovered, it is observed by Ligon that the girls can tell the name of the colors faster than the boys. Stroop also indicated that, but he mentioned there was no difference in interference for the boys and girls. The same result replicated for [51]. There is a possible difference between men and women for encoding foreign words [52]. Men may encode it phonemically and orthographically. Women do it only phonemically. This idea can be valid only for Stroop like situations and may not correct for the regular reading procedure. It is found that though there are minor differences in processing speed for color naming between but this is not strongly affecting the performance. In summary, there is not much considerable difference found in the Stroop effect for men and women.

Age Differences in Stroop Effect

Age plays a vital role in the Stroop. Many studies already proved that idea. Comalli [19] first studies the age effect for the Stroop test. The participants were 7 to 80 years of age. They found substantial interference among children. The interference became lower with the increase of age but increased among the high aged people. It is found the young and older people having more difficulty when response the Stroop words. The interference begins with the early age of the school children with grades 2 or 3. Then with the increase in a reading habit, it decreases until 60 years, but after then it starts to increase.

Paper pencil-based Stroop Task

A computerized Stroop task is a version of the Stroop test where the participants have to respond by watching the computer screen. Stroop stimuli presented on a computer screen for a certain period and the user response is recorded. According to the analysis of literature for the computerized Stroop test, most of the Stroop stimuli type is single, for example, ANAM Stroop Test 2007 [10]. The user response is either verbal or manual. For the manual response system, the participant needs to press a key from the computer keyboard. There are many pieces of research found on Computerized Stroop effect and validation of it in a different aspect. For example, DiBonaventura et al. [53] tested the Stroop effect among 68 females, where the participants had to respond on color by clicking on the corresponding key from the keyboard. The participants were in two groups, familial risk of breast cancer group and without familial risk. There were six different sets of word lists. Those are-

- six experimental word lists Cardiovascular
- consisting of cancer words
- disease words
- neutral words
- standard color words
- positively valent words
- negatively valent words

The result suggested that the familial risk of breast cancer group took more time to respond to cancer words than without a familial risk group.

Hill et al. [54] used a computerized Stroop test as a part of the Concussion Vital Signs (a test, usually for athlete's health check) test. Among 174 individuals, and their logistic regression analysis result got discrimination between user groups. Similar kind of computerized Stroop test used by Iverson et al. [55], Stroop test as a part of a neurological battery test. The test consists of three parts, at first color words printed in black, and the user needs to press the spacebar from the keyboard when they see the word on the computer screen. In the second part of the task, color words written in congruent or incongruent color. User needs to press the spacebar when they see the word match the color name. In the final part, the user presses the spacebar when there is a mismatch of the color words and color. Another computerized Stroop test used among multiple sclerosis and healthy patient [56], here the Stroop is also used as a part of computerized battery tests. The result found a significant difference between MS patients and healthy patients.

The previous research pattern shows that it is common to apply the Stroop test for different types of patients. Schweiger et al. [57] experimented with computerized Stroop test Attention Deficit Hyperactive Disorder (ADHD) patients. They found the worse responses from the patients than healthy people. Tartaglione et al. [58] used a computerized Stroop test for Cirrhosis patients. However, there are certain benefits of the computerized Stroop test, including better control in the presentation of the Stroop stimuli than the paper-pencil based Stroop test [59].

Virtual Reality Stroop Task

There are many pieces of research found, based on the paper-pencil method. Unfortunately, there is very little research exists for the Stroop Test in a Virtual Reality Environment. VR provides an environment where the test stimuli simulated in a way that is a realistic presentation to the real environment. VRST (virtual reality Stroop task) used to test the Stroop effect in the virtual environment using real-world auditory with virtual distractors [41, 42]. Hight mobility virtual vehicles are used to immerse the users, and Stroop stimuli appeared in the windshield. The purpose of the original VRST was to measure supervisory attention processing using different conditional, for example, with distractors or without distractors or both. The aspect of original paper-pencil and ANAM (the computerized version of Stroop test) was emulated in VR. The VRST presents the single item Stroop stimuli to assess the executive functioning, reading speed, and attention abilities. The summary of VSRT is the automation of paper-pencil, and ANAM based Stroop test in a single stimuli manner. In order to leverage some other previous research on VRST, we analyzed some VRST related works. Christin at al [41]showed VRST is useable for neuropsychological assessment to military personnel. They found a new promising method that is possible in real-world military performance analysis in the future. Although there exist some VR based assessment limitations like simulator sickness, The further development of the VRST is found in the virtual reality apartment-based Stroop test [60]. The participants immersed in a virtual apartment environment. The Stroop stimuli showed on a television screen inside the virtual apartment. The virtual apartment is well furnished, and participants see the kitchen, window, and other household things. Destructions happen with different things inside the apartment at various locations. Some of the audio destructions are-

- vehicles are going through the road, which is visible through the window, making noise

- cellphone ring sound is presented sometimes from a phone on the coffee table
- a robot is always moving inside the room and making a sound
- an alarm clock
- doorbell
- vacuumed cleaner
- a person sneezing
- sometimes plane going over the building

Visual destructors have existed like a woman is working in the kitchen. This research tested among some young people and found a Stroop effect with bimodal stimuli. The primary findings of the research strongly suggest that there is a possibility of using this to measure human cognitive inhabitation.

2.3. Game Design

Unreal Engine

A game engine is a software framework and essential functions of game combinations with image processing power at run time [61]. American base company Epic Games develop Unreal Engine, which is one of the most popular game engines nowadays. The latest stable version of this game engine is 4.21. Although the first target was first-person shooter games, it is now suitable for different types of game development. The language of UE is C++. In 2015 the code of the Unreal Engine became open source. Anyone can modify the source code to meet their needs. UE4 one epic, powerful tool that is a proven AAA(replicate hight quality) game engine. It is used for making many popular games like Shardbound, Kingdom Hearts III, Final Fantasy VII Remake, Unreal Tournament, and the Gears of War franchise [62]. The image of UE4 is very realistic, and it has reliable rendering power too. Production vertigo one of one problem in a VR game. UE4 reduces vertigo issues with high frame rate rendering. The cost of development and learning is high for UE [63].

The process of the UE is shown in Fig 1 . The development process of any game in the UE straightforward. It works in two steps. At first step developer makes the resources and then imports inside the Engine for processing; for example, audio implementation, image processing includes graphics.

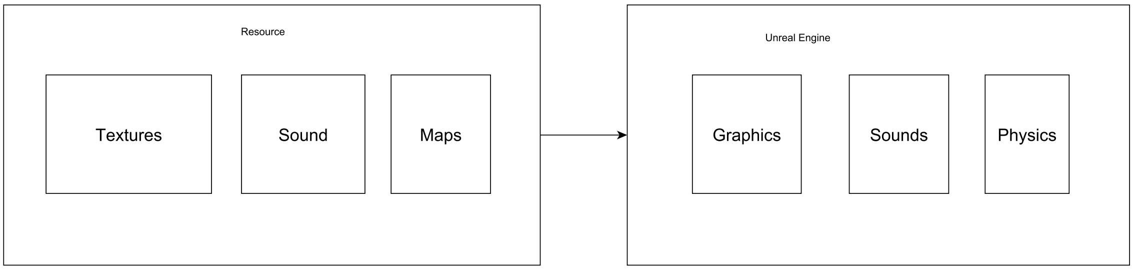

Figure 1. Unreal Engine Process

Blueprint

There are two types of options to create a game in the Unreal Engine. The programmer can write c++ class or use the hybrid system called Blueprint. Blueprint is the visual representation of classes. It provides facilities using the interface from where the developer can create player characters and behavior tree that coverts in C++ code in the background. It also incorporates some more advanced tools, i.e., EQS (environment query system), AIComponets to provide the agent perceive and sense the environment. Bluprint includes widgets, game level editing, and user interface creation tools. Each function in a blueprint is a node of a graph, and it has two connections for input and output. Fig 2 shows the structure of a basic blueprint. With this Blueprint, the system will print "hello world" on the screen. When the system starts, it fires the function Event BeginPlay, which output is connected with a print function that prints string "hello world." The blueprint function works as c++ class, and some of the essential blueprints are the world, actors, objects, and components.

Object

UE4 has robust OOP systems to handle game objects. The Object is a raw level class, and this is extended by all other classes inside the game engine. There are lots of sub-objects too. Most used Objects are the world, Actors, and Components.

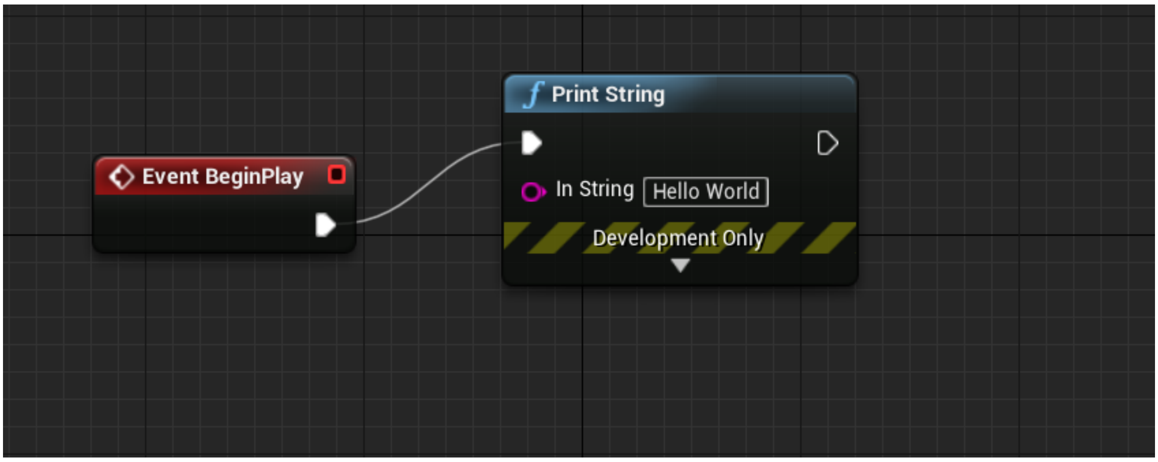

Figure 2. Unreal Engine Blueprint

World

It is the most top-level Object of the Engine where the components are rendered started or ended. It can be Parent level with multiple levels loaded or removed using blueprint functions and volumes. It also can be a set of levels systematized with Composition of World.

Actor

The actors are objects that exist inside the level. The actor has transformed; it has rotation, scale, and location. The base class of the actor is AActor. The actor creation has two ways using a blueprint or C++ code [64]. There are different type of actor exists, some of those are PlayerStartActor , StaticMeshActor, and CameraActor.

Component

A component is one kind of Object that can be attached to the actor. Some standard behavior can be shared with components, for example, sound, the ability to display the visual effect. The representation is also depending on the programmer. It is possible to represent project-specific concepts with components. UActorConponent is the name of the base class, which is extended by all the components [65]. During the game, anything that the player interacts with is a type of component. Some of the functions of the component are playing sound, making collisions, and rendering mashes.

Blueprint Communication

Sharing information between blueprints is very common when we are working with multiple blueprints. There are different types of blueprints, and we can use those according to our needs. The most commonly used blueprint communication type is direct communication. Two essential types of blueprints are as follows.

Direct Blueprint Communication

The type of Direct Blueprint Communication is one to one. One blueprint is creating a request to get access to the other. This most suitable for a situation is when we have two blueprints, and we want to exchange some information between those. The way of using direct blueprint communication is getting the reference to the other Blueprint via a public object variable and specifying the instance of the desired Blueprint. The ideal situation for using this type of communication is when we have two actors, between those we need to set communication. For example, we want to destroy a water tank, then a bullet hit on it or toggle light when a particular keypress. Fig 3 shows direct blueprint communication.

Blueprint Interfaces

When multiple types of objects need to share the same functionality, we can create user blueprint interfaces. It is like a contract; if we want to implement the specific interface, we would have to provide some functionality for sure. For example, we want to destroy the gas tank and car when there will be fire. We can create an interface with the function called ONFireStart. Then for both tank and car, we can implement that interface. In this case, the car and tank are treated similarly, and we can call the function ONFireStart. BP interface has no implementation on its own. Overriding and overloading are the two main benefits of the BP interface. Fig

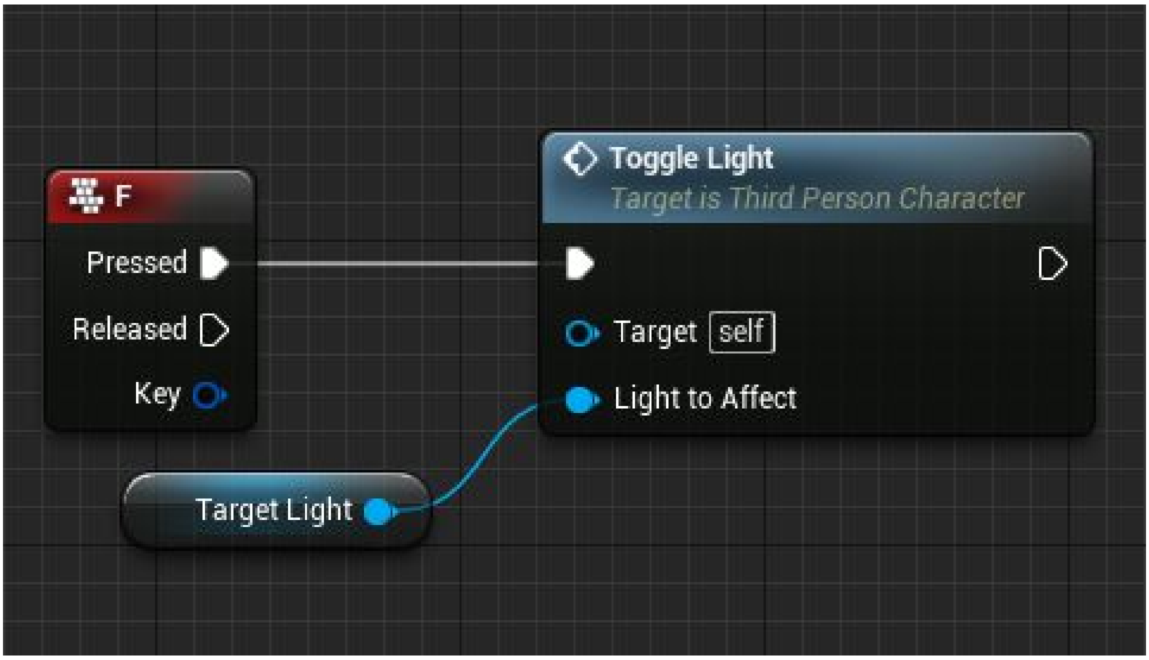

Figure 3. Direct Blueprint Communication

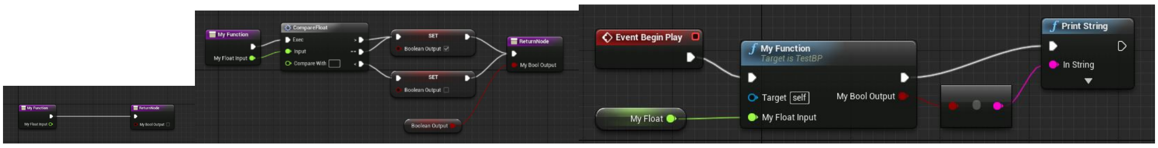

Figure 4. Blueprint interface(image source unrealengine documentation)

4 show a blueprint interface, and it is the local implementation with overwrite.

Event Dispatchers

Event Dispatcher is suitable for the situation when we need to say something to the listening blueprints [66]. For example, if Boss of any game died, then we can fire one event OnDied. Then we can bind that event with other blueprints; the number of binding is unlimited; we can bind this event with any number of blueprints. There may have some level that will open after the Boss died, or there will be some flash message for dead news. The ideal use of this BP communication is for creating communication between the character blueprints to the level blueprints and spawned (creating new instance) an actor according to the event. Fig 5 shows sample Event Dispatchers.

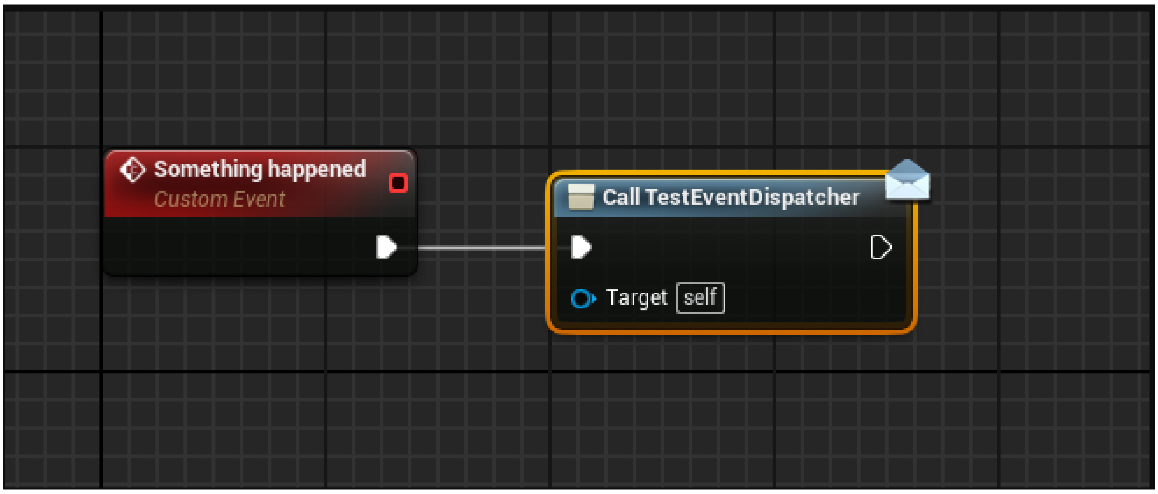

Figure 5. Event Dispatchers

Blueprint Casting

BP Casting is one particular communication for blueprints. By doing cast, we are sending one condition to the Object, and that is, if the casting Object is a particular type, then we want acceptance otherwise rejection. For example, if we create a unique blueprint for flying functionality for the player character. We can access node for getting the player character and user; it is a movement component to implement the rotation location and many more. We can not get flying ability from the player character because the player does not know how to fly. Only flying blueprint knows that. Then we can cast the flying blueprint. The player character can fly if he is using flying BP. Fig 6 shows sample blueprint casting.

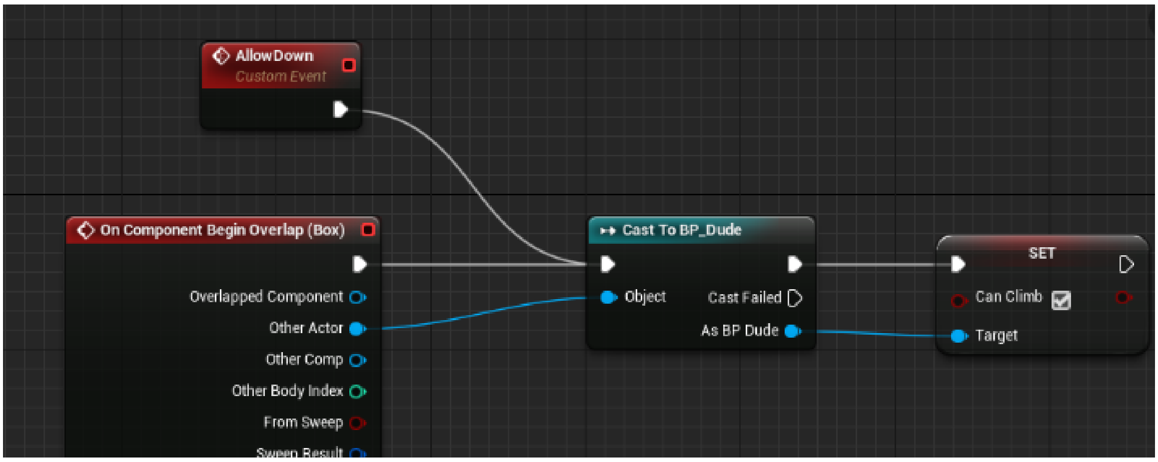

Figure 6. Blueprint Casting

3. Methodology and Design

The VR System for data collection is developed, which is a game. With that System, we collected data from the user and used that to measure Stroop effect and analysis. The method has into few sections. It starts with a demo system design; in the next step, we developed that demo system. We contacted with different participants, asked them to use the System at the same time we collected data internally and using questionnaires. We use the user data, response time for every instruction, and the correct or incorrect result saved by the System for analysis. We also analyzed statistical data provided by the user and correlate with the result to identify the subjective difficulty relation with the Stroop effect. Fig 7 shows our method for the research.

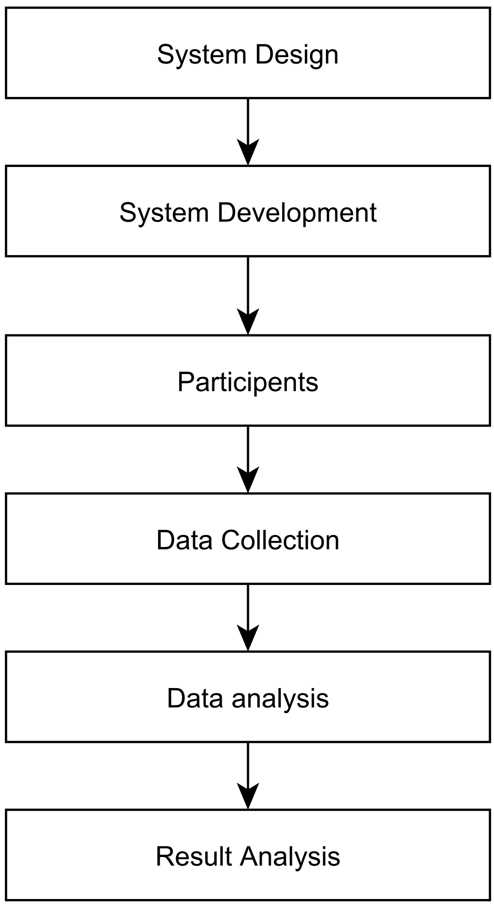

Figure 7. Research Method

3.1. System Design

With the basis of different VR systems, one VR game is designed for the user. After starting the game, the user will see the room environment with some cube on the table in front. Fig 8 shows the game environment. Users can pick, touch, and throw the cube. Three colored cubes are red, green, and blue. The user needs to throw the cube inside any of the colored wells in front of him. The user is not allowed to pick the cube from the ground. The cubes which are on the table can be picked and throw. There might be a different type of situation, i.e., the user can throw the cube inside the different colored well or the same colored well. There is a possibility to throw the cube outside the well. Users may make mistakes when picking up the cube and fall in the ground, which is not pickable. The System is counting the cube inside the well. After different types of testing, the app considered as ready for the user data collection.

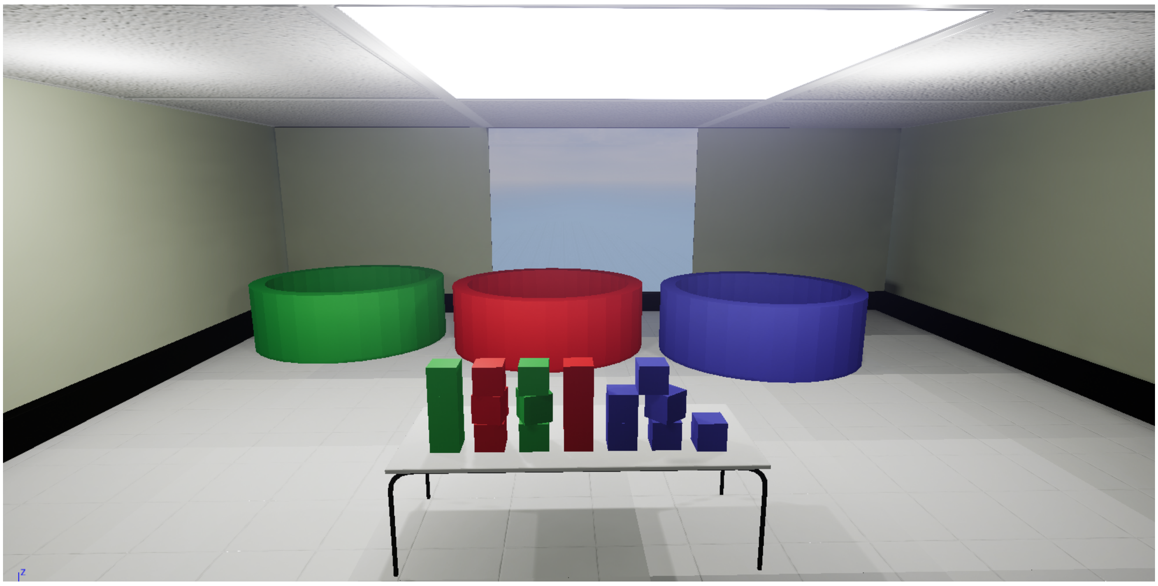

Figure 8. Game Environment

3.2. System Development

The System consists of two subsystems-

1. VR game
2. VR Plugin (used for the data collection)

Unreal Engine is the development platform for both systems. The data collection plugin is a blueprint class of the Unreal Engine. C++ language is used to make that plugin. After developing the plugin, it is integrated with the VR game. When the game starts, the event BeginPlay function of the Unreal Engine fired. The plugin starts saving user movement data from HDM, motion controller, and custom data related to the user reaction for the Stroop stimuli. The participants need to perform specific tasks according to instruction. The instructions are made using the Stroop color effect and reverse Stroop effect. The application has three-level. The first level is a tutorial for the user. The second level uses the Stroop color effect for the instruction. The third level user performs the same task, but the instruction used RSE (Reverse Stroop effect). Before the game start, the participant needs to take the VR hand controller and wear the HMD. When the game starts, if it is a tutorial level participant does not see any instruction.

In the second level, the participant gets instructions in front of him, for example, "Throw red cube on green Well," where the color is the focus. That means the participant instructed to respond to the color of the word. To make it more precise, the name of the well or cube is congruent or incongruent. User needs to react to the text color of the word.

The third level is for testing the Reverse Stroop Effect (RSE), where participants need to focus on the word, not the color. So, if the instruction is "Throw Green cube to Red well", no matter the word "Cube" and "well" is the same or different color, the participant needs to focus on the word, not the color. When the Stroop stimuli instruction is shown on the screen, the System saves the instruction time. When the participant response according to instruction, particularly when the user touches the cube, the system record the time. The gap between the instruction shown on the screen and the user touching to the cube is the response time. The plugin takes data whether the right cube according to instruction or not. The plugin also counts the cube when the user throws it inside the well.

3.3. Participants

Due to the limited resource and portability issue of VR systems, the Data Collection is done inside the lab. The participants are different by sex, age, and profession. There were both male and female participants. Some of them are students and but most of them are IT professionals. The participants are invited individually to the Virtual Reality Lab. The participants signed a consent paper that shows the data privacy and risks and benefits associated with this participation. There were a total of 18 participants. Most of the participants were 20-35 years aged, but all were under 40 years old. The average age of the participants is 25. Some of them had experience in the Virtual Reality game or environment. Many of them din not have VR experienced; for them, we provided some instructions about how the motion controller and HMD work before start interacting with our System. Participant selection followed some rules. If the participant reported some sort of brain injury within the last three years or seizure disorders, then the participant is not qualified. We did not find such conditions, and for this reason, no participants not excluded. In order to check the cognitive functioning of the participants and decision making, we asked some probing questions using google forms with time restrictions for answering. All the participants gave the answers immediately after participating in the VR game.

3.4. Data Collection

Before participation, each participant got a brief description of the study procedure, the purpose of the study, the potential risk associated with it, benefits, and what type of data is collected. The participants were given an alternative option not to participate in this study. Before participation, the participant signed written consent. After signing the consent, we collected some information by asking some questions. The questions used google form, and the user asked to provide an answer after completing the process of the Stroop test.

- How many hours per week works with pc?
- How do you rate computer skill on a Likert Scale (1- not at all and 5-for very skilled)?
- How many hours then play computer games per week?
- What type of games did you prefer to play?
- How frequently use VR (1- not at all and five regularly)?
- How comfortable were you during the game in VR?

- Did you feel any stress while playing the game?

Moreover, some other analytical ability related questions are asked with time limitation to check how quickly the participant makes the decision. The above information helps to find the relation between subjective difficulty for the Stroop Effect in VR. However, some questions answer not used in the current research. It will be helpful for the future development of the current research.

After starting the Virtual Reality game, it saves data automatically until it stopped. Motion controller data and head-mounted display (HMD) data are saving automatically using our custom plugin. From head-mounted display(HMD), we collected movement based on x, y, and z-axis with the pitch, roll, and yaw. The same data are collected to the left- and right-hand motion controller. These data are collected, but not all data used with the current study. Maybe the HMD collected data will be helpful for future development. The essential data about the user Stroop stimuli is also saved by the System automatically. The System is saving the time of instruction given. For example, "Throw Blue cube into the Red Well" instruction shows the timestamp save. The above instruction changes every 5 seconds. When the user touches the cube after getting the instruction, the System saves which colored cube the participant touched.

The difference between the instruction shown and user touch time to the cube is the response time. The different level has different instruction conditions. If the user in the second level, when we are testing the Stroop Effect, the user needs to react to the color. To make it more precise, if the instruction is "Throw Red cube into the Blue well", the color of the word "Red" and "Blue" are Green and Red respectively. If participants pick Green cube, then the response saved as correct. The user becomes biased with the Stroop effect and takes another colored cube; then, the response saved as incorrect.

The participant sees the above instruction in the third level of the game, which is for RSE (Reverse Stroop Effect) user needs to react according to the word meaning. So, the user would have to take the red cube and throw it to the blue-well, whether blue is written in using blue text color or not. Here the correctness of the response also depends on which cube picked by the use. One the other hand, the System also counting whether the user is throwing the correct cube into the correct well or not. Of course, it depends on the instruction. This data is collected to analyze how the user performance for the specific task in VR affected by the Stroop effect. As indicated earlier, participants are asked to answer some questions with time limitations. These questions are related to the analytical ability of the participant. We checked how quickly the user could make a decision when some thinking needed to answer the question. The score of these questions is used in a classified way to test whether subjective difficulty influences the Stroop effect or not.

3.5. Data Analysis

The collected data by the System saved as CSV format. One unique CSV file created for each participant for both the Stroop test and the reversed Stroop test. Raw CSV data are taken from the game engine and analyzed using Python programming language. Different python library is used for reshaping data and visualization. The python pandas library is used for data manipulation and analysis. Seaborn is another python library used for data visualization. The python script is reading all CSV files from the specific location of the host pc one by one. One file represents one participant's data. First, it gets the rows where the instructions are shown on the screen. Then it finds the cube picking point after each instruction. The time difference between these two rows is the user response time, which is calculated from the timestamp column saved by the System. The response correctness is checked by finding similarity between the instruction shown on the screen and cube picked by the user. All three types of responses for red, blue, and green color are taken into consideration to calculate the score. The score calculated as follows-

1. Dividing the correct answer by the total number of instructions of the specific color or word.
2. Adding total scores of all color or word
3. Divide by the total number of colors or words.

The application also checked the final target of the user, which is thrown cubes to the well. These values are taken directly from the CSV files. We get here how many cubes are thrown to the specific well.

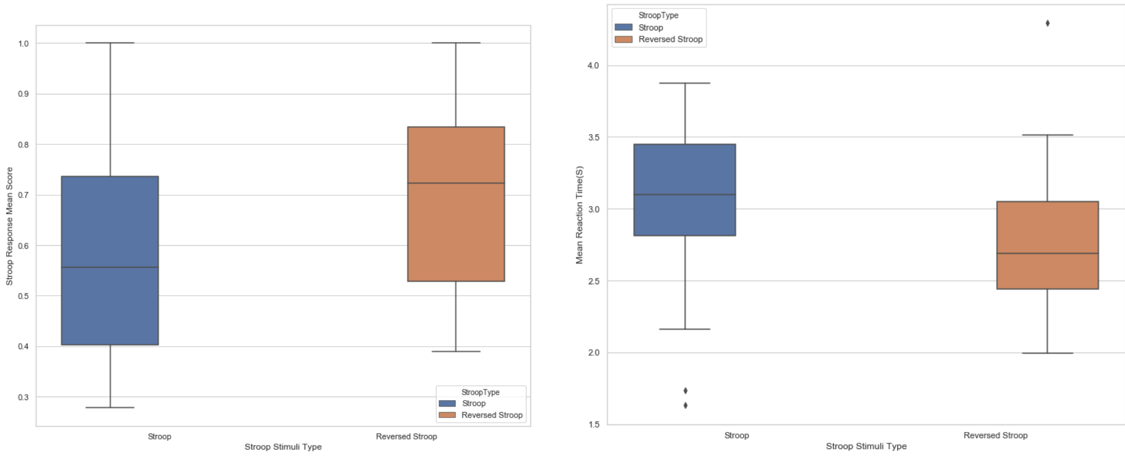

Figure 9. Mean Response Time and Score for Stroop and Reverse Stroop Test

3.6. Result Analysis

The result analysis is based on the objective of the research. Firstly, we find the mean response time for all users for both Stroop and reversed Stroop type. For a total of 18 participants, the mean response time for the Stroop based instruction was 3.0062 seconds. The reversed Stroop mean response was 2.80 seconds. Table 3 shows the mean response and score for both types of experiments.

Table 3. Mean Response Time and Score for Stroop and Reverse Stroop Test

Stroop Test Type	**Mean Response Time(s)**	**Mean Score**
Stroop Effect	3.0062	0.601
Reserve Stroop Effect	2.80	0.70

The Stroop effect was stronger than the reversed Stroop effect. Fig 9 shows the Stroop mean response and score for the both Stroop type. There is a little difference found in the score for the Stroop and reversed Stroop type. The user felt more comfortable to select the cube for the reversed Stroop task. However, most of the cases the color was incongruent still score for the reversed Stroop is better than the Stroop.

We also analyzed data according to user performance based on subjective difficulty.

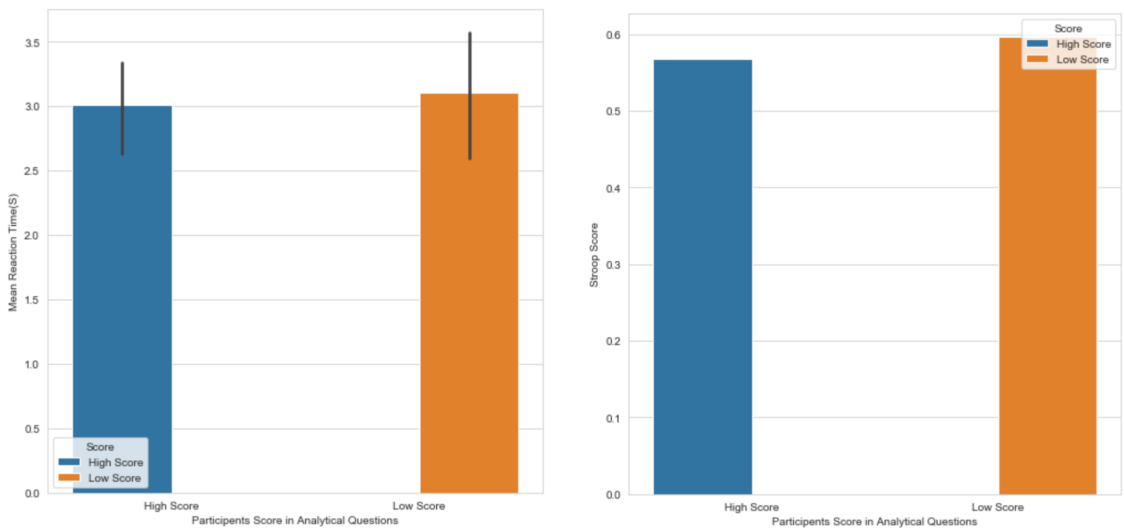

Figure 10. Mean Response and Score of Stroop Test for two group of Participants

Table 4 shows the results. Participants are asked some probing questions with time limitations to check how quickly participants make a decision. The score counted out of five. It is found that the participants who scored lower than 2 have higher response time for picking the cubes according to Stroop and reverse Stroop based instructions. It can be said that participants with lower decision-making skills became confused with the incongruent or congruent color-based instructions. Therefore, it increased the subjective difficulties and taken more time for the selection of cubes. Though participants with lower decision-making skills taken more time for selecting the cubes, the opposite result found for the scoring. The group of participants with a lower score in decision making questions, made a higher mean score. Fig 10 shows the mean response and score of the Stroop test for two groups of participants according to the score gained in the probing questions.

The reverse Stroop test also shows a similar result, which is that participants with lower decision-making skills took more time to select the cube. As like the Stroop same type of result found for the reverse Stroop effect. The participant group with a lower score in probing questions gained a higher score. Fig 11shows the mean score and response time for two groups of participants for the reverse Stroop test. Therefore, results show that subjective difficulty has some influence on the Stroop Effect in VR.

Table 4. Result By User Group

Stroop Test Type	**Participant**	**Mean Response Time(s)**	**Mean Score**
Stroop Effect Test	high scored in analytical questions	3.013	0.57
Stroop Effect Test	low scored in analytical questions	3.104	0.59
Reverse Stroop Effect Test	high scored in analytical questions	2.733	0.67
Reverse Stroop Effect Test	low scored in analytical questions	2.927	0.70

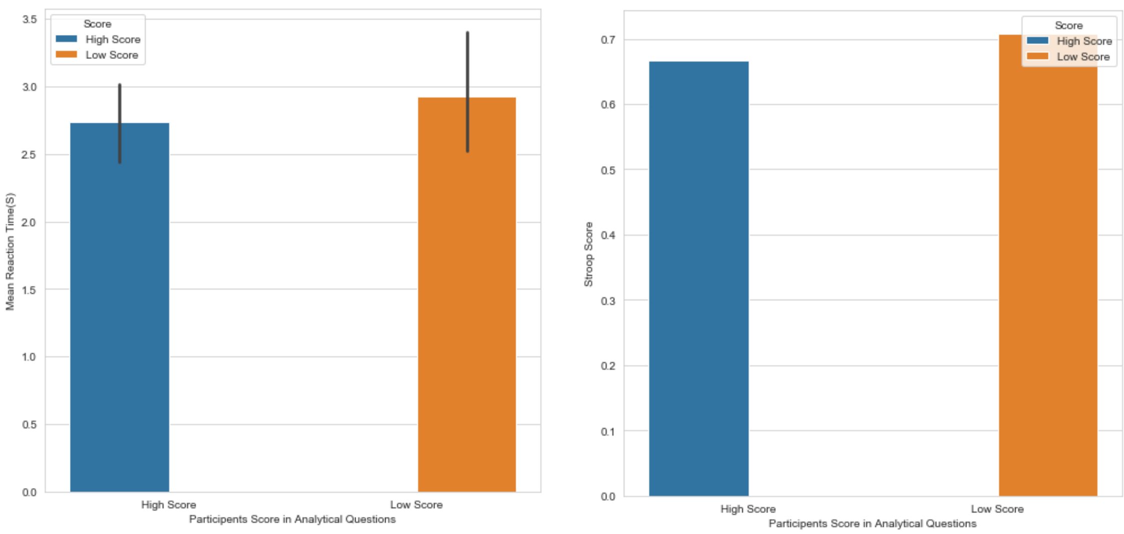

Figure 11. Mean Response and Score of Reverse Stroop Test for two group of Participants

4. Discussion and Future Work

The findings of the research can be useful for the number of practical purposes which replicate the finding by [60]. We got the Stroop phenomenon replicates in the Virtual Reality environment. This is also found by the [41], but they used only Stroop word for measuring the Stroop effect, one the other hand, we used Stroop based instructions to measure Stroop Effect. We also found that subjective difficulty may have some influence on the Stroop Effect in VR, which might be useful for cognitive interference control. This study is checking not only the response but replicate a task according to instruction. Therefore, it may provide a better result if it can be used for cognitive interference control. The computerized version and the paper pencil-based Stroop test [2] [10] may provide adequate control, and prediction may affect the result. The user gets immersion in the Virtual environment and feels involved with the goal-oriented task. Though the current research provides some exciting result still there is many possibilities for future improvement. For example, the current research is done with the 18 participants, and future research can involve more participants with variations like age group, gender, or different professions. If the participants increased, the result might affect them significantly. The psychological test for participants can be included, which may provide some exciting results in the future. Moreover, we used only three colors for testing the Stroop effect. If future more color adding might bring great results. One the other hand, the VR application can be improved by including some distractors or making some more complicated steps to test a more advanced Stroop phenomenon.

5. Conclusions

In this research, an exploratory study has been done on the Stroop and Reverse Stroop Effect in the virtual reality environment. The research process has been approached by raising two questions described in chapter one. The result shows, the Stroop Effect and Reverse Stroop Effect noticed when users emerged in the Virtual Reality environment. The Stroop Effect was stronger than the Reverse Stroop Effect. The result also shows that subjective difficulty may have some influence on the Stroop Effect and may affect the result of the Stroop phenomenon. The result of this research contributed to the heuristic value of the Stroop and Reversed Stroop phenomenon in a Virtual Reality environment. Though it is arguable, the result can be different for a complex virtual reality system and more variety of participants involved. In summary, the method presented some preliminary results and established a baseline platform for further development.

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