Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Social and Educational Sciences
Department of Psychology

Asbjørn Holt Tønsberg

# Fight-flight-freeze sensitivity and gait analysis: An innovative VR-study

## Fearful gait as a a tool for assessing personality
## PSY2910

Bachelor's thesis in Psychology
Supervisor: Benjamin Schöne
Co-supervisor: Håvard R. Karlsen and Invild Saksvik-Lehouillier
May 2024

NTNU
Norwegian University of
Science and Technology

Asbjørn Holt Tønsberg

# Fight-flight-freeze sensitivity and gait analysis: An innovative VR-study

## Fearful gait as a a tool for assessing personality
PSY2910

Bachelor's thesis in Psychology
Supervisor: Benjamin Schöne
Co-supervisor: Håvard R. Karlsen and Invild Saksvik-Lehouillier
May 2024

Norwegian University of Science and Technology
Faculty of Social and Educational Sciences
Department of Psychology

NTNU
Norwegian University of
Science and Technology

# Preface

This bachelor thesis was a part of the research project PLURAL. The project was led by Håvard Rudi Karlsen with assistance from Ingvild Saksvik-Lehouillier, and my personal supervisor; Benjamin Schöne. The Virtual Reality environments was made by our two student-assistants Jenny Josefine Bjørgen and Martine Pettersen. The questionnaire was made by the project leaders, and they provided guidelines for the execution of the experiment as well. Recruitment of participants and execution of experiments was done by the bachelor students, including myself, with the help of the student assistants. Initial movement data was processed and converted to variables in MatLab by Benjamin. Håvard did the initial conversion of the questionnaire data into excel and SPSS files. The pictures in this thesis were taken by the bachelor students, and the maze layout graphic was made by Jenny. All remaining steps, including data analysis, literature search, decisions on research questions, writing and proofreading, I declare as my own work.

I want to express my deepest gratitude to everyone that have helped me finish this thesis. I want to thank Benjamin, my supervisor, for his guidance and feedback on my rough first drafts. I want to thank our project leaders for ultimately leading a good project. There were times when the delays of the sensors made us sweat a little bit, but you rolled with it and made it work. Big thanks to our lovely student assistants, for spending countless hours on the VR conditions and with us during execution. I know you risked insanity down in that basement, and I am very grateful for it. Thanks to my friends and family for supporting me and pretending you were interested when I started to rant on about it. Thanks particularly to my bro Håkon, my first choice for a study/lifting/crime partner, and my roomie Henrik, who gave me support up until the twilight hours of this thesis.

# Sammendrag

En vanlig måte å vurdere personlighet på er å bruke spørreskjema, som for eksempel *Reinforcement Sensitivity Theory of Personality Questionnaire* (RST-PQ). Likevel kan man argumentere for at dette ikke er tilstrekkelig grunnlag for å trekke slutninger som er anvendbare i virkeligheten. Tidligere studier har indikert at deltakere som føler frykt endrer bevegelsesmønstre under gange, og maskinlærings studier har i stor grad klart å gjenkjenne emosjoner gjennom observasjoner av menneskes gange. Dette er tydelige indikasjoner på at gange kan bli en alternativ måte å måle personlighet på, og dette er også noe flere studier har etterspurt. Virtuell virkelighet har vist seg å kunne gjenskape realistisk atferd og fremkalle frykt, noe som gjør det til et effektivt verktøy til å studere frykt sensitivitet. Basert på dette er det ønskelig å utforske om sensitiviteten til «Fight-Flight-Freeze» mekanismen (FFFS) kan predikeres av gange i et skummelt virtuelt miljø. For å måle mengde bevegelse i gange utførte vi en «Principal Component Analysis». Denne identifiserte en skåre som indikerte hvor mye deltakeren sitt bevegelsesmønster samsvarte med det «gjennomsnittlige» bevegelsesmønsteret for alle deltakerne. De andre bevegelsesvariablene var Gangehastighet og håndbevegelse. I forkant av eksperimentet fikk alle deltakere utlevert RST-PQ sub-skalaen; Fight-Flight-Freeze System (FFFS), som måler deltakernes sensitivitet overfor frykt.

En multippel regresjonsmodell ble beregnet med FFFS-score som utfallsvariabel og bevegelsesvariablene som uavhengige variabler. Ingen av bevegelsesvariablene kunne signifikant predikere FFFS-scoren. Denne studien kombinerte en rekke relativt lite utprøvde metoder for å utforske dette tema, og videre blir det foreslått måter å utbedre forskningsdesignet til framtidige forsøk.

**Nøkkelord**: Frykt, Personlighet, Frykt-sensitivitet, Virtuell virkelighet, Bevegelse, Gange, Principal Component Analysis, Reinforcement Sensitivity Theory.

# Abstract

Usual methods used to assess personality could be subjective measures like Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ), yet this might not solely be enough to make inferences applicable to real-life. Previous studies have indicated that participants in fear conditions displays different movement cues, and machine learning studies have successfully recognized emotions through observed movements. This indicates that gait analysis can become an alternative way to objectively assess fear related personality, as have been encouraged by other studies. Virtual Reality have shown itself to effectively elicit fear and provide realistic behavior, making it an optimal design to study fear and movement. Based on this we intended to explore if Fight-Flight-Freeze system sensitivity can be predicted by the participants gait movements in a frightening VR-environment.

A principal component analysis of the movement patterns was preformed to find the "average" movement pattern, and absolute scores was averaged for all participants to get a general measure of their amount of movement. Walking speed and hand speed in relation to the head was also measured. Before the experiment participants answered the RST-PQ subscale; Fight-Flight-Freeze System (FFFS), measuring participants sensitivity to fear.

A multiple Regression model was computed with FFFS score as the outcome variable and the movement variables as predictors. None of the movement variables could significantly predict FFFS score. Considering the exploratory nature of our study, we further discuss the results and propose several ways for future research to improve on our research design.

**Key Words:** Fear, Personality, Fear sensitivity, Virtual Reality, Movement, gait, Principal Component Analysis, Reinforcement Sensitivity Theory

Personality plays a pivotal role in shaping an individual’s relationships, occupational choices, and behavioral tendencies. Hence, it is important to have convenient methods of assessing it, whether it is for research, clinical practice, or selection for high-risk job positions (Wen et al., 2022). While the emotion of fear has been extensively studied, the individual differences in its underlying concept, fear sensitivity, is still scarcely tested in laboratory experiments (Corr, 2018). The fight-flight-freeze system proposed by Corr (2004) can be described as a threat avoidance mechanism, and individual differences in its sensitivity (fear sensitivity) could be a crucial decider in high-threat situations. The widespread use of questionnaires, even thou well validated when testing against other questionnaires, may not alone provide a comprehensive understanding of real-life behavior (Wen et al., 2022). To account for this body movements, even thou scarcely researched, have been proposed as a convenient and non-invasive way to assess personality and fear (Wen et al., 2022; Xu et al., 2022).

Theories of embodiment indicates that our cognition is highly interconnected with our movements (Schmidt et al., 2024; Stins et al., 2014), thus far no literature has explored if fear sensitivity can be accurately assessed by movement. The need for alternative ways to assess personality have been necessitated in previous studies (Diniz Bernardo et al., 2021; Wen et al., 2022), and if movement could assess fear sensitivity it could serve to further validate behavioral findings in personality research. For instance, movement cues could be used to indicate fear sensitivity in clinical studies on phobias without the need for extensive pre-test questionnaires (Diniz Bernardo et al., 2021). Additionally, this research could further add to practical applications like security camera technology (Riemer et al., 2023; Wen et al., 2022). Compared to traditional emotion or personality biometrics, such as facial expression, speech, and physiological parameters, movement is remotely observable, more difficult to imitate, and requires less cooperation from the subject (Xu et al., 2022). Machine learning studies have already been able to predict relatively accurately a participants emotions based on advanced machine learning algorithms, giving indication that assessing fear sensitivity might be possible (Jianwattanapaisarn et al., 2022; Riemer et al., 2023).

Although questionnaires and rigid 2-dimensional laboratory experiments was considered the gold standard in behavioral studies, emerging methods have demonstrated significant improvements to particularly two aspects of its validity. Firstly, in large part due to the strict scientific requirements of modern research, psychological lab experiments often have to choose between rigorous experimental control or ecological validity (Rosa & Breidt, 2018). As the examination of movement cues requires both naturalistic behavior and strict experimental control, this challenge could potentially impede the scientific credibility of our findings (Gelder et al., 2018; Rosa & Breidt, 2018; Xu et al., 2022). Secondly, affective research mostly utilizes pictures, music, or video before or during experiment to elicit the appropriate emotion (Diniz Bernardo et al., 2021). This was previously considered the most effective way to elicit emotions, nonetheless modern technology has provided an approach that consistently produces realistic behavior, strong ecological validity, and effective elicitation of emotions (Diniz Bernardo et al., 2021).

Virtual Reality (VR) have been introduced as a viable and innovative new way to realistically study behavior in controlled conditions (Pan & Hamilton, 2018). New advances in VR technology during the last decade, like commercially affordable Head Mounted Displays (HMD), greatly improved graphics and easier to use development programs have made VR-lab experiments into a new track of psychological research (Rosa & Breidt, 2018; Schöne, Kisker, Sylvester, et al., 2023). Findings from various VR studies have shown strong evidence that people display similar behavior in VR as in real life (Kisker, Gruber, & Schöne, 2021; Kisker, Lange, et al., 2021; Schöne, Kisker, Lange, et al., 2023). Findings exhibited in a systematic review of literature by Diniz Bernardo et al. (2021) also concluded that virtual reality is a very effective way of eliciting emotions in participants. By using VR, we also increase test-retest reliability and maintain strictly controlled conditions, allowing for rigorous scientific inferences (Pan & Hamilton, 2018; Rosa & Breidt, 2018).

The scarce experimental literature on individual differences in fear sensitivity repeatedly measures the same personality disorders or traits like anxiety or neuroticism (Biedermann et al., 2017; Ellmers & Young, 2019; Lin, 2017). While these are highly associated with the topic, it leaves an unfortunate paucity of research on other personality constructs that might better relate to the intended field of study (Perkins et al., 2007). Most notably, findings have indicated that anxiety and fear are not interchangeable constructs, with neuroticism showing a stronger association with anxiety (Perkins et al., 2007). Henceforth, this study intends to use the well-recognized Reinforcement Theory of Sensitivity to further explore fear sensitivity.

## Theory

### *Reinforcement Sensitivity Theory of Personality*

At the core of this study lies the revised Reinforcement Sensitivity Theory of Personality (rRST), which seek to integrate neuroscientific and biological findings with trait theory, thereby producing a novel model of personality (Corr, 2004; Gray, 1982). The theory consists of 3 systems: Behavioral Approach System (BAS), Behavioral Inhibition System (BIS), and the Fight-Flight-Freeze System (FFFS). BAS is related to sensitivity to reward seeking behavior, BIS pertains to inhibition of behavior, and FFFS accounts for sensitivity to punishment avoiding behavior (Corr & McNaughton, 2012). This theory states that individual differences emerge from the sensitivity and interactions between the different systems. A notable strength of this theory is its enhanced differentiation between anxiety and fear, something other trait approaches have largely ignored in the past (Corr & McNaughton, 2012; Perkins et al., 2007).

rRST defined fear as a physiological and cognitive reaction to perceived threat to our body or psyche (Corr, 2018). Fear is often associated with activation in the amygdala and the noradrenalin and serotonin pathways (Corr & McNaughton, 2012; Gullone, 2000). Common symptoms include elevated heart rate, respiration, perspiration, and muscle activation. All these physical responses are linked to the preparation of movement (Corr & McNaughton, 2012; Wallbott, 1998). High FFFS sensitivity have been found to positively predict depression and anxiety (Katz et al., 2020), increase avoidance behavior (Bacon et al., 2018; Krupić et al., 2016), magnify perceived threats (Perkins et al., 2010), and increase perceived personal space (Sambo & Iannetti, 2013). Corr and Cooper (2016) found a moderate correlation between the RST-PQ FFFS subscale and Neuroticism trait from both the five-factor model ($r$ = .35), and the Eysenck's PEN model ($r$ = .43). Surprisingly, it exhibited only a modest correlation with trait-anxiety ($r$ = .23). This suggests robust construct and discriminant validity, underscoring the rRST's superior ability to distinguishing between fear and anxiety (Corr & Cooper, 2016; Perkins et al., 2007).

### ***Movement and gait***

Embodiment of psychology is a growing field in the scientific literature (Nummenmaa et al., 2014; Wallbott, 1998), moreover strong evidence indicates that movement is more intricately linked to our cognition and emotions than previously thought (Schmidt et al., 2024). This relationship becomes increasingly evident with recent machine learning studies utilizing movements to predict emotions and personality (Jianwattanapaisarn et al., 2022; Riemer et al., 2023; Wen et al., 2022). Riemer et al. (2023) developed machine learning models to classify emotions in actors using a collection of parameters. They examined 6 prediction models, with the most accurate predicting 46% when choosing from a list of five basic emotions. The researchers found that fear was most accurately distinguished from other emotions (over 60%) when observing a participant’s gait (Riemer et al., 2023). Findings from Wen et al. (2022) extends this by also having machine learning models predict Big Five personality traits from gait. Both studied different movement parameters specifically to their intended topics.

Halovic and Kroos (2018) Tried to identify kinematic cues (movement tendencies) of emotional-specific gait. They recruited university students that where tasked with identifying the emotions portrayed by actors through emotional gait at different levels of intensities (low, moderate, intense). Following this, participants disclosed the cues they employed to identify the emotion, and an analysis of the emotion-specific gait was carried out to verify the presence of the aforementioned cue. Their results indicated that fear was recognized through fast, short strides and more distal arm swing (little arm movement) (Halovic & Kroos, 2018). Even though this study only identified perceived cues, it still gives some suggestion as to what gait variables we should observe.

We decided to use a Principal Component Analysis (PCA) to operationalize movement (Li et al., 2016). This method has been used in a number of studies on specific physical ailments (Federolf et al., 2013), animals (Lloyd et al., 2008) and children (Clark et al., 2019; Storli et al., 2024). It was validated by Van Andel et al. (2022) with multiple principle components acquired by different methods showed great internal consistency ($r > .78$). Alongside using the composite score to ascertain average movement patterns for participants, we also decided to measure average hand speed relative to the head of participants, because it indirectly measures hand movement. If a participant for example swings their hand a lot while walking this will increase hand speed relative to the head. This is important because arm movement was one of the kinematic cues previously mentioned

(Halovic & Kroos, 2018). Lastly, we want to measure average walking speed. The utility of walking speed as a measure of emotion or personality has been subject to some debate (Crawford et al., 2024; Satchell et al., 2017). Nonetheless, several VR experiments have found relations between objective fear measures, like heart rate, and walking time in acute fear conditions (Gromer et al., 2018; Kisker, Gruber, & Schöne, 2021).

### *Virtual Reality*

Virtual Reality can be defined as an immersive 3-dimensional computer-generated environment and is usually induced by wearing an HMD that is connected to a computer. Numerous studies have concluded that VR is an excellent tool to study human behavior (Biedermann et al., 2024; Bohil et al., 2011; Schöne, Kisker, Sylvester, et al., 2023). Slater (2009) hypothesized that there were two main mechanisms allowing for the exceptional realistic behavior in VR. The first is “Place Illusion” (PI) and refers to how individuals believe they are “present” in a real place. The second is “Plausibility illusion” (Psi) and refers to the illusion that the scenario being depicted is actually occurring (Slater, 2009). This sense of presence is cited as a major key to success when using VR in lab experiments, as several key studies have found it to increase the emotional involvement the participants feel (Diniz Bernardo et al., 2021), and predict more realistic behavior (Gelder et al., 2018; Schöne, Kisker, Lange, et al., 2023).

To achieve strong PI and Psi, research often strive for something called “deep immersion”. This is when the researchers control for as many sensory variables as possible to optimize the realism of the VR-experience. Surprisingly, the quality of the visual or auditory content (graphics and sound) is found to not be as important as increased levels of user-tracking or stereoscopic visuals (Cummings & Bailenson, 2016). This is theorized to be caused by a two-step formative process, in which the user first constructs a spatial mental model of the mediated environment, and then accepts or decline this environment as their primary frame of self-reference (Cummings & Bailenson, 2016; Gelder et al., 2018). This second step is determined by the perceived self-location and possibilities to act within the environment. In essence this theory proposes that the graphical or auditory quality is not as important as the realistic feeling of being in an actual space and having a perceived ability to interact with it.

To elicit negative psychological arousal in participants, evidence suggest either making a highly arousing Environment (PI), or by having a highly arousing stimuli (Psi), or a combination of both. A VR-EEG-experiment by Kisker, Lange, et al. (2021) concluded that the most effective way to elicit high psychological arousal is a combination of both a high arousal PI and Psi, and furthermore a study on VR horror games and gender differences found that participants generally reported Psi to elicit more fear then PI (Lin, 2017). Nevertheless, results from a number of VR height exposure studies and a VR-cave exploration experiment have shown that a sufficiently threatening environment alone can elicit adequate behavioral reactions in participants (Biedermann et al., 2024; Diniz Bernardo et al., 2021; Kisker, Gruber, & Schöne, 2021).

### ***FFFS, movement and VR***

The previously mentioned study by Kisker, Lange, et al. (2021) studied university students traverse through a VR-cave. They assigned participants to a negative or neutral condition and used a mixed reality design to elicit authentic fear reactions. After data collection, participants in the negative condition were further categorized to the “hesitating” and the “hasting” groups based on their in-experiment behavior. The main difference between these groups was that the “hesitating” group spent approximately three times longer in the last section of the cave compared to the “hasting” group. The researchers noted that even though the “hesitating” group did not score significant higher on FFFS, this might have been caused by a too small sample size (n = 21) in the “hesitating” group (Kisker, Lange, et al., 2021). This result indicates that walking time could become a predictor of FFFS in our experiment.

This conclusion fits the findings in a threat scenario questionnaire study by Perkins et al. (2010) that suggested interindividual variance in defensive reactions is associated with all three RST constructs; BIS, BAS and FFFS. They found that fear-prone individuals (high score on FSS, a long version of FFFS), preferred an orientation away from threat (e.g., run away or hide) and that fear-prone individuals also tended to perceive threats as magnified (Perkins et al., 2010). This leads us to believe that individuals with higher scores on FFFS might exhibit more cautious movements in a perceived threatening environment, potentially employing less and slower movements (avoidance approach). A closely related example was found in a study on state-trait anxiety, where gait speed was accurately predicted by trait-anxiety (Norouzian et al., 2024).

### ***Study Aim***

The objective of the present study is to explore if differences in the Fight-Flight-Freeze System can be predicted by the participants gait movements in a frightening virtual environment. By doing this we explore if movement can be used as an alternative way to assess fear sensitivity. We also address a gap in the existing body of literature on the Reinforcement Sensitivity Theory and embodiment of emotions. This study will also contribute to the growing body of literature on VR, as no other works have combined VR and a quantitative measure of movement (PCA) to our knowledge. This study aims to answer the following research question:

RQ: Can Fight-Flight-Freeze system sensitivity be predicted by the participants gait movements in a frightening VR-environment?

Considering prior literature, we suggest that the composite score, hand speed relative to head, and average walking speed will significantly predict differences in the FFFS score of the participants. Based on the study by Halovic and Kroos (2018), it is suggested that higher FFFS will have a relation with the kinematic cues they found, indicating more distal arm swing, less upper body movement, shorter and more rapid steps. The defensive behavior study and other gait analyses indicate composite score is going to negatively predict FFFS score (Norouzian et al., 2024; Perkins et al., 2010). Virtual height exposure studies by Biedermann et al. (2017) and Kisker, Gruber and Schöne (2021) additionally suggest slower walking times might positively predict higher FFFS. Their findings generally indicate that individuals exhibiting higher levels of anxiety or acrophobia tend to demonstrate slower walking times and display less risk-taking behavior in height conditions. The literature has mostly found small to moderate effect sizes on this topic (Kisker, Lange, et al., 2021; Perkins & Corr, 2006) and based on the nature of our movement analysis method (Storli et al., 2024), we expect small to moderate effect sizes in this study as well. This paper proposes this hypothesis:

$H_1$: FFFS score can be significantly predicted by the composite score, average walking speed and relative hand speed of participants in negative VR environment.

$H_0$: FFFS score cannot be significantly predicted by the composite score, walking speed and relative hand speed of participants in negative VR environment.

## Methods

### *Participants*

47 participant was recruited using a method of convenience and was mostly consistent of students attending the Norwegian University of Science and Technology. Potential participants were sent an information flyer by email and was asked to inform the researcher if they did not pass the exclusion criteria. The exclusion criteria screened for (I) diagnosis of psychological disorders like schizophrenia, anxiety, or depression (II) neurological disorders like epilepsy, migraines or sudden unexpected loss of consciousness (III) medicine use (IV) influence of alcohol (V) having sought or considered seeking psychotherapy in the last 5 years. Participants also needed to be between the ages of 18 and 35. The Participants was to complete both conditions, however which condition they started with was randomly and evenly distributed among the participants (Negative or Neutral condition). They were blind to which condition, they were doing. Approval from the Norwegian data protection services for research (SIKT, 2024) was acquired with reference number 494059.

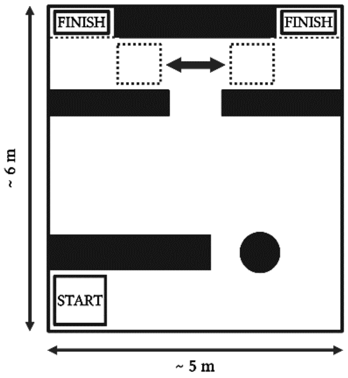
The sample size was determined based on a previous body of literature on similar virtual reality experiments (Schöne, Kisker, Sylvester, et al., 2023). We aimed for an initial minimum of 30 participants, however during data acquisition it was decided to increase the number of participants. Out of our 47 participants (30 = female, 2 = did not give gender), the mean age was 22.00 (*SD* = 2.17, Min = 18, Max = 30). The movement data from 9 participants was excluded due to failure to properly execute the experiment procedure. That left 38 participants in the movement analysis (26 = female, 1 = did not give gender) and the mean age of these was 21.71 years old (*SD* = 1.80, Min = 18, Max = 27).

### *VR setup*

The experiment was comprised of a neutral and a negative condition, and both conditions used a fully virtual design. The virtual environments for both conditions were made and designed in the development engine Unity (version 2021.3.33f1) using assets from Unity Asset Store and was played using SteamVR (version 2.4.3). The layout and path of both conditions was identical, and two possible paths would lead to the exit (see Figure 1). Movement was synchronized in virtual reality and reality, allowing the participants to move in virtual reality through actual walking. Their hands and feet were however not visible in VR. To ensure that the participants had enough walking time, the layout was designed like a T-maze. A T-maze is a structure featuring a straightforward pathway leading into a simple two-way junction resembling the shape of a T. When participants walked in one direction the other end of the maze would open and there, they would see the exit (see Figure 1).

**Figure 1**

*Layout of the Virtual Reality maze*



*Note.* Figure 1 is a top-down view of the VR-maze layout for both conditions. The stipulated lines on the far wall are closed walls when participants first enter the T-section, but when the participant steps on a stipulated box the opposite wall will open revealing the “Level Complete” sign. The sign is not visible until participants look around the corner where the wall disappeared.

All participants wore a Vive Pro 2 head mounted display (HMD) which allowed for 3D imaging along 6 axes with head tracking, giving the participants an immersive visual experience. A cable connecting the headset to the computer was necessary for the environment to function properly. HTC Vive Tracker 3.0 sensors was attached to the outside of the wrists and outside of the ancle on all participants (see Figure 2). This enabled tracking of the movements and positioning of the participants limbs and head by using 6 tracking cameras attached to opposite walls in the laboratory. Participants conducted the experiment with identical slippers to ensure that they all feel the same haptic sensation from walking. The slippers where black with thin rubber soles and came in 2 general sizes (see Figure 3).

**Figure 2-4**

*Researcher demonstrating the technical setup.*

*Note.* Figure 2 (left) represents a researcher demonstrating how the technical equipment is attached. Figure 3 (middle) is of the slippers used. Figure 4 (right) is HTC Vive Tracker 3.0 sensors that were used, and where they are placed on the arm.

### *Exploration of the VR-environment*

The neutral condition consisted of a pleasant forest environment with a brick structure (see Figure 5-6). It was designed to be a non-emotional or pleasant environment and was well illuminated with brighter colors. Bird noises and the sound of moving leaves was added. The negative condition was designed to be a gloomy version of the neutral environment. It depicted a similar forest and brick structure as the neutral condition, but it was set at night. It was dimly illuminated by virtual flames on the ground and walls, and the forest had no leaves. For added fear stimuli the pleasant sounds of birds and leaves was replaced with the sounds of crows, howling wind and sparkling flames (see Figure 7-9). No other threatening stimuli were added, as it might have caused bias to the movement variables.

**Figure 5-6**

*VR-setup Neutral condition*

**Figure 7-9**

*VR-setup Negative condition*

*Note.* Figure 5-9 is a virtual representation of the environment the participants experience.

### *Procedure*

The participants were instructed that they were going to explore a virtual environment and their goal was to find the way out. They were told that the experiment would be complete when they saw a sign that said, “Level Complete” (see Figure 10). Participants were instructed to treat the virtual environment as though it were real, with the recommendation not to attempt walking through walls. Trackers was then placed on their wrists and ancles, and the headset was put on and adequately adjusted to fit their head and vision. To increase immersion, the researchers informed the participants that they were not going to talk to them or answer any of their questions unless they experienced technical difficulties, or they wanted to terminate the experiment. The participants were guided to the start of the maze and was told the experiment would start. After the participant completed the first maze they were helped back to the starting position by a researcher and instructed to get ready ones more.

**Figure 10**

*Level Complete sign.*

*Note.* Figure 10 is a visual representation of the “Level Complete” sign that signaled the end of the condition. It was similar in both conditions. Positioned easily visible.

Before the experiment, the participants filled out a consent form and then answered the IPIP-120 Norwegian version (Johnson, 2014; Pran, 2021), the Emotion Regulation Questionnaire (ERQ)(Gross & John, 2003), the RST-PQ assessing fight-flight-freeze system sensitivity (Corr & Cooper, 2016), and previous experience with VR on a scale from 1-10. They also answered questions about their age and gender they identified as. Immediately after the experiment, the participants answered the IVEQ assessing immersion in the virtual reality (Tcha-Tokey et al., 2016). Before leaving the participants were debriefed about the purpose of the experiment, data privacy rights and asked if they had any questions or feedback. Researchers made sure participants left feeling good and comfortable.

## ***Measurements***

### *RST-PQ*

The fight-flight-freeze system (FFFS) subscale of the Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ) was used to assess the participants sensitivity to fear (Corr & Cooper, 2016). RST-PQ is divided into 6 subscales: BIS, FFFS and 4 different subscales measuring different factors in BAS. The RST-PQ have shown adequate psychometric properties in studies, with Cronbach alpha of, $\alpha = .78$, for the FFFS subscale (Corr & Cooper, 2016). This shows great internal consistency. Our research team translated the questionnaire to Norwegian for this study.

### *Movement*

Movement data was acquired through the sensors placed on the outside of the participants wrists, ankles, and the headset. Subsequently, we conducted a Principal Component Analysis on the detailed dataset of spatial positions recorded over time in MatLab. This gave us the most significant movement pattern in the dataset, called Principal Component 1 (PC1). We then averaged the absolute values of this score for each participant to get their composite score. This score is a standardized value indicating the frequency in which the movements of the participant align with the "average" emotional movement pattern. A high score indicates more and faster movements. We will also study average walking speed measured from the head throughout the experiment, and the average hand speed relative to the head of the participant.

### ***Data analysis***

The statistical program IBM SPSS version 29.0.0 was used to organize and analyze the data. A multiple linear regression model was computed with FFFS score as the outcome variable and the movement variables as predictors. Predictors was chosen based on our hypothesis and prior literature, and consisted of the composite score, walking speed and relative hand speed (see table 1). To check for assumptions a Durbin-Watson test scored 2.31 indicating no autocorrelation. Multicollinearity was assessed with a VIF value and Collinearity Tolerance. Both values were within acceptable values with VIF score of 2.47 and Collinearity Tolerance of .405 for the model (Field, 2018). Inspection of distribution of residuals and P-P plot showed the error to be close enough to normally distributed. Assessing homoskedasticity with a scatterplot displaying predicted values and standardized residuals showed no funnel. No outliers were found during inspection of scatterplots and standard residuals scored a maximum of 1.89 supporting that assumption. We got a Cronbach alpha score of $\alpha = .85$ on the FFFS questionnaire indicating good internal consistency between the items (Field, 2018). Lastly normality was assumed based on the central theorem of sample sized above 30 datapoint (Field, 2018).

## Results

The model, with the composite score (*M* = 1.37, *SD* = 0.22), average walking speed (*M* = 0.52, *SD* = 0.14), and average hand speed relative to head (*M* = 0.04, *SD* = 0.01) as predictors, could not significantly predict the FFFS score, *M* = 2.38, *SD* = 0.69, *F*(2, 34) = 1.95, $p = .139$, $R^2 = .15$. None of the individual predictors showed any statistical significance, with the composite score being the only one coming close, $p = .077$.

**Table 1**

*Regression Analysis Summary for Predicting Fight-Flight-Freeze system score (*n *= 38)*

| Variable | *b* | *SE b* | β | $R^2$ | *p* |
|---|---|---|---|---|---|
| Model | | | | .147 | |
| Composite score | -0.933 | 0.513 | - .298 | | .077 |
| Average walking speed | -2.344 | 1.513 | - .381 | | .130 |
| Relative hand speed | 14.859 | 13.076 | .283 | | .264 |

*Note. n = 38, *= p < .05*

## Discussion

The aim of the study was to identify if gait movement could predict FFFS sensitivity in participants walking in a frightening VR-environment. This was done to explore if gait movements could be used to assess fear sensitivity in the future. We found that no movement variable could significantly predict FFFS score. Although these findings may seem conclusive, the exploratory nature of our methods and variance in data does not allow for casual inferences solely based on this result. The extent to which this result is attributed to a lack of relation, or to the impact of confounding factors in our experimental design remains unclear. However, inspections of related literature support the later (Kisker, Lange, et al., 2021; Norouzian et al., 2024). In the next section, these findings are discussed in relation to previous efforts to examine movements and fear related personality. Furthermore, we will also discuss potential improvements based this exploratory study, allowing for future studies to build upon our design.

The regression model did identify the composite score as the closest to significant predictor, even though it did turn out non-significant. Based on prior findings from height exposure and emotion recognition studies we expected the composite score to negatively predict FFFS (Kisker, Gruber, & Schöne, 2021; Kisker, Lange, et al., 2021; Riemer et al., 2023). One possible explanation for why this did not happen could be because the composite score functions as more of an average, disregarding subtle nuances (Xu et al., 2022). We will propose further ways to improve on this for later.

The observed non-significance of the hand speed variable conflicts with findings from Halovic and Kroos (2018), which indicated it might negatively predict FFFS. One reason for this could be that our measurement of hand movement was based on hand speed relative to the head, ignoring parts of arm position and movement patterns. Our findings on average hand speed found very little movement and variance in general ($M = 0.04$, $SD = 0.01$, Range = 0.05) indicating that participants didn't move their hands much in general. This lack of variance suggests that our variable was poorly operationalized to predict similar arm movement cue as Halovic and Kroos (2018) found.

We found that average walking speed was not a significant predictor for FFFS sensitivity. This contradicted findings from various virtual height exposure studies (Gromer et al., 2018; Kisker, Gruber, & Schöne, 2021; Krupić et al., 2021). Moreover, conclusions from the VR-cave experiment conducted by Kisker, Lange, et al. (2021) also indicated slower walking speed could be associated with FFFS sensitivity. Yet, several factors could have caused walking speed to turn out non-significant in our study. We will discuss these in the section on future improvements of this study.

Another reason why our result might have deviated from the literature we based it on might be that we observed slightly different mechanisms. Our study looked at a direct measure of gait movement from participants that had their emotions elicited through VR, rather than how people make judgements about emotion based on gait videos, which may explain some of the difference between our findings and those of Halovic and Kroos (2018). In that instance, the observer's perception acts as a mediating factor, and the authors acknowledged this.

One factor that might have affected the result of this study was that the negative condition might not have been scary enough to identify more radical movement differences. We did not include any specific subjective measures of fear in our study, but one of the items in the Immersive Virtual Reality Questionnaire (Tcha-Tokey et al., 2016) that we administered asked if the participant ever felt scared in the virtual environment (fear item). We found that the fear item score slightly low ($M$ = 3.55, $SD$ = 2.72, Min = 1.00, Max = 10.00), and only a small to moderate positive Pearson correlation was found between it and FFFS score, $r(37) = .33$, $p = .025$. The fear item did not significantly correlate with any of our other variables, including average walking speed, despite walking speed having shown relations with objective measures of fear in similar experiments (Gromer et al., 2019; Kisker, Gruber, & Schöne, 2021; Kisker, Lange, et al., 2021). We acknowledge that this analysis was based on a single item, which limits the extent to which definitive inferences can be drawn. Nevertheless, this analysis suggests that participants did not experience a sufficient degree of fear for it to be discernable from the movement data. Findings from prior literature supports this (Kisker, Gruber, & Schöne, 2021; Norouzian et al., 2024).

Our results might highlight a key weakness in comparing gait movement in virtual height conditions with non-height threat conditions. Evidence suggests there is fundamental differences in gait when we are afraid of falling in comparison to other potential threats (Madeira et al., 2021; Raffegeau et al., 2023). In VR height conditions where participants can walk in self-selected speeds, results show that almost all choose significantly shorter steps and slower movements, regardless of personality or fear of heights (Kisker, Gruber, & Schöne, 2021; Raffegeau et al., 2023). However, slower walking is attributed to an increased desire for stability as a risk aversion strategy (Raffegeau et al., 2023), rater then to increased aversion by freezing or fleeing (Kisker, Lange, et al., 2021; Merscher & Gamer, 2024). Even thou both height and non-height threats is measuring similar mechanisms, the difference in attribution could significantly alter the prevailing movements of the participants. Based on this we propose that inferences about movement in virtual height exposure studies are viewed separately from non-height conditions.

### *Improvements for future research*

Initially, we determined our sample size based on prior literature, but a subsequent power analysis indicated that a larger sample size would have been preferable. We conducted a post hoc F-test using G*power with α error probability set at .05, effect size of $R^2 = 0.15$, a sample of 38 participants and 3 predictors. The resulting power was 0.52, indicating low statistical power (Cohen, 1992). To ascertain an appropriate sample size for future studies, we did a prior on the same parameters, but setting desired Power to 0.80. The result determined that a sample size of 66 participants was ideal for this experiment. This was a limitation for this experiment and future studies should keep this in mind when planning for experiments.

Another limitation that may have influenced the non-significant model could be the use of too singular movement parameters as variables. Riemer et al. (2023) concluded in their emotional recognition study that no single motion parameter could effectively predict emotions, but that a complex set of parameters and movement cues was necessary to identify emotions accurately. Although our study did not investigate emotions specifically, but rater personality, findings from Wen et al. (2022) assessing Big Five personality traits from gait video also found that more complex machine learning algorithms was necessary to ascertain valid models. Still, our study utilized principal component analysis largely due to our singular focus on fear sensitivity in a frightening environment, thus not needing to identify other emotions. Regardless employing machine learning tools akin to those utilized by Riemer et al. (2023), like decision tree algorithms or support vector machine learning, might provide a more precise means of assessing movements in future studies.

Future studies could benefit from developing slightly more frightening virtual environments, as we previously discussed. Both height exposure experiments (Kisker, Gruber, & Schöne, 2021; Krupić et al., 2021) and the cave study by Kisker, Lange, et al. (2021) displayed more severe threats. This might have increased presence and exaggerated behavioral cues (Diniz Bernardo et al., 2021; Gromer et al., 2019). It was decided not to add a threatening Psi in our experiment, as it might have disrupted the movement variables. However, adding more threatening sounds or altering the environment to make it slightly more arousing might have impacted the participants that scored low on FFFS to behave more in line with a fearful emotional pattern. Another alternative for future studies could be to explicitly warn participants of a potential threat that does not actually occur, as anticipatory threats have been shown to effectively illicit fear in other studies (Merscher & Gamer, 2024).

The maze layout we selected may have influenced the walking speed of participants, as it can have caused uncertainty regarding the correct path to progress. Several participants were observed turning back at the t-section before activating the virtual trigger, consequently missing the possible opening (Figure 1). These participants reported post-experiment that they initially thought it was a dead end and turned to searched for an alternative exit. Some of these participants was among the 9 excluded from the movement analysis. In contrast, a design like the Cave-experiment by Kisker, Lange, et al. (2021) with a single unambiguous way to progress could have avoided bias caused by uncertainty in the participants. It is important to point out that we deliberately designed the maze layout to encourage longer walking times, as it would afford us more movement data. Moreover, the inclusion of the t-section was intentional, serving to assess the amount of hesitation in participants movements. Nevertheless, future studies could use a maze layout more like the Cave-experiment to avoid uncertainty becoming too strong of a confounding variable (Kisker, Lange, et al., 2021).

This study intended walking time to consequently be a measure of the participants experienced fear, but another physical measurement of fear would have been ideal to further validate this concept. A systematic review by Diniz Bernardo et al. (2021) looked at the effectiveness of VR to elicit emotions. They concluded that the two most common physical measurements of emotion were Electrodermal activity (EDA) measures and heart rate. In a study by Merscher and Gamer (2024) investigating motion patterns in relation to avoidable threats, EDA and heart rate had a significant positive correlation and gave great insight into the activation of the sympathetic nerve system for the participants. The height exposure study by Kisker, Gruber and Schöne (2021) also utilized heart rate and found that it increased significantly more in a height condition compared to a ground condition. Both these results support the conclusion from Diniz Bernardo et al. (2021) that physical measures of activation are valid and could give great insight into the sense of realism and fear the participants experience. Our experiment decided to not include any physical measures of fear due to time restraints and logistical issues.

Considering the ethics of exposing participants to more intense fear in VR, this study advocates for followed guidelines proposed by existing literature (Diniz Bernardo et al., 2021; Slater et al., 2020). VR poses a new challenges in research ethics as the feeling of presence grants participants a stronger feeling of “being there and doing it” then when it is displayed on a monitor (Slater et al., 2020). This might lead to increased risk of psychological harm, particularly regarding participants more sensitive to fear and anxiety (Zuj et al., 2016). Despite this, studies by Lin (2017) on next day fright from playing VR survival horror games found that very few of the 144 participants experienced next day fright. In addition, several studies have found that participants experiencing high fear or anxiety before experiment, often experience more positive affect after the experiment completion (Kisker, Gruber, & Schöne, 2021; Lin et al., 2018). This was hypothesized to be because they experienced greater relief and sense of accomplishment from finishing the task. They did however conclude that this effect only goes up to a certain threshold, as to much fright might overwhelm the participants (Kisker, Gruber, & Schöne, 2021; Lin et al., 2018). Properly defining a sample and adjusting the appropriate level of arousal could be increasingly vital to future VR experiments as the gain of knowledge must justify the strain on participants (Slater et al., 2020).

There are many strengths of this exploratory study. Firstly, it adheres to modern research standards by using well validated questionnaires and theories (Corr & Cooper, 2016). Secondly, the VR-environments were specifically made for this study. By customizing our own VR-environments we could ensure more precise control over the experimental variables, fitting them to our research question (Diniz Bernardo et al., 2021). Lastly, this study is to our knowledge the first to use a combination of both a gait analysis of naturalistic movements, and VR technology to elicit fear. This study has now opened for other studies to use similar methods on other topics. Even thou our model was not able to predict FFFS, the result can be used to make further improve on our research design.

## Conclusion

In conclusion this thesis set out to explore if FFFS score could be predicted by movement variables. This was done to explore if gait could be used as a convenient and non-invasive assessment of fear sensitivity in future studies. The experiment yielded no significant results, but this could be due to a too small sample size. However, no other studies have combined an investigation of movement and personality using VR to induce fear, and by investigating this we have now opened for further studies to improve on our design. Future studies could particularly build on our study by using machine learning methods to examine more complex movement parameters, use a more unambiguous maze layout, and design a more frightening virtual environment within ethical boundaries. It could also be beneficial to have an objective measure of fear, like a heart rate monitor, to further validate criterion validity. Lastly, we encourage future studies investigating gait movements to view height conditions and non-height conditions separately.

# References

APA. (2019). *Publication manual of the American psychological association*. American Psychological Association.

Bacon, A. M., Corr, P. J., & Satchell, L. P. (2018). A reinforcement sensitivity theory explanation of antisocial behaviour. *Personality and individual differences*, *123*, 87-93. https://doi.org/10.1016/j.paid.2017.11.008

Biedermann, S. V., Biedermann, D. G., Wenzlaff, F., Kurjak, T., Nouri, S., Auer, M. K., Wiedemann, K., Briken, P., Haaker, J., Lonsdorf, T. B., & Fuss, J. (2017). An elevated plus-maze in mixed reality for studying human anxiety-related behavior. *BMC Biol*, *15*(1), 125-125. https://doi.org/10.1186/s12915-017-0463-6

Biedermann, S. V., Roth, L., Biedermann, D., & Fuss, J. (2024). Reliability of repeated exposure to the human elevated plus-maze in virtual reality: Behavioral, emotional, and autonomic responses. *Behav Res Methods*, *56*(1), 187-198. https://doi.org/10.3758/s13428-022-02046-5

Bohil, C. J., Alicea, B., & Biocca, F. A. (2011). Virtual reality in neuroscience research and therapy. *Nat Rev Neurosci*, *12*(12), X752-762. https://doi.org/10.1038/nrn3122

Clark, C. C. T., Barnes, C. M., Duncan, M. J., Summers, H. D., & Stratton, G. (2019). Physical activity, motor competence and movement and gait quality: A principal component analysis. *Hum Mov Sci*, *68*, 102523-102523. https://doi.org/10.1016/j.humov.2019.102523

Corr, P. J. (2004). Reinforcement sensitivity theory and personality. *Neurosci Biobehav Rev*, *28*(3), 317-332. https://doi.org/10.1016/j.neubiorev.2004.01.005

Corr, P. J. (2018). A Neuroscience of Approach, Avoidance and Conflict Personality Traits. *International journal of psychophysiology*, *131*, S57-S57. https://doi.org/10.1016/j.ijpsycho.2018.07.169

Corr, P. J., & Cooper, A. J. (2016). The Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ): Development and Validation. *Psychol Assess*, *28*(11), 1427-1440. https://doi.org/10.1037/pas0000273

Corr, P. J., & McNaughton, N. (2012). Neuroscience and approach/avoidance personality traits: A two stage (valuation-motivation) approach. *Neurosci Biobehav Rev*, *36*(10), 2339-2354. https://doi.org/10.1016/j.neubiorev.2012.09.013

Crawford, M. T., Maymon, C., Miles, N. L., Blackburne, K., Tooley, M., & Grimshaw, G. M. (2024). Emotion in motion: perceiving fear in the behaviour of individuals from minimal motion capture displays. *Cogn Emot*, 1-12. https://doi.org/10.1080/02699931.2023.2300748

Cummings, J. J., & Bailenson, J. N. (2016). How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive Technology on User Presence. *Media psychology*, *19*(2), 272-309. https://doi.org/10.1080/15213269.2015.1015740

Diniz Bernardo, P., Bains, A., Westwood, S., & Mograbi, D. C. (2021). Mood Induction Using Virtual Reality: a Systematic Review of Recent Findings. *Journal of technology in behavioral science*, *6*(1), 3-24. https://doi.org/10.1007/s41347-020-00152-9

Ellmers, T. J., & Young, W. R. (2019). The Influence of Anxiety and Attentional Focus on Visual Search During Adaptive Gait. *J Exp Psychol Hum Percept Perform*, *45*(6), 697-714. https://doi.org/10.1037/xhp0000615

Federolf, P. A., Boyer, K. A., & Andriacchi, T. P. (2013). Application of principal component analysis in clinical gait research: Identification of systematic differences between healthy and medial knee-osteoarthritic gait. *J Biomech*, *46*(13), 2173-2178. https://doi.org/10.1016/j.jbiomech.2013.06.032

Field, A. P. (2018). *Discovering statistics using IBM SPSS Statistics* (5th edition. ed.). SAGE.

Gelder, B., Kätsyri, J., & Borst, A. W. (2018). Virtual reality and the new psychophysics. *Br J Psychol*, *109*(3), 421-426. https://doi.org/10.1111/bjop.12308

Gray, J. A. (1982). *The Neurophysiology of Anxiety. An Inquiry into the Functions of the Septo-Hippocampal System*.

Gromer, D., Madeira, O., Gast, P., Nehfischer, M., Jost, M., Müller, M., Mühlberger, A., & Pauli, P. (2018). Height simulation in a virtual reality cave system: Validity of fear responses and effects of an immersion manipulation. *Front Hum Neurosci*, *12*, 372-372. https://doi.org/10.3389/fnhum.2018.00372

Gromer, D., Reinke, M., Christner, I., & Pauli, P. (2019). Causal interactive links between presence and fear in virtual reality height exposure. *Front Psychol*, *10*, 141-141. https://doi.org/10.3389/fpsyg.2019.00141

Gross, J. J., & John, O. P. (2003). Individual Differences in Two Emotion Regulation Processes: Implications for Affect, Relationships, and Well-Being. *J Pers Soc Psychol*, *85*(2), 348-362. https://doi.org/10.1037/0022-3514.85.2.348

Gullone, E. (2000). The development of normal fear: A century of research. *Clin Psychol Rev*, *20*(4), 429-451. https://doi.org/10.1016/S0272-7358(99)00034-3

Halovic, S., & Kroos, C. (2018). Not all is noticed: Kinematic cues of emotion-specific gait. *Hum Mov Sci*, *57*, 478-488. https://doi.org/10.1016/j.humov.2017.11.008

Jianwattanapaisarn, N., Sumi, K., Utsumi, A., Khamsemanan, N., & Nattee, C. (2022). Emotional characteristic analysis of human gait while real-time movie viewing. *Frontiers in artificial intelligence*, *5*, 989860-989860. https://doi.org/10.3389/frai.2022.989860

Johnson, J. A. (2014). Measuring thirty facets of the Five Factor Model with a 120-item public domain inventory: Development of the IPIP-NEO-120. *Journal of research in personality*, *51*, 78-89. https://doi.org/10.1016/j.jrp.2014.05.003

Katz, B. A., Matanky, K., Aviram, G., & Yovel, I. (2020). Reinforcement sensitivity, depression and anxiety: A meta-analysis and meta-analytic structural equation model. *Clin Psychol Rev*, *77*, 101842-101842. https://doi.org/10.1016/j.cpr.2020.101842

Kisker, J., Gruber, T., & Schöne, B. (2021). Behavioral realism and lifelike psychophysiological responses in virtual reality by the example of a height exposure. *Psychol Res*, *85*(1), 68-81. https://doi.org/10.1007/s00426-019-01244-9

Kisker, J., Lange, L., Flinkenflügel, K., Kaup, M., Labersweiler, N., Tetenborg, F., Ott, P., Gundler, C., Gruber, T., Osinsky, R., & Schöne, B. (2021). Authentic Fear Responses in Virtual Reality: A Mobile EEG Study on Affective, Behavioral and Electrophysiological Correlates of Fear. *Frontiers in virtual reality*, *2*. https://doi.org/10.3389/frvir.2021.716318

Krupić, D., Križanić, V., & Corr, P. J. (2016). Personality and defensive behaviour: A factor analytic approach to threat scenario choices. *Personality and individual differences*, *94*, 303-308. https://doi.org/10.1016/j.paid.2016.01.045

Krupić, D., Žuro, B., & Corr, P. J. (2021). Anxiety and threat magnification in subjective and physiological responses of fear of heights induced by virtual reality. *Personality and individual differences*, *169*, 109720. https://doi.org/10.1016/j.paid.2019.109720

Li, S., Cui, L., Zhu, C., Li, B., Zhao, N., & Zhu, T. (2016). Emotion recognition using Kinect motion capture data of human gaits. *PeerJ*, *2016*(9), e2364-e2364. https://doi.org/10.7717/peerj.2364

Lin, J.-H. T. (2017). Fear in virtual reality (VR): Fear elements, coping reactions, immediate and next-day fright responses toward a survival horror zombie virtual reality game.

*Computers in human behavior*, *72*, 350-361. https://doi.org/10.1016/j.chb.2017.02.057

Lin, J.-H. T., Wu, D.-Y., & Tao, C.-C. (2018). So scary, yet so fun: The role of self-efficacy in enjoyment of a virtual reality horror game. *New media & society*, *20*(9), 3223-3242. https://doi.org/10.1177/1461444817744850

Lloyd, A. S., Martin, J. E., Bornett-Gauci, H. L. I., & Wilkinson, R. G. (2008). Horse personality: Variation between breeds. *Applied animal behaviour science*, *112*(3), 369-383. https://doi.org/10.1016/j.applanim.2007.08.010

Madeira, O., Gromer, D., Latoschik, M. E., & Pauli, P. (2021). Effects of Acrophobic Fear and Trait Anxiety on Human Behavior in a Virtual Elevated Plus-Maze. *Frontiers in virtual reality*, *2*. https://doi.org/10.3389/frvir.2021.635048

Merscher, A. S., & Gamer, M. (2024). Can I see it in the eyes? An investigation of freezing-like motion patterns in response to avoidable threat. *Psychophysiology*, e14567-e14567. https://doi.org/10.1111/psyp.14567

Norouzian, P., Horslen, B. C., & Martens, K. A. E. (2024). The effects of trait and state anxiety on gait in healthy young adults. *Exp Brain Res*. https://doi.org/10.1007/s00221-024-06800-3

Nummenmaa, L., Glerean, E., Hari, R., & Hietanen, J. K. (2014). Bodily maps of emotions. *Proc Natl Acad Sci U S A*, *111*(2), 646-651. https://doi.org/10.1073/pnas.1321664111

Pan, X., & Hamilton, A. F. d. C. (2018). Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape. *Br J Psychol*, *109*(3), 395-417. https://doi.org/10.1111/bjop.12290

Perkins, A. M., Cooper, A., Abdelall, M., Smillie, L. D., & Corr, P. J. (2010). Personality and Defensive Reactions: Fear, Trait Anxiety, and Threat Magnification: Personality and

Defensive Reactions. *Journal of personality*, *78*(3), 1071-1090. https://doi.org/10.1111/j.1467-6494.2010.00643.x

Perkins, A. M., & Corr, P. J. (2006). Reactions to threat and personality: Psychometric differentiation of intensity and direction dimensions of human defensive behaviour. *Behav Brain Res*, *169*(1), 21-28. https://doi.org/10.1016/j.bbr.2005.11.027

Perkins, A. M., Kemp, S. E., & Corr, P. J. (2007). Fear and Anxiety as Separable Emotions: An Investigation of the Revised Reinforcement Sensitivity Theory of Personality. *Emotion*, *7*(2), 252-261. https://doi.org/10.1037/1528-3542.7.2.252

Pran, P. (2021). IPIP-NEO-120 på norsk: En pilotundersøkelse av psykometriske egenskaper. In.

Raffegeau, T. E., Clark, M., Fawver, B., Engel, B. T., Young, W. R., Williams, A. M., Lohse, K. R., & Fino, P. C. (2023). The effect of mobility-related anxiety on walking across the lifespan: a virtual reality simulation study. *Exp Brain Res*, *241*(7), 1757-1768. https://doi.org/10.1007/s00221-023-06638-1

Riemer, H., Joseph, J. V., Lee, A. Y., & Riemer, R. (2023). Emotion and motion: Toward emotion recognition based on standing and walking. *PLoS One*, *18*(9), e0290564-e0290564. https://doi.org/10.1371/journal.pone.0290564

Rosa, S., & Breidt, M. (2018). Virtual reality: A new track in psychological research. *Br J Psychol*, *109*(3), 427-430. https://doi.org/10.1111/bjop.12302

Sambo, C. F., & Iannetti, G. D. (2013). Better safe than sorry? The safety margin surrounding the body is increased by anxiety. *J Neurosci*, *33*(35), 14225-14230. https://doi.org/10.1523/JNEUROSCI.0706-13.2013

Satchell, L., Morris, P., Mills, C., O'Reilly, L., Marshman, P., & Akehurst, L. (2017). Evidence of Big Five and Aggressive Personalities in Gait Biomechanics. *J Nonverbal Behav*, *41*(1), 35-44. https://doi.org/10.1007/s10919-016-0240-1

Schmidt, E. M., Smith, R. A., Fernández, A., Emmermann, B., & Christensen, J. F. (2024). Mood induction through imitation of full-body movements with different affective intentions. *Br J Psychol*, *115*(1), 148-180. https://doi.org/10.1111/bjop.12681

Schöne, B., Kisker, J., Lange, L., Gruber, T., Sylvester, S., & Osinsky, R. (2023). The reality of virtual reality. *Front Psychol*, *14*, 1093014-1093014. https://doi.org/10.3389/fpsyg.2023.1093014

Schöne, B., Kisker, J., Sylvester, R. S., Radtke, E. L., & Gruber, T. (2023). Library for universal virtual reality experiments (luVRe): A standardized immersive 3D/360° picture and video database for VR based research. *Current psychology (New Brunswick, N.J.)*, *42*(7), 5366-5384. https://doi.org/10.1007/s12144-021-01841-1

SIKT. (2024). *Norwegian Agency for Shared Services in Education and Research*. https://sikt.no/en/home

Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Phil. Trans. R. Soc. B*, *364*(1535), 3549-3557. https://doi.org/10.1098/rstb.2009.0138

Slater, M., Gonzalez-Liencres, C., Haggard, P., Vinkers, C., Gregory-Clarke, R., Jelley, S., Watson, Z., Breen, G., Schwarz, R., Steptoe, W., Szostak, D., Halan, S., Fox, D., & Silver, J. (2020). The Ethics of Realism in Virtual and Augmented Reality. *Frontiers in virtual reality*, *1*. https://doi.org/10.3389/frvir.2020.00001

Stins, J. F., Lobel, A., Roelofs, K., & Beek, P. J. (2014). Social embodiment in directional stepping behavior. *Cogn Process*, *15*(3), 245-252. https://doi.org/10.1007/s10339-013-0593-x

Storli, L., Sandseter, E. B. H., & Lorås, H. (2024). Individual differences in children's movement variability in a virtual reality playground task. *Hum Mov Sci*, *93*, 103171-103171. https://doi.org/10.1016/j.humov.2023.103171

Tcha-Tokey, K., Christmann, O., Loup-Escande, E., & Richir, S. (2016). Proposition and Validation of a Questionnaire to Measure the User Experience in Immersive Virtual Environments. *The international journal of virtual reality*, *16*(1), 33-48. https://doi.org/10.20870/IJVR.2016.16.1.2880

Van Andel, S., Mohr, M., Schmidt, A., Werner, I., & Federolf, P. (2022). Whole-body movement analysis using principal component analysis: What is the internal consistency between outcomes originating from the same movement simultaneously recorded with different measurement devices? *Front Bioeng Biotechnol*, *10*, 1006670-1006670. https://doi.org/10.3389/fbioe.2022.1006670

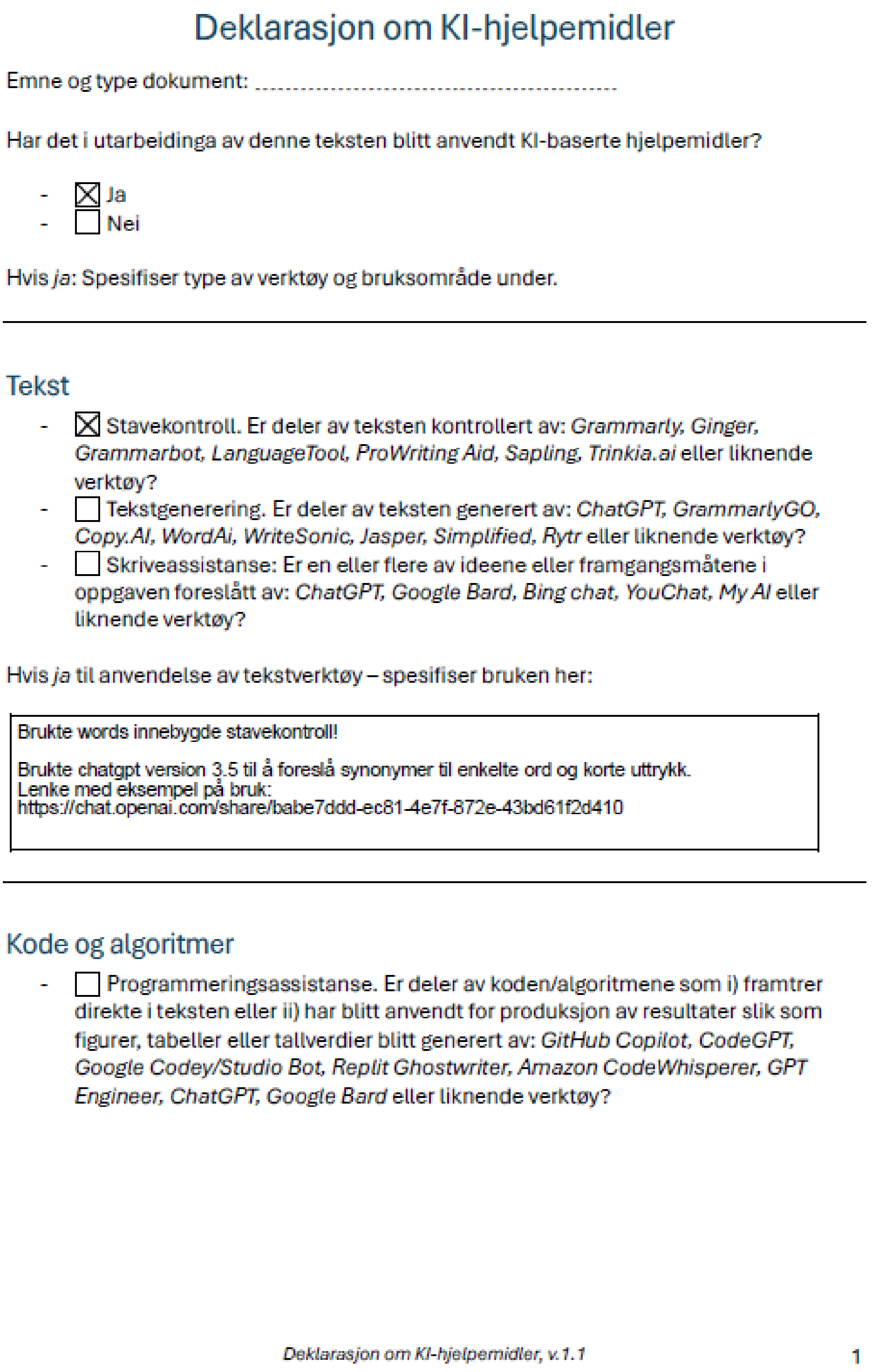
Wallbott, H. G. (1998). Bodily expression of emotion. *Eur. J. Soc. Psychol*, *28*(6), 879-896. https://doi.org/10.1002/(SICI)1099-0992(1998110)28:6

Wen, Y., Li, B., Chen, D., & Zhu, T. (2022). Reliability and validity analysis of personality assessment model based on gait video. *Frontiers in behavioral neuroscience*, *16*, 901568-901568. https://doi.org/10.3389/fnbeh.2022.901568

Xu, S., Fang, J., Hu, X., Ngai, E., Wang, W., Guo, Y., & Leung, V. C. M. (2022). Emotion Recognition From Gait Analyses: Current Research and Future Directions. *arXiv.org*. https://doi.org/10.48550/arxiv.2003.11461

Zuj, D. V., Palmer, M. A., Lommen, M. J. J., & Felmingham, K. L. (2016). The centrality of fear extinction in linking risk factors to PTSD: A narrative review. *Neurosci Biobehav Rev*, *69*, 15-35. https://doi.org/10.1016/j.neubiorev.2016.07.014

# Appendix



## Deklarasjon om KI-hjelpemidler

Emne og type dokument: ............................................................

Har det i utarbeidinga av denne teksten blitt anvendt KI-baserte hjelpemidler?

- ☒ Ja
- ☐ Nei

Hvis *ja*: Spesifiser type av verktøy og bruksområde under.

---

### Tekst

- ☒ Stavekontroll. Er deler av teksten kontrollert av: *Grammarly, Ginger, Grammarbot, LanguageTool, ProWriting Aid, Sapling, Trinkia.ai* eller liknende verktøy?
- ☐ Tekstgenerering. Er deler av teksten generert av: *ChatGPT, GrammarlyGO, Copy.AI, WordAi, WriteSonic, Jasper, Simplified, Rytr* eller liknende verktøy?
- ☐ Skriveassistanse: Er en eller flere av ideene eller framgangsmåtene i oppgaven foreslått av: *ChatGPT, Google Bard, Bing chat, YouChat, My AI* eller liknende verktøy?

Hvis *ja* til anvendelse av tekstverktøy – spesifiser bruken her:

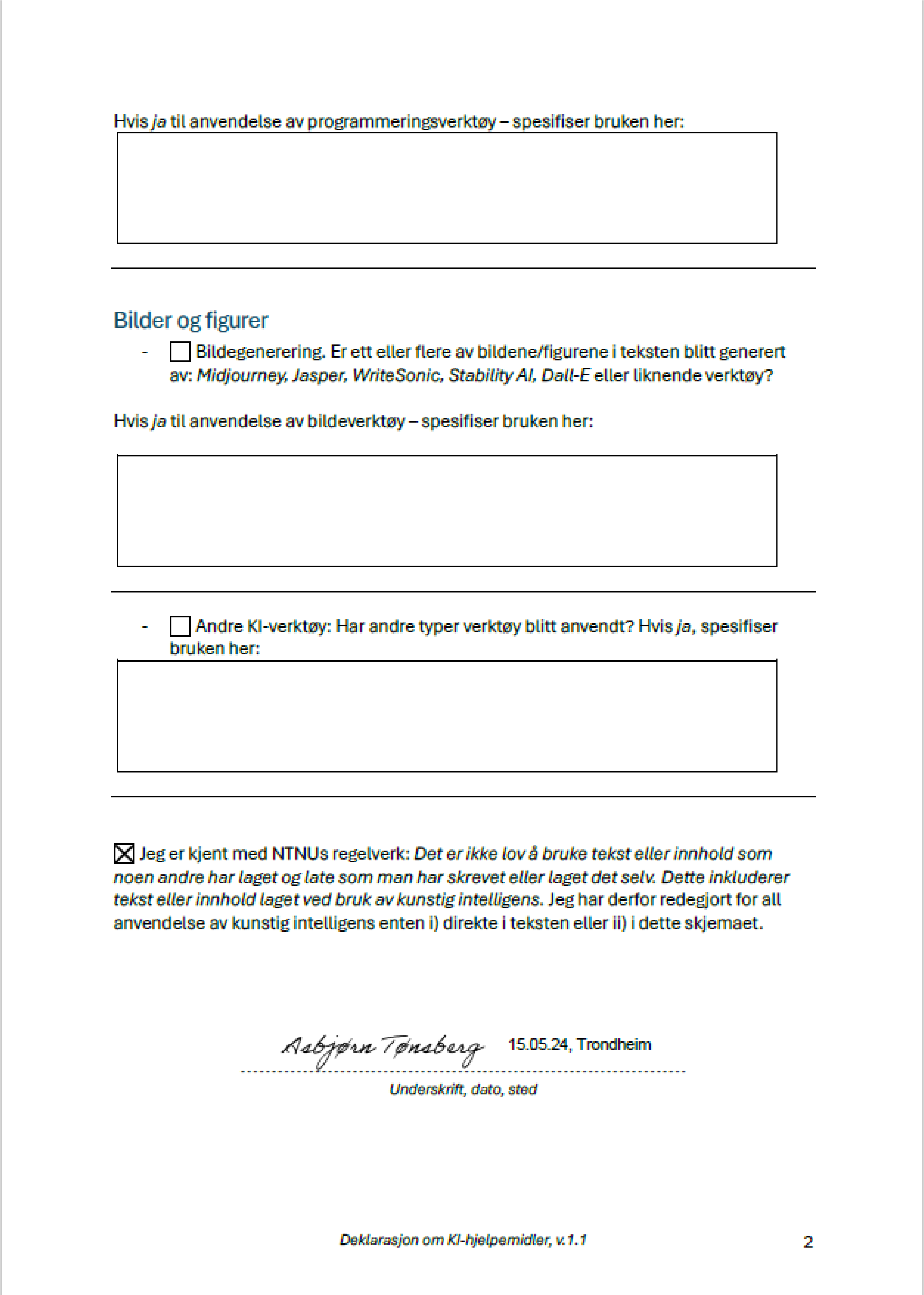
Brukte words innebygde stavekontroll!

Brukte chatgpt version 3.5 til å foreslå synonymer til enkelte ord og korte uttrykk.
Lenke med eksempel på bruk:
https://chat.openai.com/share/babe7ddd-ec81-4e7f-872e-43bd61f2d410

---

### Kode og algoritmer

- ☐ Programmeringsassistanse. Er deler av koden/algoritmene som i) framtrer direkte i teksten eller ii) har blitt anvendt for produksjon av resultater slik som figurer, tabeller eller tallverdier blitt generert av: *GitHub Copilot, CodeGPT, Google Codey/Studio Bot, Replit Ghostwriter, Amazon CodeWhisperer, GPT Engineer, ChatGPT, Google Bard* eller liknende verktøy?



Hvis *ja* til anvendelse av programmeringsverktøy – spesifiser bruken her:

---

## Bilder og figurer

- ☐ Bildegenerering. Er ett eller flere av bildene/figurene i teksten blitt generert av: *Midjourney, Jasper, WriteSonic, Stability AI, Dall-E* eller liknende verktøy?

Hvis *ja* til anvendelse av bildeverktøy – spesifiser bruken her:

---

- ☐ Andre KI-verktøy: Har andre typer verktøy blitt anvendt? Hvis *ja*, spesifiser bruken her:

---

☒ Jeg er kjent med NTNUs regelverk: *Det er ikke lov å bruke tekst eller innhold som noen andre har laget og late som man har skrevet eller laget det selv. Dette inkluderer tekst eller innhold laget ved bruk av kunstig intelligens.* Jeg har derfor redegjort for all anvendelse av kunstig intelligens enten i) direkte i teksten eller ii) i dette skjemaet.

Aabjørn Tønsberg 15.05.24, Trondheim

*Underskrift, dato, sted*

NTNU

Norwegian University of
Science and Technology