Title:

WORK AT HEIGHTS TRAINING: CONVENTIONAL APPROACH WITH AND WITHOUT IMMERSIVE VIRTUAL REALITY

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STATISTICAL ANALYSIS PLAN

1. Specific objective 1:

Compare the acquisition of theoretical knowledge and practical skills between the two groups (RVI vs. traditional).

- Variables to be analyzed:
  - Theoretical knowledge: Score obtained in pre and post training tests.
  - Practical skills: Score on the pre and post evaluation of specific work tasks at heights.
- Statistical tests:
  - Intragroup comparison (pre and post training):
    - Paired samples t-test (if data follows a normal distribution) to compare pre- and post-scores in each group.
    - If the data do not follow a normal distribution, use the Wilcoxon test for related samples.
  - Intergroup comparison (post training between RVI and traditional):
    - Student 's t test for independent samples to compare scores between groups after training.
    - If the data are not normal, the Mann-Whitney U test will be used to compare the post scores between the two groups.
- Expected results:
  - A significant increase in post scores in the RVI group compared to the traditional group will indicate the effectiveness of immersive virtual reality training in the acquisition of knowledge and skills.

2. Specific objective 2:

Analyze the physiological reactions of trainees during training sessions by measuring biosignals .

- Variables to be analyzed:
  - Biosignals : Continuous measurements of heart rate (HR), heart rate variability (HRV), respiratory rate and respiratory rate variability, taken during training.

- Statistical tests:
    - Repeated measures ANOVA: To evaluate how biosignals change during different stages of training (beginning, middle, end) in each group.
        - If sphericity (assumption of equality of variances) is not met, corrections such as Greenhouse-Geisser or Huynh-Feldt will be used .
    - Intergroup comparison:
        - Compare biosignals between the RVI and traditional groups using a repeated measures ANOVA with one between-subjects factor (group) and one within-subjects factor (time).
- Expected results:
    - Trainees in the RVI group are expected to present more stable physiological responses (smaller increases in heart rate, greater heart rate variability) than those in the traditional group, which would suggest better stress management.

3. Specific objective 3:

To assess postures and workload perception in participants during the execution of high-risk tasks .

- Variables to be analyzed:
    - Postural stability : Body alignment and stability will be assessed during task execution.
    - Workload : The NASA-TLX scale will be used to measure the subjective perception of mental load during training.
- Statistical tests:
    - Posture:
        - Repeated measures ANOVA to compare postures between different time points (pre, post) within each group.
        - Compare postural changes between the RVI and traditional groups using two-way ANOVA.
    - Mental load:
        - Student 's t test for independent samples to compare the perceived mental workload scores between the two groups post-training.
        - If there is no normality in the data, the Mann-Whitney U test will be used.
- Expected results:
    - Better postural performance in the RVI group would suggest greater effectiveness of training in physical stability.
    - The RVI group is expected to report lower mental load due to greater familiarity with high-risk tasks thanks to the simulation.

4. Specific objective 4:

Explore the influence of individual cognitive abilities (attention and memory) on the results of theoretical knowledge and practical skills .

- Variables to be analyzed :
  - Cognitive abilities : Scores on psychometric tests of attention and memory.
  - Results of theoretical knowledge and practical skills : Scores obtained in the post-training tests.
- Statistical tests :
  - Correlation analysis :
    - Pearson correlation (if data are normal) or Spearman correlation (if not normal) will be used to explore the relationship between cognitive abilities (attention and memory) and post scores on knowledge and practical skills.
  - Multiple linear regression :
    - multiple linear regression model will be used to analyze the influence of cognitive abilities and type of training (RVI vs. traditional) on post-scores of knowledge and practical skills.
    - Cognitive skills and type of training will be predictor variables and post scores will be the dependent variables .
- Expected results :
  - Cognitive abilities, especially attention, are expected to play a significant role in the acquisition of theoretical knowledge and practical skills, and the RVI group is expected to be less influenced by these abilities thanks to the visual and practical support of the virtual environment.

Control of confounders

- To control for the influence of variables such as age , previous experience , and gender , these variables can be included in the analyses as covariates using an ANCOVA in the intergroup comparison models and in the regression.

Additional tests

- Normality test (Shapiro-Wilk) to verify the normality of the data before performing parametric tests.
- Homogeneity of variances test (Levene) before running tests such as Student 's t test , to ensure that the variances of the groups are comparable.

Biosignals:

To process the captured biosignals (heart rate and respiratory rate) and calculate the variability of both, the following will be performed:

1. Signal Capture and Preprocessing

a. Heart Rate (HR) with Polar H10

- **Data capture** : Polar SDK API will be used to obtain real-time heart rate data.
  - Format: RR intervals in milliseconds (intervals between heartbeats).
  - Sampling frequency: between 0.5 and 4 Hz.
- **Preprocessing** :
  - **Artifact filtering : A** low-pass filter will be used to remove noise caused by motion or interference.

b. Respiratory Rate (RR) with Xiaomi Buds

- **Data Capture** : The wireless hearing aid microphone will be used as an input source to capture respiratory sounds.
- **Preprocessing** :
  - **Noise filtering** : Apply a 0.1-0.5 Hz low-pass filter to isolate respiratory sounds and eliminate ambient noise.
  - **Respiratory spike detection** : Use spike detection algorithms to identify respiratory cycles (inhalation/exhalation).

2. Feature Extraction

a. Heart Rate (HR)

- **Average HR** : The average heart rate over a specific time interval will be calculated.
- **Heart Rate Variability (HRV)** :
  - **Time domain** :
    - **SDNN** (Standard deviation of RR intervals).
    - **RMSSD** (Root of the square differences between adjacent RR intervals).
  - **Frequency domain** :
    - Fast Fourier transform (FFT) or power spectral analysis will be applied to determine low frequency (LF) and high frequency (HF) components.
    - **LF/HF ratio** : To assess sympathetic-parasympathetic balance.

b. Respiratory Rate (RR)

- **Average RR** : The respiratory rate (breaths per minute) will be calculated over a period of time.
- **Respiratory Rate Variability (RRV)** :
  - **Time domain** :
    - The variability between inhalation/exhalation peaks will be calculated.
    - **SDNN-RR** : Standard deviation of respiratory intervals.
  - **Frequency domain** :
    - Fourier transform (FFT) to identify low and high frequency components in respiration.
    - **Spectral analysis** : Respiratory frequency patterns associated with respiratory phases will be identified.

3. Signal Synchronization

- Heart rate and respiratory signals will be synchronized for comparative analysis over time.
- The timestamp of each captured signal will be used to align them and ensure that the comparison between them is consistent.

4. Analysis of the HRV and RRV Relationship

- The correlation between heart rate variability (HRV) and respiratory rate variability (RRV) will be assessed.
  - **Statistical methods : Pearson or** Spearman correlation calculation will be performed to identify the relationship between both signals.
  - **Cross-analysis** : How one signal influences the other will be evaluated using spectral coherence techniques or linear models.

5. Data Visualization

- Graphs will be generated showing the HR and RR signals over time, along with their variability:
  - HR and RR graphs in the time domain.
  - HRV and RRV graphs in the frequency domain.
  - Scatter diagrams to represent the relationship between HRV and RRV.

6. Statistical Analysis

- **Data segment comparison** : Data will be split into specific segments (e.g., during different phases of activity or rest) to assess differences in HRV and RRV.

- **Descriptive statistics** : Mean, standard deviation, minimum and maximum of HR, RR, HRV and RRV.
- **Trend analysis** : Changes in variations over time will be evaluated to identify significant trends.

7. Final Report

- **Summary of results** : the main metrics calculated and their interpretation will be described.
- **Conclusions** : Heart rate and respiratory rate variability, their relationship and the physiological or health implications that can be drawn will be evaluated.

Technical Tools

- **Libraries for analysis** :
  - For heart rate (HRV): libraries such as pyHRV or HRV- Analysis will be used to work in Python.
  - For respiratory rate (RRV): Signal processing algorithms such as FFT and peak detection will be implemented, using libraries such as SciPy or Libros for audio analysis.