# Final-project_Jack

## Links Between Physiological and Perceptual Strain in Uncompensable Heat Stress

**Xiujing Zhao**

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### 1. Introduction

Exercise or work in the heat challenges human physiological systems (e.g., thermoregulatory and cardiovascular) due to increases in metabolic heat production (e.g., muscle activity) and environmental heat load [1]. Heat stress impairs heat balance and results in an increase in heat strain. Notably, uncompensable heat stress would deteriorate body thermoregulation via an uncontrollable elevation in body core temperature and increase the risk of heat-related injury or illness [2-4]. Heat strain refers to the body's physiological (e.g., thermal and cardiovascular) and perceptual responses to heat stress [5]. In this regard, the heart rate (HR), body core temperature ($T_c$), and skin temperature ($T_{sk}$) responses to heat stress can be indicators to reflect physiological heat strain [6]. As for perceptual heat strain, the previous study has defined the rate of perceived exertion (RPE) and thermal sensation (TS) as perceptual strain index (PeSI) to quantify the magnitude of perceptual strain during exposure to heat stress [7]. Identifying the magnitude of heat strain is crucial to predicting physiological and perceptual tolerance and protecting people from heat-related injuries when exposed to hot environments [1].

Many heat strain indices were developed as holistic tools to determine the risk level of physiological, perceptual strains or predict tolerance times at various activities in a range of heat stress [7-9, 10]. The physiological strain index (PhSI), proposed by Moran and his colleagues, was most widely used to track heat strain via physiological measures of thermoregulatory ($T_c$) and cardiovascular (HR) strain [10]. PhSI has been validated to assess heat strain levels in various climates [11], clothing assembles [11], exercise intensity [11], hydration levels [12], ages [13], and between genders [14]. Moreover, PhSI classified the heat strain as a single arbitrary value from 0 (no strain) to 10 (very high strain), which would be significant in quantifying the heat strain levels and easily comparable at varying environmental conditions [6, 10]. However, the calculation of PhSI relies on the direct, accurate measurement of $T_c$ and HR. These physiological measures need to be sensitive devices and directly attached to the individual, which is unsuitable for some field settings in extreme environments (e.g., firefighting and military operations) [15]. In addition, considering necessary resources for large cohorts, the expense of measurement devices, and inaccessible measurement sites (e.g., rectal, oesophageal), a reliable, simple, alternative monitoring protocol should be developed to overcome these limitations of PhSI.

Some subjective perceptual measures (e.g., RPE and TS) may provide insight to reflect the objective measures of PhSI. RPE and TS have been used to complement physiological monitoring for athletes [16, 17]. Moreover, a plethora of literature demonstrated the close relation between perceptual measures of RPE and TS and physiological measures of $T_c$ and HR [18-21]. As such, modelled on the PhSI, Tikusiss et al. proposed an integrated tool to assess heat strain in 2002, namely PeSI, which was calculated by attributing equal weight to RPE and TS [7]. A previous study suggests that PeSI has the potential to estimate PhSI via measuring RPE and TS [7]. In this regard, the RPE scale reflects the subjective assessment of an individual's physical effort, which could act as a surrogate of HR. TS is the subjective perception of temperature from central and peripheral tissues, which can indicate $T_c$ [15]. As PhSI, PeSI is also a reliable and validated heat strain index that can identify heat strain in different fitness levels [7], exercise intensity, and clothing assembles [22]. Furthermore, many investigations sought to determine whether PeSI can be an alternative to PhSI to assess heat strain at various heat stresses in laboratory or field settings [4, 6, 7, 15, 22-25]. Many studies revealed that PeSI was strongly associated with PhSI and can be a simple, robust, and user-friendly tool for heat strain assessment in firefighting and occupational settings [6, 22,23]. Other studies suggest that PeSI can predict PhSI in varying heat stress [wet-bulb globe temperature (WBGT) of 21-37] in 50-120 minutes of low-to-moderate intensity exercise with a variety of protective garments [4, 24, 25]. However, Walker's study found that PeSI had a poor association with PhSI during both self-paced and set-paced firefighting tasks in the heat [15]. Moreover, the fundamental mechanism of the PeSI in predicting PhSI is the ability of TS and RPE to provide an accurate subjective prediction of $T_c$ and HR. However, previous studies have reported that the relationship between TS and $T_c$ ($r = 0.28$-$0.72$) is weaker than the relationship between RPE and HR ($r = 0.81$-$0.92$) [4, 24, 26, 27]. Savage also found that TS poorly predicted the $T_c$ [28]. The responses to TS in the heat may be primarily driven by $T_{sk}$ rather than $T_c$ [29, 30]. Foster [30] reported that $T_{sk}$ can adequately predict TS ($R^2 = 0.840$). Vecellio [18] also found that TS was associated with $T_{sk}$, but not $T_c$ during light physical activity in the heat. In consideration of the close relationship between TS and $T_{sk}$, adding $T_{sk}$ as an essential physiological measure is necessary and valuable when investigating the link of objective physiological measures to subjective perceptual measures during varying heat stress.

Therefore, the current study aims to evaluate the relationship between PeSI and physiological measures in hot-dry (HD) and warm-humid (WH) conditions with matched WBGT during moderate-intensity cycling.

## 2. Methods

*2.1. Participants*

Ten healthy, physically active, and non-heat-acclimated males were involved in this study. Participants were excluded if they self-reported previous heat illness within the past three years, current musculoskeletal injury, or were taking any medications that might affect thermoregulation, and if they used tobacco or electronic cigarettes. Prior to testing, written informed consent was obtained from all participants before participation in accordance with the Declaration of Helsinki. All participants completed a medical history questionnaire prior to participation.

All experimental procedures were approved by The University Institutional Review Board prior to data collection (IRB approved protocol number: 2309490663). All participants were asked to refrain from alcohol use for 24 hours, caffeine was matched for each trial, and strenuous activity was restricted for 24 hours before both preliminary and experimental trials. Participants wore a thin tee shirt or cycling jersey, shorts, socks, and cycling shoes that were matched between trials. The current data were collected as part of a large project, the main paper which was recently submitted elsewhere.

*2.2. Environmental conditions and metabolic rate*

All trials were completed in an environmental chamber. The WBGT of 30 °C was obtained by the HD condition (39.2°C, 30% of RH) and WH condition (34.2°C, 55% of RH). WBGT, ambient temperature, RH, and wind speed were measured every 15 minutes throughout (Kestrel 4400, Nielsen-Kellerman, Boothwyn, PA, USA). The two randomized experimental trials (HD and WH) were separated by at least six days and occurred at the same time of day to account for circadian rhythm. Within each trial, participants completed 60 minutes of cycling at 55% of the wattage reached during the last stage of the $VO_{2peak}$ test.

*2.3 Preliminary and experimental protocol*

During the preliminary visit, participants were familiarized with the environmental chamber, experimental protocols, and completed a $VO_{2peak}$ test. Body composition was assessed via dual energy x-ray absorptiometry prior to the experimental trial (DXA, Lunar Prodigy, General Electric, Madison, WI, USA). $VO_{2peak}$ was assessed via a cycle ergometer (Racer Mate, Seattle, WA) graded exercise protocol. Participants were informed on the RPE scale [29], instrumented with 3-lead ECG (Tango II, Suntech, Medical Inc, Morrisville, NC, USA), and adjusted the seat and handlebars prior to testing. Participants warmed up at 100W for five minutes at a self-selected cadence. Following the warm-up, resistance was increased by 25-50W every two minutes until the participant could not maintain 60 revolutions per minute (RPM) on the cycle ergometer. During the $VO_{2peak\ k}$, HR, RPE, respiratory exchange ratio (RER), and relative $VO_2$ were recorded every 30 seconds. The $VO_2$ value was considered as a $VO_{2peak}$ provided at least two of the following physiological criteria were met: a) a plateau in oxygen consumption with increasing workload, b) RER value > 1.15, and/or c) HR  95% of age-predicted HR maximum (HRmax = 220 – age) and/or d) RPE rating of 19-20 at the final stage.

During the experimental trials, on arrival, participants provided a 24-hour urine sample to ensure euhydration, defined as urine specific gravity < 1.020 (USG, Master-SUR, Atago Co Ltd, Tokyo, Japan) [30]. Suppose participants' USG >1.020, a 500ml bottled water was provided before the trial commenced. Participants then transitioned to the environmental chamber for a 10-minute upright seated acclimation period. After adjustment of the handlebars and seat, participants began a warm-up for 2-5 minutes at a self-selected load. Participants then began 60 minutes of cycling at 55% of the wattage reached during the last stage of the $VO_{2peak}$ test. After 60 minutes of cycling, participants completed a 5-minute cooldown on the cycle ergometer at a self-selected cadence and workload (matched between trials). After this, researchers removed instrumentation and measured nude body mass. Participants were provided refreshments, and future trials were scheduled, if necessary.

*2.4 Physiological outcomes measure*

HR was measured via a 3-lead ECG (Tango II, Suntech, Medical Inc, Morrisville, NC, USA). Rectal temperature ($T_{re}$) was determined by a rectal thermistor (RET-1, Physitemp Instrumental Inc, Clifton, NJ, USA) inserted ~15 cm past the anal sphincter before participants started experimental trials. $T_{sk}$ was continuously measured by thermocrons (iButton, Maxim Integrated, San Jose, CA, USA) attached with porous zinc oxide tape to the chest, triceps, thigh, and calf on the right side of the body to assess four-site mean weighted skin temperature [31]. $T_{re}$, $T_{sk}$ data were continuously transmitted to a PowerLab data acquisition system and LabChart signal processing software (AD Instruments, Colorado Springs, CO). HR, $T_{re}$, and $T_{sk}$ were recorded at 15-minute intervals in addition to the baseline, allowing the PSI to be calculated at these same intervals. These intervals were selected based on a previous study [4, 7]. The PhSI employed in the current study was developed initially by Moran et al. [10] and presented in Eq. (1) below.

$$PhSI = 5\ ((T_{ret} - T_{reb}) / (39.5 - T_{reb})) + 5\ ((HR_t - HR_b) / (HR_{max} - HR_b)) \quad (1)$$

Where $T_{reb}$ and $HR_b$ are the baseline $T_{re}$ and HR, respectively. $T_{ret}$ and $HR_t$ represent the $T_{re}$ and HR at a particular time point. $HR_{max}$ is the participant's maximum attainable HR.The PhSI attributes equal weight to thermoregulatory and cardiovascular measures, and rates physiological strain on a 0 to 10 scale. Strain was considered as: no/little (0–2.9), low–moderate (3–6.9), and high–very high (7–10) [10].

*2.5 Perceptual outcomes measure*

Perceptual parameters included RPE [29] and TS [32] and were recorded every 15 minutes. RPE was measured using a previously validated 15-point scale of 6 (very, very light) to 20 (very, very hard) [29]. RPE scales were visually presented to participants and accompanied by standardized written and verbal instructions of "how hard are you feeling" [29]. The participants responded by pointing to a number on a chart presented to them by researchers.

Thermal sensation was measured using a 17-point scale of 0.0 (unbearably cold) to 8.0 (unbearably hot) [15, 32]. Similarly, participants were asked, "How do you feel about the current environment?" and responded by pointing to a number on a chart. A modified PeSI was PeSI first proposed by Tikuisis et al. [7] (0 -10 scales) and later adapted by Petruzzello et al. [22]. To calculate, RPE and TS were transformed at each time point using Eq. (2) as below.

PeSI = 5 ((TS-4) / 4) * 5 ((RPE -6) /14) (2)

Where TS and RPE are the thermal sensations and RPE recordings at the time of interest, similarly to the PSI, strain was considered as: no/little (0–2.9), low–moderate (3–6.9), and high–very high (7–10).

*2.6 Statistical analysis*

Two-way ANOVA with the factor of time (five levels: baseline, 15, 30, 45, and 60-min of cycling) and experimental condition (two levels: HD and WH) were used to compare differences in WBGT, $T_{re}$, $T_{sk}$, HR, PhSI, and PeSI between HD and WH conditions. A Pearson's correlation coefficient was used to determine the relationship between the PeSI and PhSI, $T_{re}$, $T_{sk}$, and HR. All data were recorded in Excel format. Data cleaning, format transformation, and analyses were completed using R, and statistical significance was set at $p < .05$.

## 3. Results

3.1 data cleaning

```r
library(tidyverse)
library(readxl)
Data_set_for_R_project <- read_excel("Data set for R project.xlsx")

rename(Data_set_for_R_project, Bodyfat = 'Body fat')
```

3.2 Participants characteristics

```r
mean(Data_set_for_R_project$Age)
age_mean <- mean(Data_set_for_R_project$Age)
sd(Data_set_for_R_project$Age)
age_sd <- sd(Data_set_for_R_project$Age)
mean(Data_set_for_R_project$Bodymass)
bodymass_mean <- mean(Data_set_for_R_project$Bodymass)
sd(Data_set_for_R_project$Bodymass)
bodymass_sd <- sd(Data_set_for_R_project$Bodymass)
mean(Data_set_for_R_project$Height)
height_mean <- mean(Data_set_for_R_project$Height)
```

```
sd(Data_set_for_R_project$Height)
height_sd <- sd(Data_set_for_R_project$Height)
mean(Data_set_for_R_project$VO2peak)
VO2peak_mean <- mean(Data_set_for_R_project$VO2peak)
VO2peak_sd <- sd(Data_set_for_R_project$VO2peak)
```

```
summary_table <- data.frame(Variable = c("Age (years)", "Body Mass (kg)", "Heigh (cm)", "VO2p
print(summary_table, row.names = FALSE)
```

```
           Variable   Mean        SD
        Age (years)  28.80  7.284687
     Body Mass (kg)  77.36  9.344898
         Heigh (cm) 178.99 10.531060
 VO2peak (ml/kg/min)  51.93  5.335010
```

### 3.3 Repeated measures ANOVA

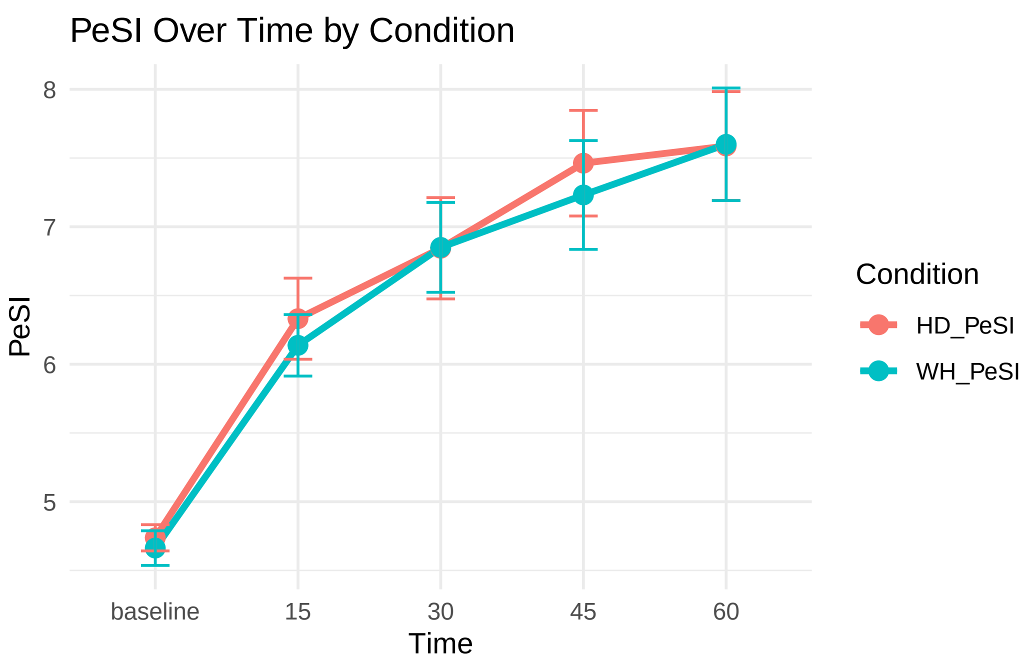
3.3.1 PeSI

```
df_long <- Data_set_for_R_project %>%
       select(ID, starts_with("HD_PeSI"), starts_with("WH_PeSI")) %>%
       pivot_longer(
             cols = -ID,
             names_to = "Condition_Time",
            values_to = "PeSI"
         ) %>%
       separate(Condition_Time, into = c("Condition", "Time"), sep = "-") %>%
       mutate(
             Time = factor(Time, levels = c("baseline", "15", "30", "45", "60")),
             Condition = factor(Condition),
             ID = factor(ID)
         )
anova_model <- aov(PeSI ~ Condition * Time + Error(ID/(Condition*Time)), data = df_long)
summary(anova_model)
```

```
Error: ID
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals  9  64.19   7.133
```

```
Error: ID:Condition
          Df Sum Sq Mean Sq F value Pr(>F)
Condition  1  0.232  0.2316   0.353  0.567
Residuals  9  5.899  0.6555

Error: ID:Time
          Df Sum Sq Mean Sq F value   Pr(>F)
Time       4 106.69   26.67   55.57 6.51e-15 ***
Residuals 36  17.28    0.48
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: ID:Condition:Time
               Df Sum Sq Mean Sq F value Pr(>F)
Condition:Time  4  0.253 0.06314   0.405  0.804
Residuals      36  5.619 0.15607
```

```r
library(ggplot2)
ggplot(df_long, aes(x = Time, y = PeSI, color = Condition, group = Condition)) +
       stat_summary(fun = mean, geom = "line", size = 1.2) +
       stat_summary(fun = mean, geom = "point", size = 3) +
       stat_summary(fun.data = mean_se, geom = "errorbar", width = 0.2) +
       labs(title = "PeSI Over Time by Condition", y = "PeSI", x = "Time") +
       theme_minimal()
```

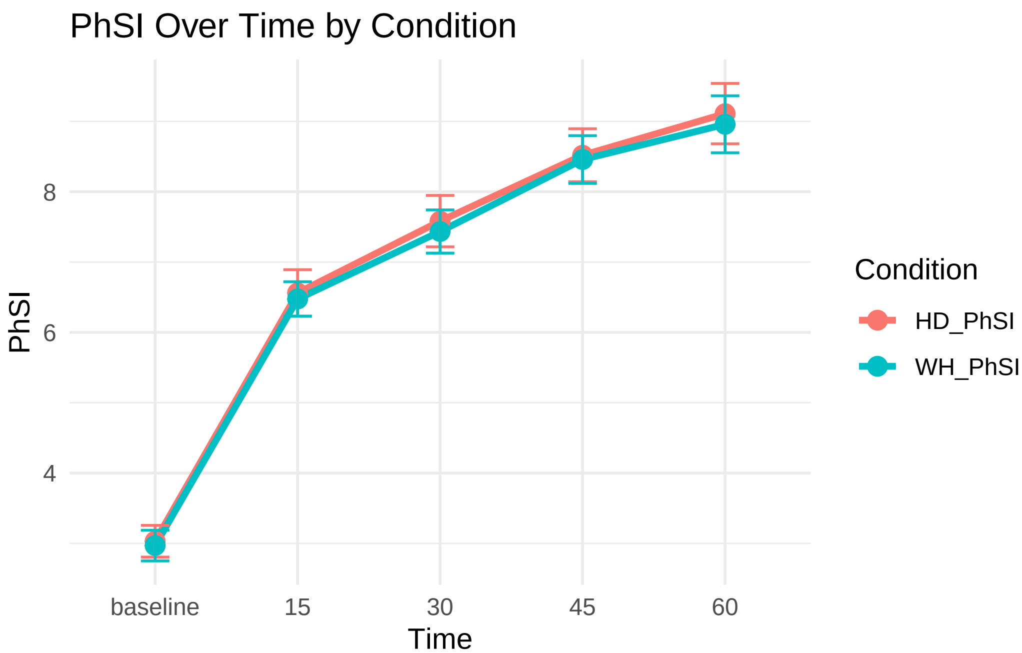


### 3.3.2 PhSI

```
# Select only PhSI-related columns and ID
df_phsi <- Data_set_for_R_project%>%
     select(ID, starts_with("HD_PhSI"), starts_with("WH_PhSI")) %>%
  pivot_longer(
            cols = -ID,
            names_to = "Condition_Time",
            values_to = "PhSI"
        ) %>%
       separate(Condition_Time, into = c("Condition", "Time"), sep = "-") %>%
       mutate(
            Time = factor(Time, levels = c("baseline", "15", "30", "45", "60")),
            Condition = factor(Condition),
            ID = factor(ID)
        )

model_phsi <- aov(PhSI ~ Condition * Time + Error(ID/(Condition*Time)), data = df_phsi)
summary(model_phsi)
```

```
Error: ID
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals  9  76.84   8.538

Error: ID:Condition
          Df Sum Sq Mean Sq F value Pr(>F)
Condition  1  0.258  0.2576   0.499  0.498
Residuals  9  4.644  0.5160

Error: ID:Time
          Df Sum Sq Mean Sq F value Pr(>F)
Time       4  456.0  114.01   295.8 <2e-16 ***
Residuals 36   13.9    0.39
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: ID:Condition:Time
               Df Sum Sq Mean Sq F value Pr(>F)
Condition:Time  4  0.041 0.01015   0.101  0.982
Residuals      36  3.635 0.10096
```

```
ggplot(df_phsi, aes(x = Time, y = PhSI, color = Condition, group = Condition)) +
       stat_summary(fun = mean, geom = "line", size = 1.2) +
       stat_summary(fun = mean, geom = "point", size = 3) +
       stat_summary(fun.data = mean_se, geom = "errorbar", width = 0.2) +
       labs(title = "PhSI Over Time by Condition", y = "PhSI", x = "Time") +
       theme_minimal()
```

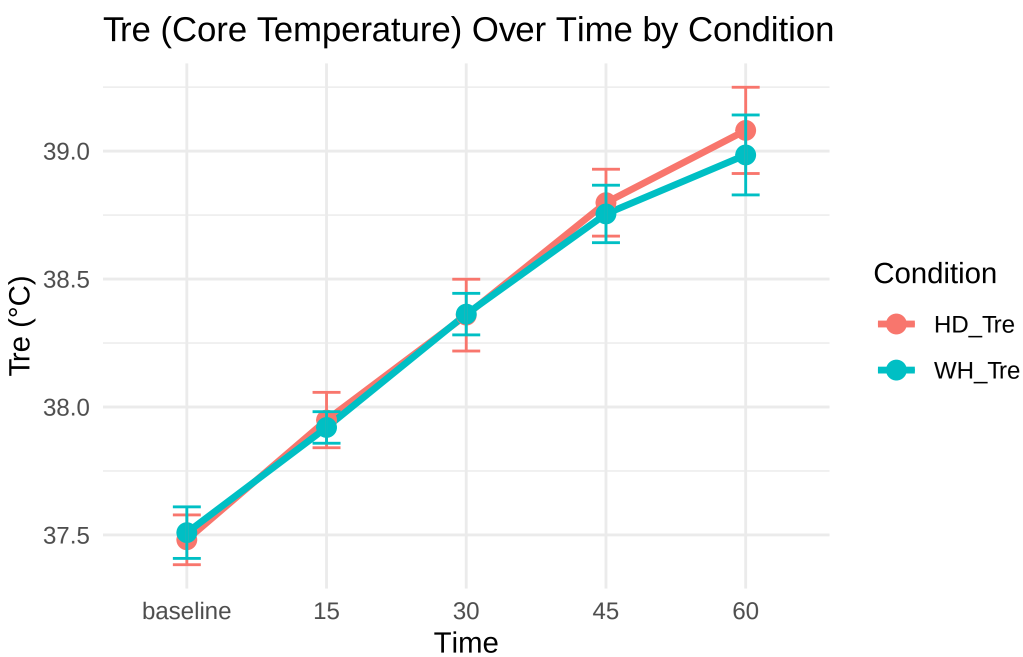



### 3.3.3 Tre

```
df_tre <- Data_set_for_R_project %>%
       select(ID, starts_with("HD_Tre"), starts_with("WH_Tre")) %>%
       pivot_longer(
             cols = -ID,
             names_to = "Condition_Time",
             values_to = "Tre"
         ) %>%
       separate(Condition_Time, into = c("Condition", "Time"), sep = "-") %>%
       mutate(
             Time = factor(Time, levels = c("baseline", "15", "30", "45", "60")),
             Condition = factor(Condition),
             ID = factor(ID)
         )
model_tre <- aov(Tre ~ Condition * Time + Error(ID/(Condition*Time)), data = df_tre)
summary(model_tre)
```

```
Error: ID
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals  9  8.078  0.8975

Error: ID:Condition
          Df Sum Sq Mean Sq F value Pr(>F)
Condition  1 0.0188 0.01877   0.173  0.687
Residuals  9 0.9772 0.10858

Error: ID:Time
          Df Sum Sq Mean Sq F value Pr(>F)
Time       4 30.954   7.738   92.63 <2e-16 ***
Residuals 36  3.007   0.084
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: ID:Condition:Time
               Df Sum Sq Mean Sq F value Pr(>F)
Condition:Time  4 0.0452 0.01130    0.46  0.765
Residuals      36 0.8845 0.02457
```

```
ggplot(df_tre, aes(x = Time, y = Tre, color = Condition, group = Condition)) +
       stat_summary(fun = mean, geom = "line", size = 1.2) +
       stat_summary(fun = mean, geom = "point", size = 3) +
       stat_summary(fun.data = mean_se, geom = "errorbar", width = 0.2) +
       labs(title = "Tre (Core Temperature) Over Time by Condition", y = "Tre (°C)", x = "Ti
       theme_minimal()
```



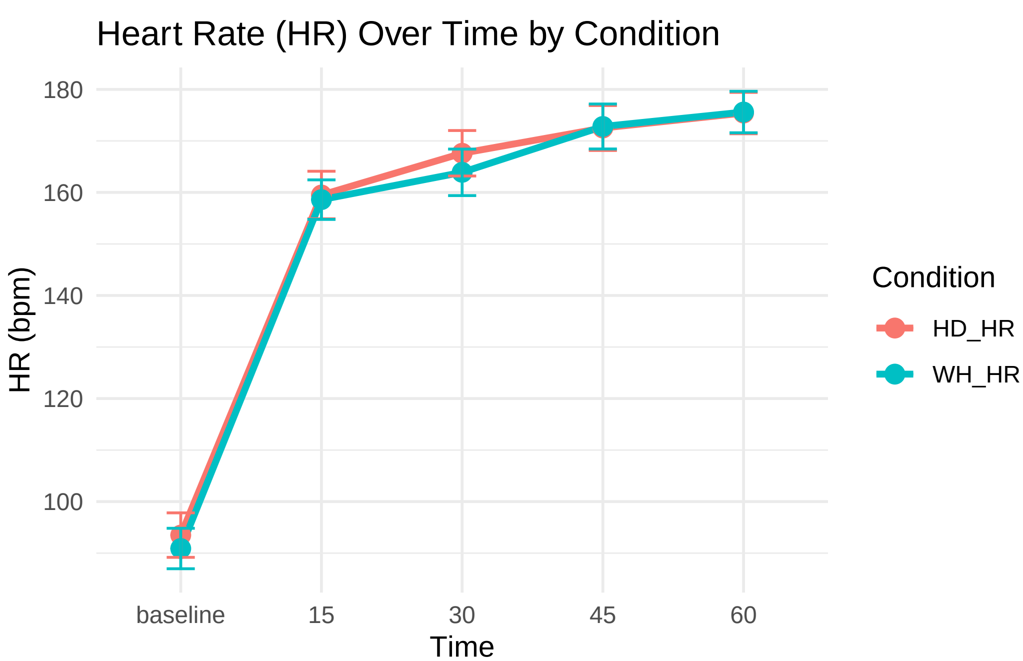

3.3.4 HR

```
df_hr <- Data_set_for_R_project %>%
       select(ID, starts_with("HD_HR"), starts_with("WH_HR")) %>%
       pivot_longer(
             cols = -ID,
             names_to = "Condition_Time",
             values_to = "HR"
         ) %>%
       separate(Condition_Time, into = c("Condition", "Time"), sep = "-") %>%
       mutate(
             Time = factor(Time, levels = c("baseline", "15", "30", "45", "60")),
             Condition = factor(Condition),
             ID = factor(ID)
         )
model_hr <- aov(HR ~ Condition * Time + Error(ID/(Condition*Time)), data = df_hr)
summary(model_hr)
```

```
Error: ID
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals  9  11590    1288

Error: ID:Condition
```

```
          Df Sum Sq Mean Sq F value Pr(>F)
Condition  1   44.9   44.89   0.699  0.425
Residuals  9  577.6   64.18

Error: ID:Time
          Df Sum Sq Mean Sq F value Pr(>F)
Time       4  95763   23941   239.1 <2e-16 ***
Residuals 36   3604     100
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: ID:Condition:Time
               Df Sum Sq Mean Sq F value Pr(>F)
Condition:Time  4   62.1   15.52   1.244   0.31
Residuals      36  448.9   12.47
```

```
ggplot(df_hr, aes(x = Time, y = HR, color = Condition, group = Condition)) +
       stat_summary(fun = mean, geom = "line", size = 1.2) +
       stat_summary(fun = mean, geom = "point", size = 3) +
       stat_summary(fun.data = mean_se, geom = "errorbar", width = 0.2) +
       labs(title = "Heart Rate (HR) Over Time by Condition", y = "HR (bpm)", x = "Time") +
       theme_minimal()
```

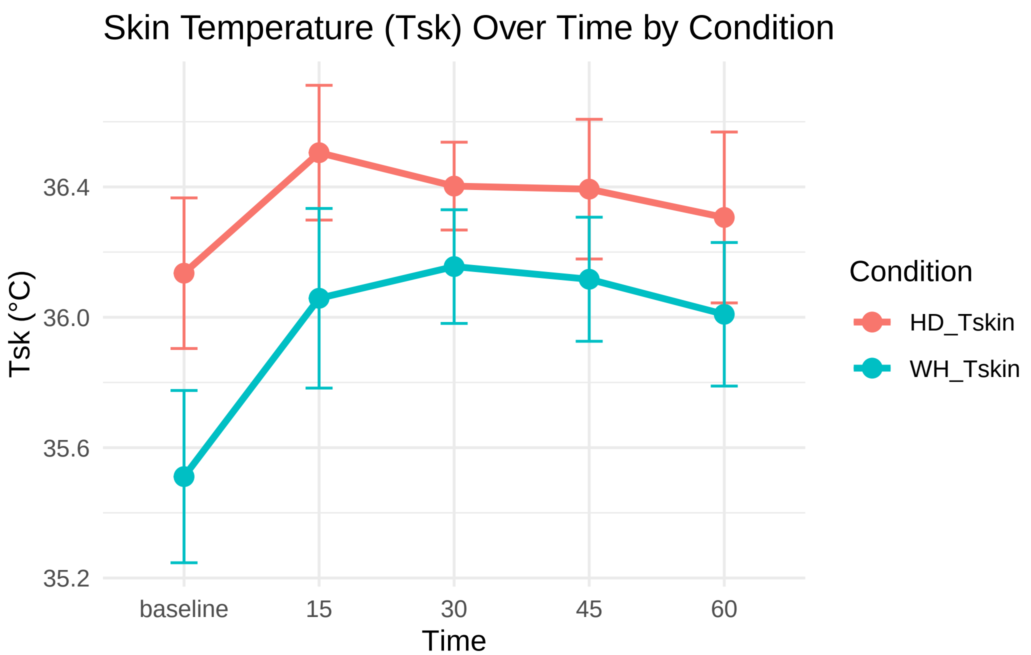



3.3.5 Tsk

```r
df_tsk <- Data_set_for_R_project %>%
       select(ID, starts_with("HD_Tsk"), starts_with("WH_Tsk")) %>%
       pivot_longer(
             cols = -ID,
             names_to = "Condition_Time",
             values_to = "Tsk"
         ) %>%
       separate(Condition_Time, into = c("Condition", "Time"), sep = "-") %>%
       mutate(
             Time = factor(Time, levels = c("baseline", "15", "30", "45", "60")),
             Condition = factor(Condition),
             ID = factor(ID)
         )
model_tsk <- aov(Tsk ~ Condition * Time + Error(ID/(Condition*Time)), data = df_tsk)
summary(model_tsk)
```

```
Error: ID
          Df Sum Sq Mean Sq F value Pr(>F)
Condition  1  0.226  0.2256   0.076   0.79
Residuals  8 23.707  2.9633

Error: ID:Condition
          Df Sum Sq Mean Sq F value Pr(>F)
Condition  1  3.991   3.991   6.169 0.0379 *
Residuals  8  5.175   0.647
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: ID:Time
               Df Sum Sq Mean Sq F value  Pr(>F)
Time            4  2.779  0.6947   4.238 0.00727 **
Condition:Time  4  0.073  0.0182   0.111 0.97780
Residuals      32  5.246  0.1639
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Error: ID:Condition:Time
               Df Sum Sq Mean Sq F value Pr(>F)
Condition:Time  4  0.491  0.1226   0.904  0.473
Residuals      32  4.341  0.1357
```

```r
ggplot(df_tsk, aes(x = Time, y = Tsk, color = Condition, group = Condition)) +
  stat_summary(fun = mean, geom = "line", size = 1.2) +
  stat_summary(fun = mean, geom = "point", size = 3) +
  stat_summary(fun.data = mean_se, geom = "errorbar", width = 0.2) +
  labs(title = "Skin Temperature (Tsk) Over Time by Condition",
       y = "Tsk (°C)", x = "Time") +
  theme_minimal()
```




### 3.4 Peason correlation

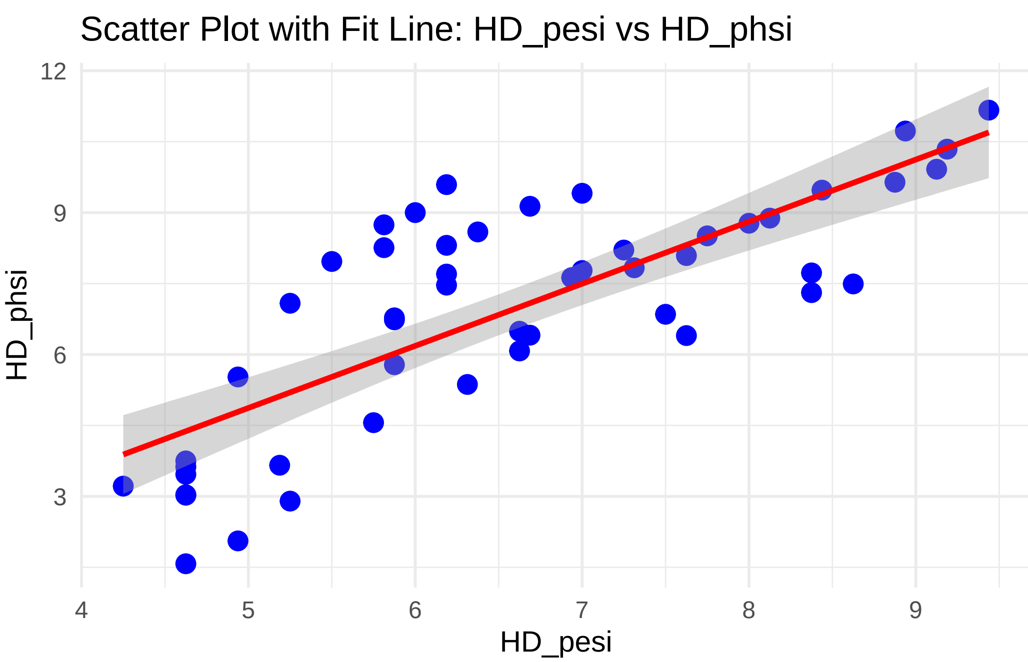
#### 3.4.1 PeSI & PhSI in HD

```r
Lenght_format_R_project <- read_excel("Lenght_format_R project.xlsx")
cor.test(Lenght_format_R_project$HD_pesi, Lenght_format_R_project$HD_phsi, method = "pearson"
```

```
    Pearson's product-moment correlation

data:  Lenght_format_R_project$HD_pesi and Lenght_format_R_project$HD_phsi
t = 8.6908, df = 48, p-value = 2.031e-11
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
```

```
 0.6436939 0.8707652
sample estimates:
      cor
0.7819408
```

```r
library(ggplot2)
ggplot(Lenght_format_R_project, aes(x = HD_pesi, y = HD_phsi)) +
  geom_point(color = "blue", size = 3) +
  geom_smooth(method = "lm", color = "red", se = TRUE) +
  labs(
    title = "Scatter Plot with Fit Line: HD_pesi vs HD_phsi",
    x = "HD_pesi",
    y = "HD_phsi"
  ) +
  theme_minimal()
```



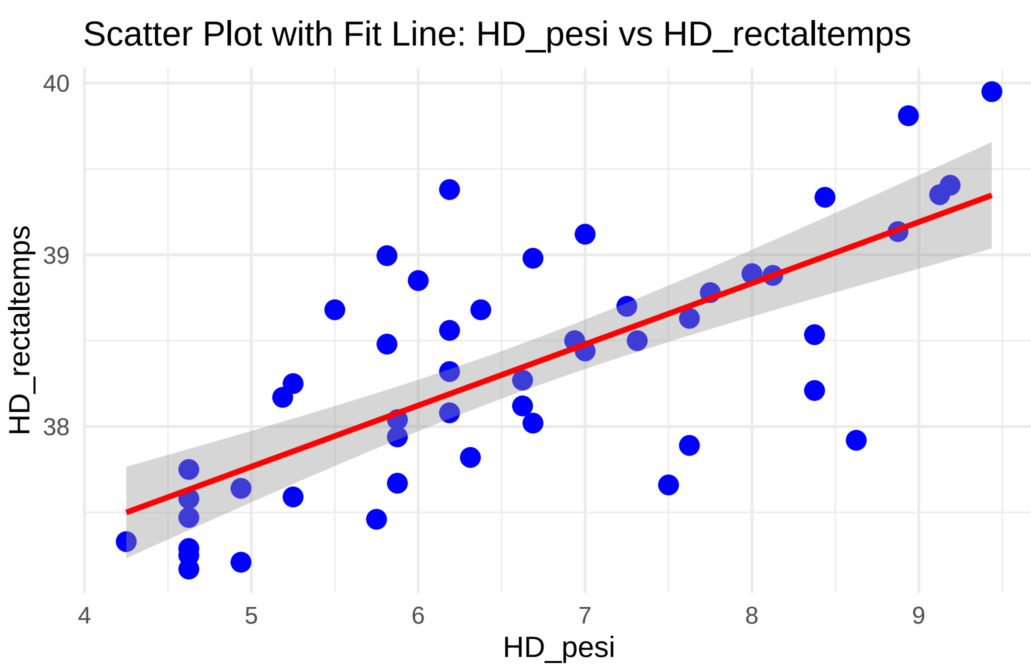

3.4.2 PeSI & Tre in HD

```r
cor.test(Lenght_format_R_project$HD_pesi, Lenght_format_R_project$HD_rectaltemps, method = "
```

```
	Pearson's product-moment correlation
```

```
data:  Lenght_format_R_project$HD_pesi and Lenght_format_R_project$HD_rectaltemps
t = 7.3565, df = 48, p-value = 2.093e-09
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.5638987 0.8367729
sample estimates:
      cor
0.7279824
```

```
ggplot(Lenght_format_R_project, aes(x = HD_pesi, y = HD_rectaltemps)) +
  geom_point(color = "blue", size = 3) +
  geom_smooth(method = "lm", color = "red", se = TRUE) +
  labs(
    title = "Scatter Plot with Fit Line: HD_pesi vs HD_rectaltemps",
    x = "HD_pesi",
    y = "HD_rectaltemps"
  ) +
  theme_minimal()
```

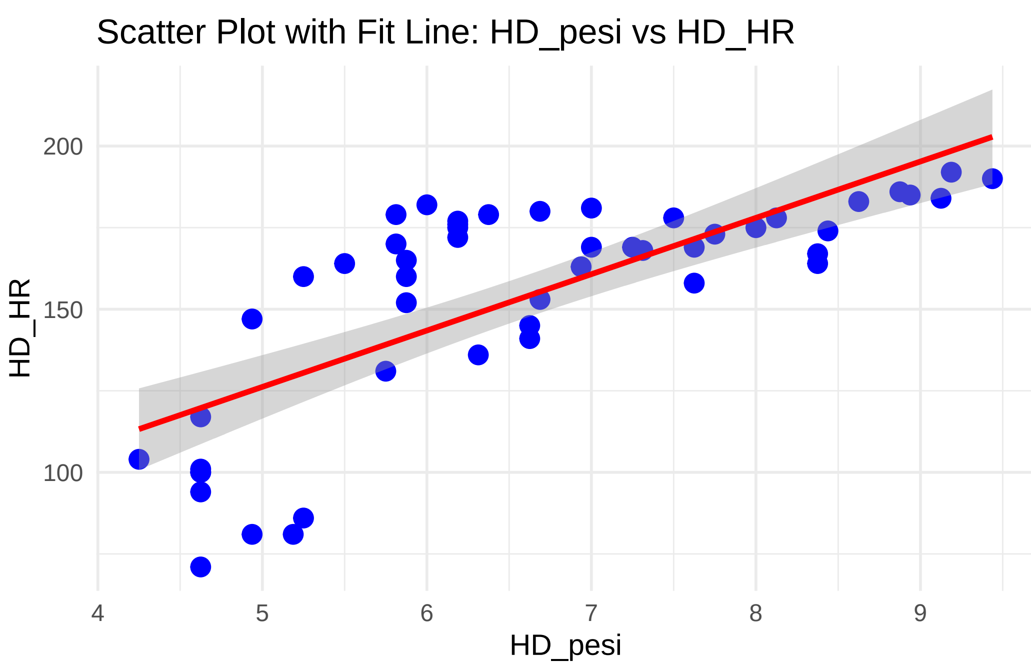



3.4.3 PeSI & HR in HD

```
cor.test(Lenght_format_R_project$HD_pesi, Lenght_format_R_project$HD_HR, method = "pearson")
```

```
	Pearson's product-moment correlation

data:  Lenght_format_R_project$HD_pesi and Lenght_format_R_project$HD_HR
t = 7.6221, df = 48, p-value = 8.239e-10
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.5813909 0.8444089
sample estimates:
      cor
0.7399873
```

```r
ggplot(Lenght_format_R_project, aes(x = HD_pesi, y = HD_HR)) +
  geom_point(color = "blue", size = 3) +
  geom_smooth(method = "lm", color = "red", se = TRUE) +
  labs(
    title = "Scatter Plot with Fit Line: HD_pesi vs HD_HR",
    x = "HD_pesi",
    y = "HD_HR"
  ) +
  theme_minimal()
```

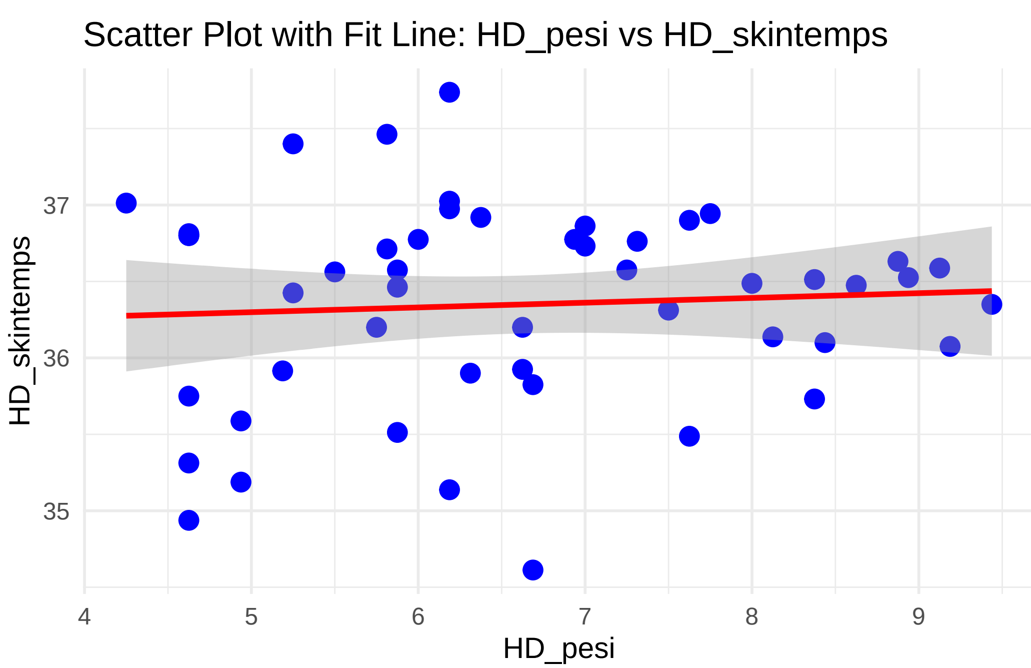



3.4.4 PeSI & Tsk in HD

```r
cor.test(Lenght_format_R_project$HD_pesi, Lenght_format_R_project$HD_HR, method = "pearson")
```

```
	Pearson's product-moment correlation

data:  Lenght_format_R_project$HD_pesi and Lenght_format_R_project$HD_HR
t = 7.6221, df = 48, p-value = 8.239e-10
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.5813909 0.8444089
sample estimates:
      cor 
0.7399873 
```

```r
ggplot(Lenght_format_R_project, aes(x = HD_pesi, y = HD_skintemps)) +
  geom_point(color = "blue", size = 3) +
  geom_smooth(method = "lm", color = "red", se = TRUE) +
  labs(
    title = "Scatter Plot with Fit Line: HD_pesi vs HD_skintemps",
    x = "HD_pesi",
    y = "HD_skintemps"
  ) +
  theme_minimal()
```

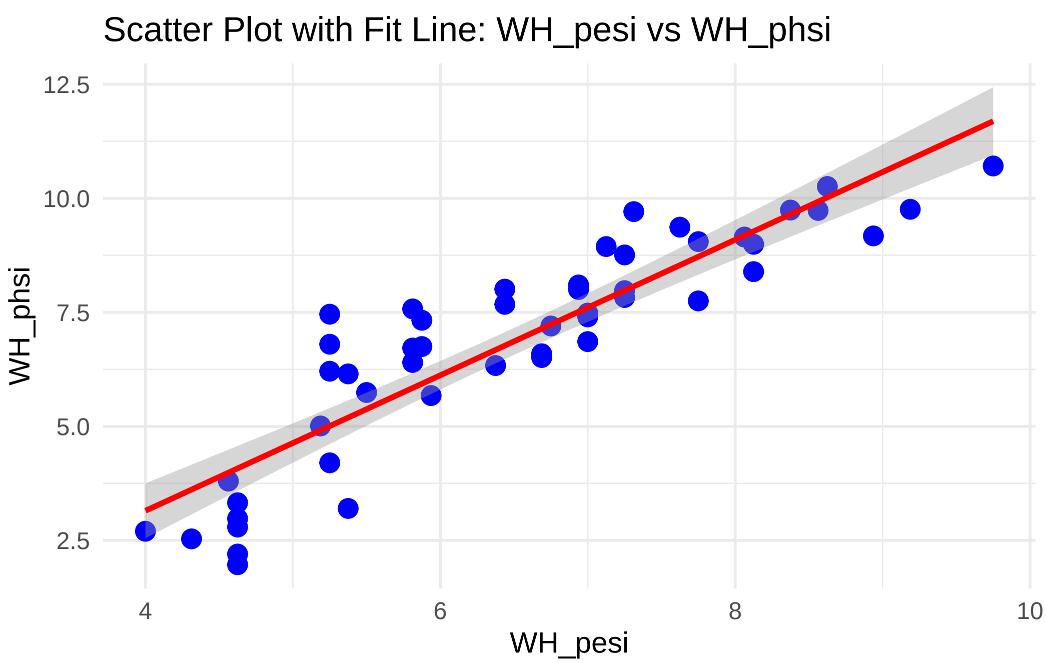


3.4.5 PeSI & PhSI in WH

```r
cor.test(Lenght_format_R_project$WH_pesi, Lenght_format_R_project$WH_phsi, method = "pearson"
```

```
	Pearson's product-moment correlation

data:  Lenght_format_R_project$WH_pesi and Lenght_format_R_project$WH_phsi
t = 14.223, df = 48, p-value < 2.2e-16
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.8278258 0.9417124
sample estimates:
      cor
0.8990186
```

```r
ggplot(Lenght_format_R_project, aes(x = WH_pesi, y = WH_phsi)) +
  geom_point(color = "blue", size = 3) +
  geom_smooth(method = "lm", color = "red", se = TRUE) +
  labs(
    title = "Scatter Plot with Fit Line: WH_pesi vs WH_phsi",
    x = "WH_pesi",
    y = "WH_phsi"
  ) +
  theme_minimal()
```



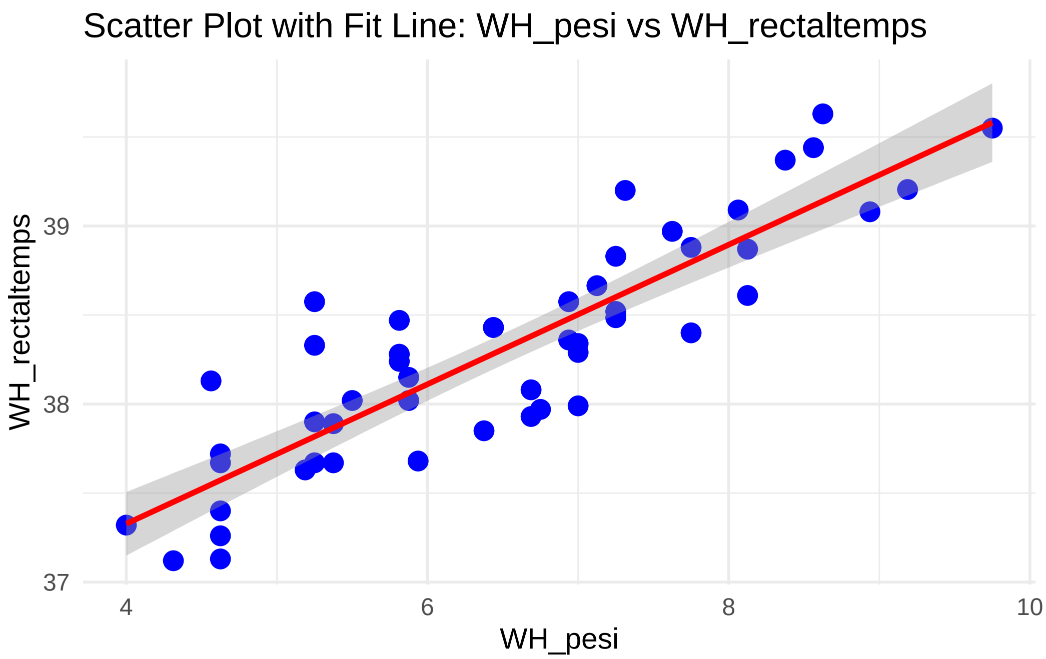

3.4.6 PeSI & Tre in WH

```
cor.test(Lenght_format_R_project$WH_pesi, Lenght_format_R_project$WH_rectaltemps, method = "p
```

```
	Pearson's product-moment correlation

data:  Lenght_format_R_project$WH_pesi and Lenght_format_R_project$WH_rectaltemps
t = 12.644, df = 48, p-value < 2.2e-16
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.7919370 0.9286358
sample estimates:
      cor
0.8769707
```

```
ggplot(Lenght_format_R_project, aes(x = WH_pesi, y = WH_rectaltemps)) +
  geom_point(color = "blue", size = 3) +
  geom_smooth(method = "lm", color = "red", se = TRUE) +
  labs(
    title = "Scatter Plot with Fit Line: WH_pesi vs WH_rectaltemps",
    x = "WH_pesi",
    y = "WH_rectaltemps"
```

```
  ) +
  theme_minimal()
```



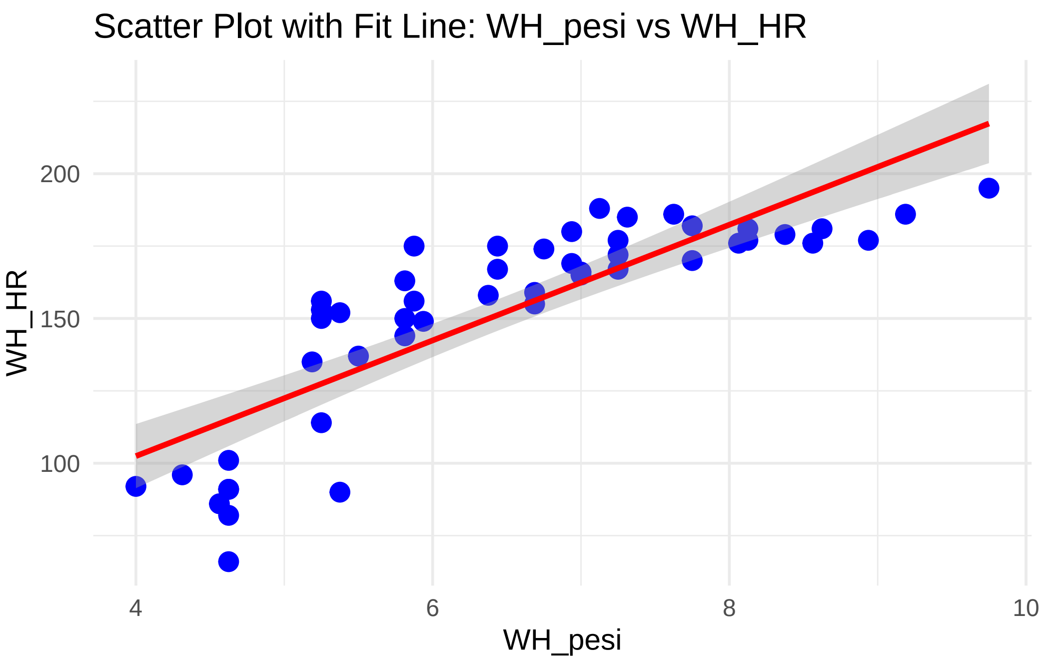

3.4.7 PeSI & HR in WH

```
cor.test(Lenght_format_R_project$WH_pesi, Lenght_format_R_project$WH_HR, method = "pearson")
```

```
	Pearson's product-moment correlation

data:  Lenght_format_R_project$WH_pesi and Lenght_format_R_project$WH_HR
t = 10.393, df = 48, p-value = 7.073e-14
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.7205999 0.9015938
sample estimates:
     cor
0.832056
```

```
ggplot(Lenght_format_R_project, aes(x = WH_pesi, y = WH_HR)) +
  geom_point(color = "blue", size = 3) +
  geom_smooth(method = "lm", color = "red", se = TRUE) +
```

```
  labs(
    title = "Scatter Plot with Fit Line: WH_pesi vs WH_HR",
    x = "WH_pesi",
    y = "WH_HR"
  ) +
  theme_minimal()
```

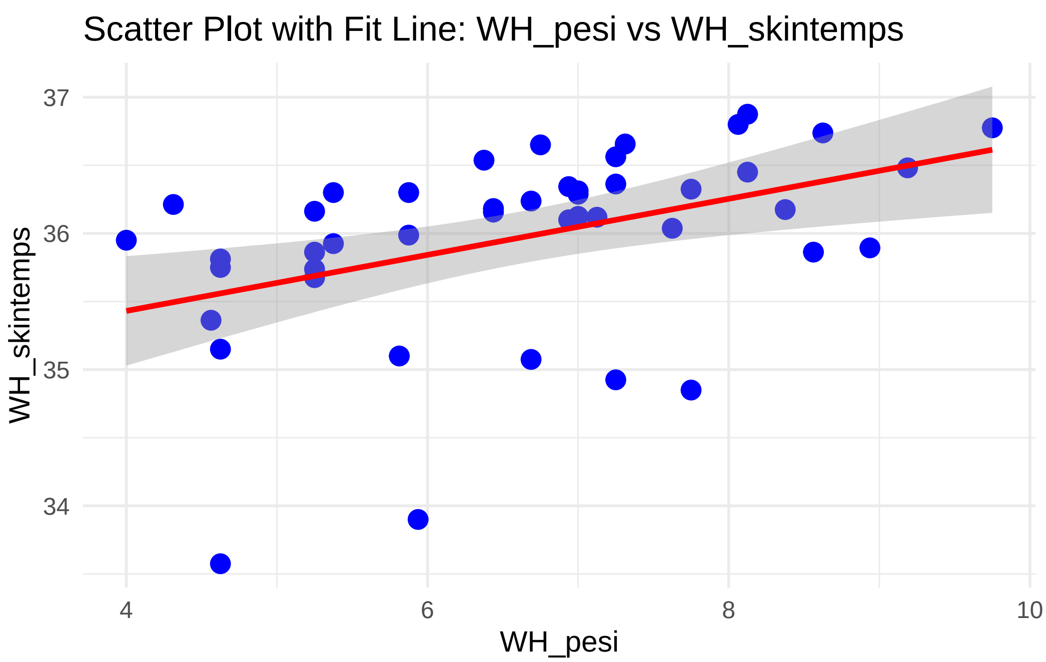



3.4.8 PeSI & Tsk in WH

```
cor.test(Lenght_format_R_project$WH_pesi, Lenght_format_R_project$WH_skintemps, method = "pea
```

```
	Pearson's product-moment correlation

data:  Lenght_format_R_project$WH_pesi and Lenght_format_R_project$WH_skintemps
t = 3.0784, df = 43, p-value = 0.003616
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.1501563 0.6388086
sample estimates:
      cor
0.4249597
```

```r
ggplot(Lenght_format_R_project, aes(x = WH_pesi, y = WH_skintemps)) +
  geom_point(color = "blue", size = 3) +
  geom_smooth(method = "lm", color = "red", se = TRUE) +
  labs(
    title = "Scatter Plot with Fit Line: WH_pesi vs WH_skintemps",
    x = "WH_pesi",
    y = "WH_skintemps"
  ) +
  theme_minimal()
```




## 4. Discussion and Future Direction

Although the PeSI has been validated as an analogue of the PhSI in firefighters and occupational settings at varying environmental conditions, the current study is the first to determine the ability of PeSI to predict PhSI in two different types of uncompenable heat stress (HD and WH) with equivalent WBGT during the moderate to heavy intensity exercise. The primary findings of this study were 1): PeSI adequately differentiates physiological strain in varying environments with equivalent WBGT; 2): a moderate to strong correlation between PhSI and PeSI was observed at HD and WH conditions, as well as between PeSI and $T_{re}$, HR.

Further, in consideration of the essential effect of clothing on human's thermoregulation in addition to the demand for many field settings (e.g., firefights, military operations, and athletics), future studies should validate the relationship between perceptual and physiological parameters with different clothing assembles during prolonged heat stress exposure.

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