Sequencia de analise da Parte 1 - Apenas com os dados dos não videntes:  
  
- Para Carga Mental do NASA:  
~~A) Tabela 8.7 como está - com os valores brutos  
B) Tabela 8.8 como está.  
C) Figura 8.5 como está - com o bar plot por método e por round  
D) Figura 8.9 como está - box plot por método + Figura com box plot por  
round  
E) Resultado da ANOVA considerando 2 fatores (round e method) e possivel  
interacao entre fatores - Acho que basta o p-value de cada caso (round,  
method e interacao round-method).  
F) Incluir shapiro wilk de todos os dados + Barlett por fator (round e  
method) -> Confirmar com o Sutério se é isso mesmo.~~ (Substitui pelos qqplot e gráfico de dispersão dos residuos)  
~~G) Tabela 8.15 comparacao par a par dos métodos -> incluir uma coluna  
com o p-value~~ O livro que to usando não cita um p-value pro teste de Fisher  
~~H) Tabela 8.9 com média do DELTA (nao calcular %, usar valor absoluto do  
delta)  
I) Resultado da ANOVA para o Delta, com apenas 1 fator (method).  
J) Incluir shapiro wilk de todos delta + Barlett -> Confirmar com o  
Sutério se é isso mesmo.~~ (Substitui pelos qqplot e gráfico de dispersão dos resíduos) ~~K) Tabela 8.13 de comparacao par a par dos delta -> incluir uma coluna  
com o p-value~~   
~~- Para o NASA TLX completo e SAGAT adaptado, seguir os mesmos passos A)  
a K) .~~  
  
~~- Para o Questionario, colocar apenas itens A a E.~~  
  
- Para o ECG - BPM:  
~~Tenho a impressao que nao faz sentido comparar com a baseline (a  
baseline deveria ser em repouso, deveria ser menor, com certeza eles  
estavam ansiosos e isso afetou o resultado). Talvez faça mais sentido  
calcular a media do período inteiro (sem a baseline) e calcular o delta  
em relacao a media (sem porcentagem). Se fizermos isso, talvez o BVI 2  
nao esteja tao fora.~~

A) ~~Colocar Tabela de dados pag 17 com o valor de delta ao inves do valor  
absoluto e sem a baseline~~.  
B) ~~Colocar o bar plot do delta~~C) ~~Tabela 8.33 colocar a média do delta (nao da porcentagem)~~D) ~~Figura 8.24, colocar box plot por metodo e do lado colocar por round~~E) ~~Colocar ANOVA do delta com dois fatores (metodo e round)~~F) ~~Incluir shapiro wilk de todos os dados + Barlett por fator (round e  
method)~~ (Substitui pelos qqplot e gráfico de dispersão dos residuos)  
G) ~~Tabela de comparacao par a par dos métodos~~  
  
~~- Para o ECG - SDNN e GSR, seguir o mesmo procedimento do ECG-BPM, itens  
A) a G). Nao entendi o que é o GSR acumulado. Tiraria essa parte.~~  
~~Sequencia para a parte 2 - com dados dos BVI e nao BVI mas sem dados do  
método BASE:  
-> Repetir a mesma análise da parte 1, colocando lado a lado os  
resultados do BVI e do nao-BVI SEM os dados do método BASE para ambos os  
BVI e nao-BVI.~~

# 8 Results’ analysis and discussion

Throughout the experiment, three data sources were gathered from the participants, and this chapter will show their values, explain the process to analyze the data and discuss their results. This chapter is divided into two sections, each one related to one of the objectives:

* Evaluation of assistive device from a human factors’ perspective in a virtual environment;
* Comparison between BVI users and sighted users.

From this point, the data from the blind participants will be called the“Blind”sample and the data from the sighted participants will be called the “Sight” sample.

## 8.1 Evaluation of assistive device from a human factors’ perspective in a virtual environment

### 8.1.1 Subjective data

There were 3 different questionnaires in this experiment. Each of these questionnaires was meant to verify one of the experiment goals:

* NASA-TLX;

Meant to verify the mental workload of the user. Is expected that after each“First” round, the mental workload would decrease and that one of the methods would have the least mental workload.

* Adapted SAGAT;

Meant to verify the situation awareness and the mental map of the user. Is expected to notice an increase from the“First”round to the“Return”round at each method.

* Guidance method’s questionnaire.

Meant to assess the user experience with each method.

#### 8.1.1.1 NASA-TLX

It is possible to analyze the mental workload using NASA-TLX in two different ways. The first is by analyzing only the mental demand scale and the second is by analyzing the NASA-TLX score, which is an average of the scales’ rating.

##### 8.1.1.1.1 Analysis of the mental demand scale

The Table 8.1 presents the mental demand averages by each blinded participant on each scene and they are plotted in the Figures 8.1. The Figure 8.1 shows a systematic reduction on the perceived mental demand in all methods between the rounds. This shows that the participants started to get used with the device after the first use.

TABLE 8.1 – Mental demand felled by the blinded participants.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Round |  |  |  |  |  |
| 001C | First | 3 | 1 | 14 | 3 | 6 |
|  | Return | 1 | 1 | 10 | 2 | 6 |
| 002C | First | 5 | 1 | 1 | 10 | 12 |
|  | Return | 1 | 1 | 1 | 10 | 3 |
| 003C | First | 5 | 5 | 5 | 8 | 1 |
|  | Return | 3 | 1 | 1 | 2 | 1 |
| 004C | First | 9 | 10 | 15 | 10 | 10 |
|  | Return | 7 | 10 | 14 | 8 | 10 |

The Figure 8.2 presents a box plot with the mental demand grouped by method. This Figure shows that there may be two different groups, one with lower demand formed by the ”Base”and the ”Audio”method, and another with the higher demand. The Figure 8.3 presents a box plot with the mental demand grouped by the rounds. This figure shows that both rounds have similar variations.

The Table 8.2 shows the average mental demand in the“blind”sample and is possible to notice how the average perceived mental demand by the “blind” sample was lower during the “Audio” and the “Base” methods.

The Figures 8.4 and 8.5 shows the distribution and variance of the Table 8.1. These Figures shows that the data are normally distributed and that the methods have a similar

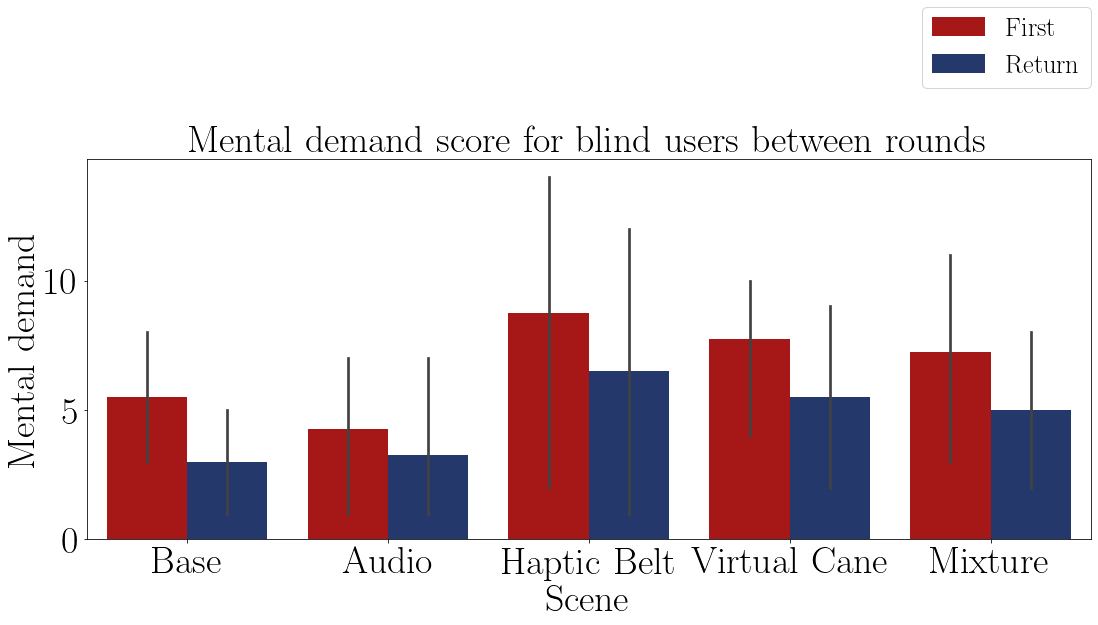


FIGURE 8.1 – Barplot of the average mental demand of the blind participants on each method.

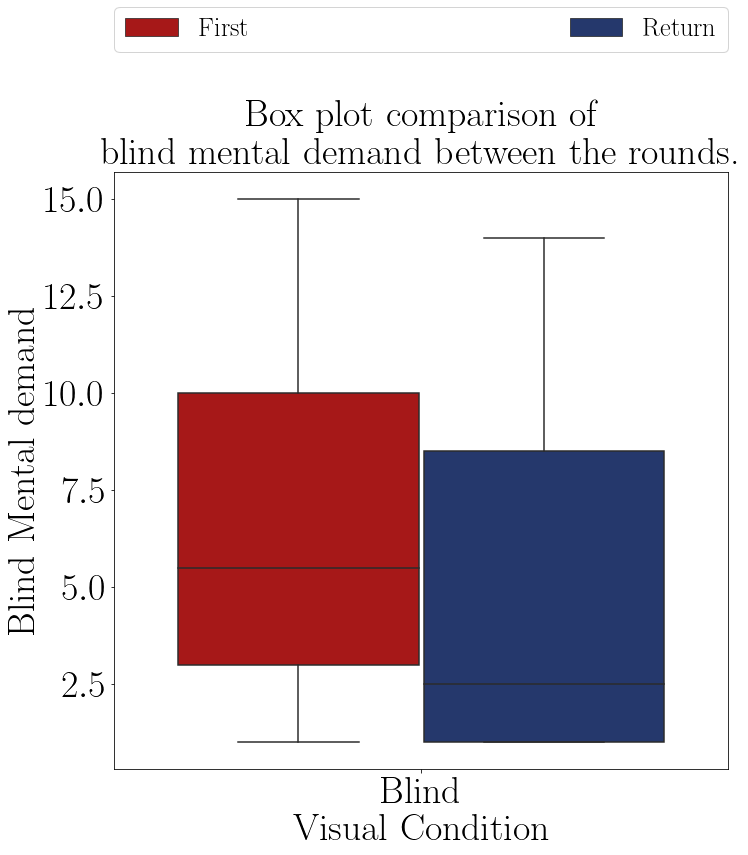
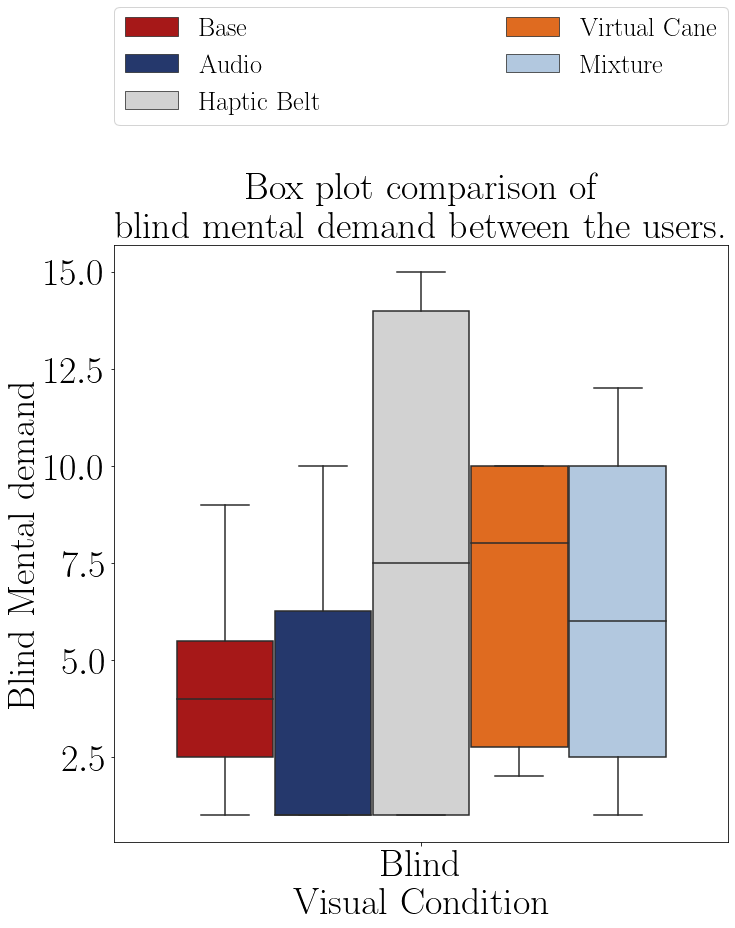


FIGURE 8.3 – Boxplot of the mental demand FIGURE 8.2 – Boxplot of the mental demand of the blind participants grouped by round. of the blind participants grouped by method.

TABLE 8.2 – Mental demand average grouped by participant and visual condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 4.25 | 3.75 | 7.62 | 6.62 | 6.125 |

variance. The Table 8.3 shows the Anova test p-values of the mental demand of the ”blind” sample between the guidance methods. The method’s and the round’s p-values indicates that there is no influence from them in the mental demand. The interaction between the methods and the round also does not influences the mental demand.

The Table 8.4 shows the average of the mental demand variation between the rounds.

TABLE 8.3 – Anova p-value for the mental demand average on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 298.475 | 3 | 99.492 | 8.133 |  |
| Methods | 85.150 | 4 | 21.288 | 1.740 | 0.170 |
| Rounds | 42.025 | 1 | 42.025 | 3.436 | 0.075 |
| Interaction | 2.850 | 4 | 0.712 | 0.058 | 0.993 |
| Experimental Error | 330.275 | 27 | 12.232 |  |  |
| Total | 758.775 | 39 |  |  |  |

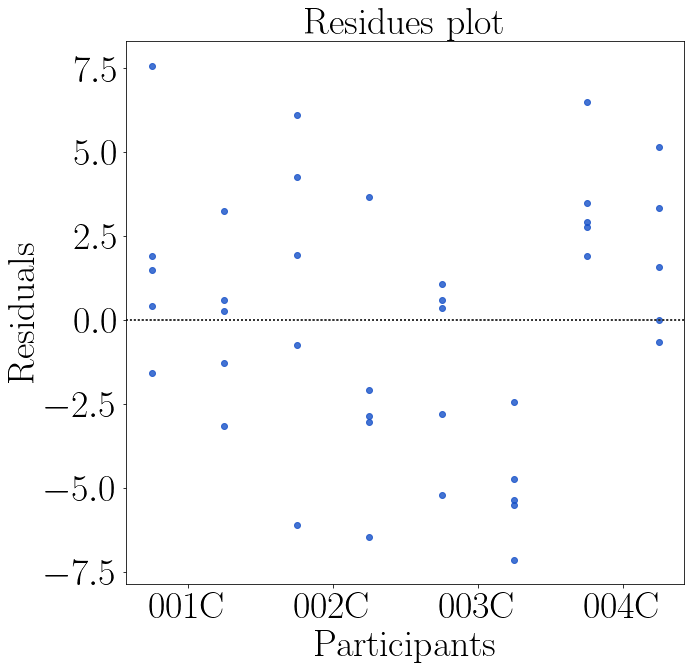
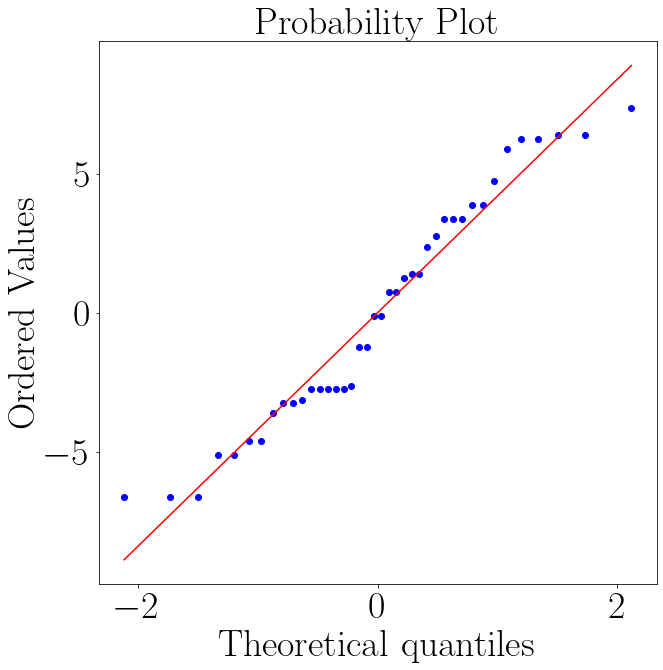


FIGURE 8.5 – Residual plot of the mental FIGURE 8.4 – QQ plot of the mental demand demand score the blind participants on each of the blind participants on each method. method.

This table shows that the mental demand variation from the “Audio” has the lower variation, and the rest are similar variations.

TABLE 8.4 – Mental demand variation grouped by participant and visual condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | -2.5 | -1.0 | -2.2 | -2.2 | -2.2 |

The Figures 8.6 and 8.7 shows the distribution and variance of the mental demand variation of the Table 8.1. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.5 shows the Anova test p-value of the mental demand of the ”blind” sample between the guidance methods. The p-value indicates that there is no influence of the methods in the variation of mental demand between the rounds.

To close up, according to the ANOVA test at Table 8.3 there is no influence in the tested methods in the participants mental demand, but at the Figure 8.2 it is posible to notice that there is at least two different groups of mental demand reactions, one formed by

TABLE 8.5 – Anova p-value for the mental demand variation on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (blocks) | 15.750 | 3 | 1.425 | 0.674 |  |
| Method | 5.700 | 4 | 5.250 | 0.183 | 0.943 |
| Experimental error | 93.500 | 12 | 7.792 |  |  |
| Total | 114.950 | 19 |  |  |  |

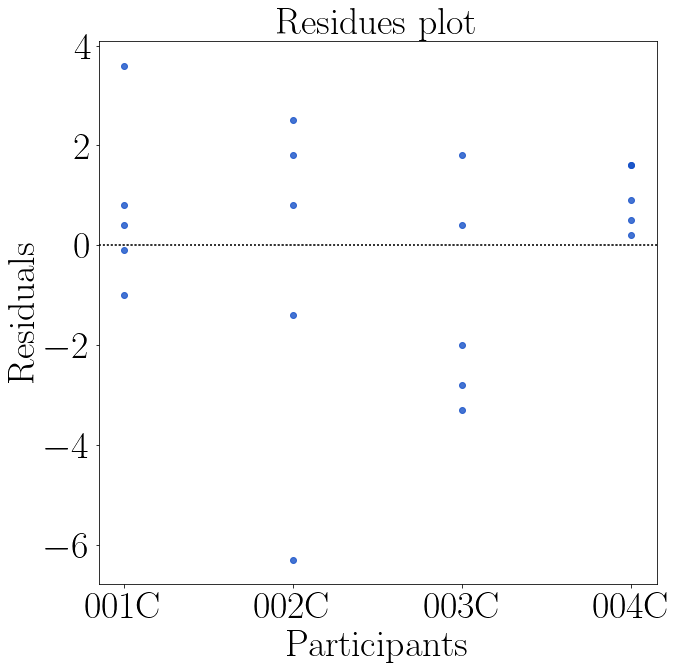
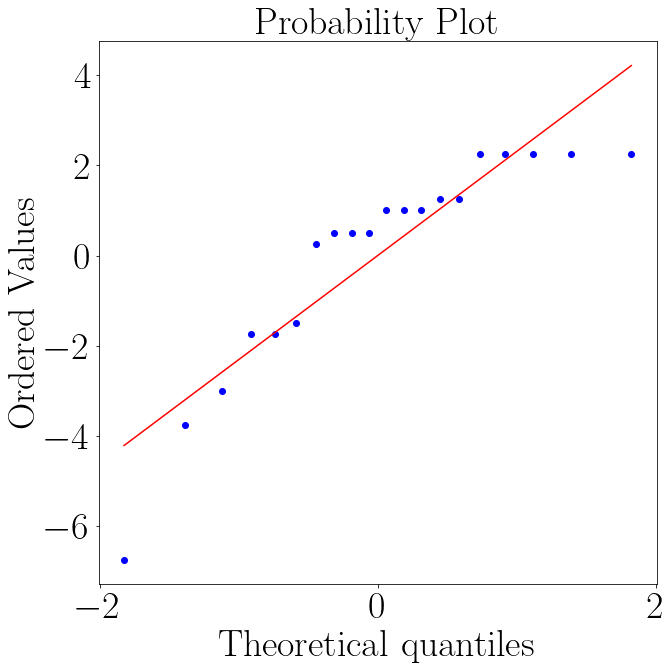


FIGURE 8.6 – Residual plot of the mental de- FIGURE 8.7 – Residual plot of the mental demand variation of the blind participants on each mand variation of the sighted participants on method. each method.

the ”Base”and the ”Audio”methods and another formed by the rest of the methods. The first group has lower mental demand than the last. That could mean that the presence of a haptic device increases the mental demand of the navigation activity for the BVI users.

This was not reflected in the ANOVA results because of the small sample size.

##### 8.1.1.1.2 Analysis of the NASA-TLX score

The Table 8.6 presents the NASA-TLX score averages by each blinded participant on each scene and they are plotted in the Figures 8.8. The Figure 8.8 shows a similar behaviour of the mental demand barplot at Figure 8.1, all NASA-TLX score decreased from the ”First” to the ”Return” round. This a kind of learning between the rounds.

The Figure 8.9 presents a box plot with the NASA-TLX score grouped by method. This Figure shows it is possible to split the methods in two different groups, one with lower demand formed by the ”Base”and the ”Audio”method, and another with the higher demand, similar as it was with the mental demand in the 8.2. It appears that the presence of the an haptic device elevated the NASA-TLX score. The Figure 8.10 presents a box plot with the NASA-TLX score grouped by the rounds. This figure shows that both rounds have similar variations.

TABLE 8.6 – NASA-TLX score felled by the blinded participants.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Round |  |  |  |  |  |
| 001C | First | 4.833 | 4.000 | 8.833 | 5.167 | 6.333 |
|  | Return | 4.167 | 4.000 | 6.667 | 4.500 | 6.167 |
| 002C | First | 6.333 | 4.833 | 4.833 | 9.000 | 7.000 |
|  | Return | 4.500 | 4.833 | 4.833 | 7.000 | 5.167 |
| 003C | First | 4.000 | 4.000 | 5.333 | 6.667 | 3.500 |
|  | Return | 4.000 | 3.833 | 3.667 | 3.500 | 3.500 |
| 004C | First | 9.833 | 10.000 | 12.667 | 9.667 | 11.000 |
|  | Return | 8.667 | 9.167 | 11.667 | 9.333 | 10.833 |

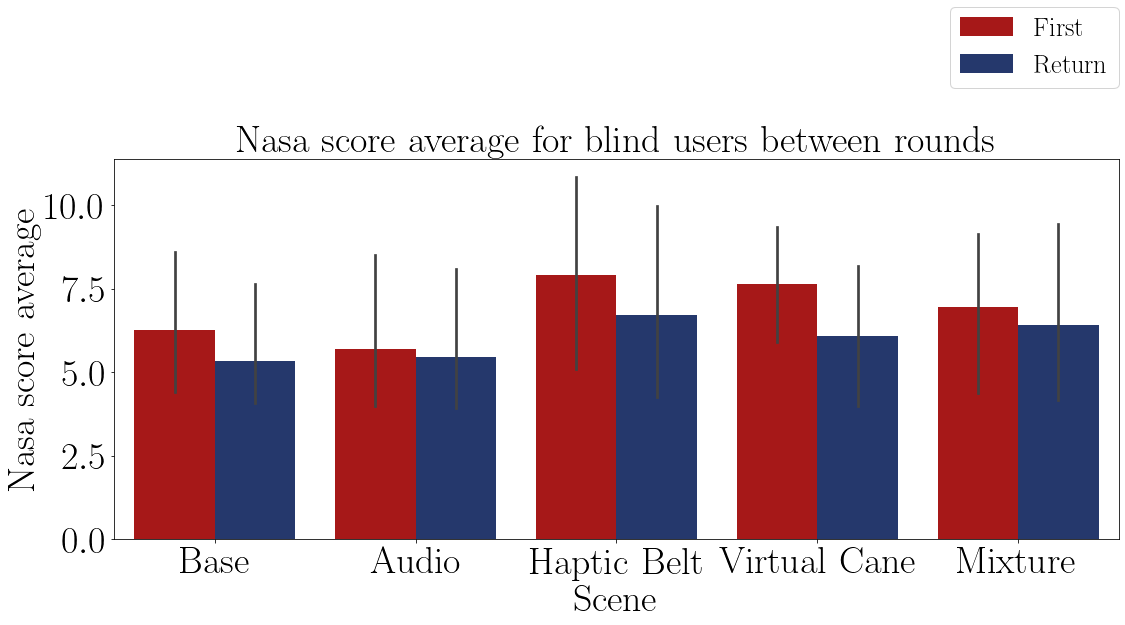


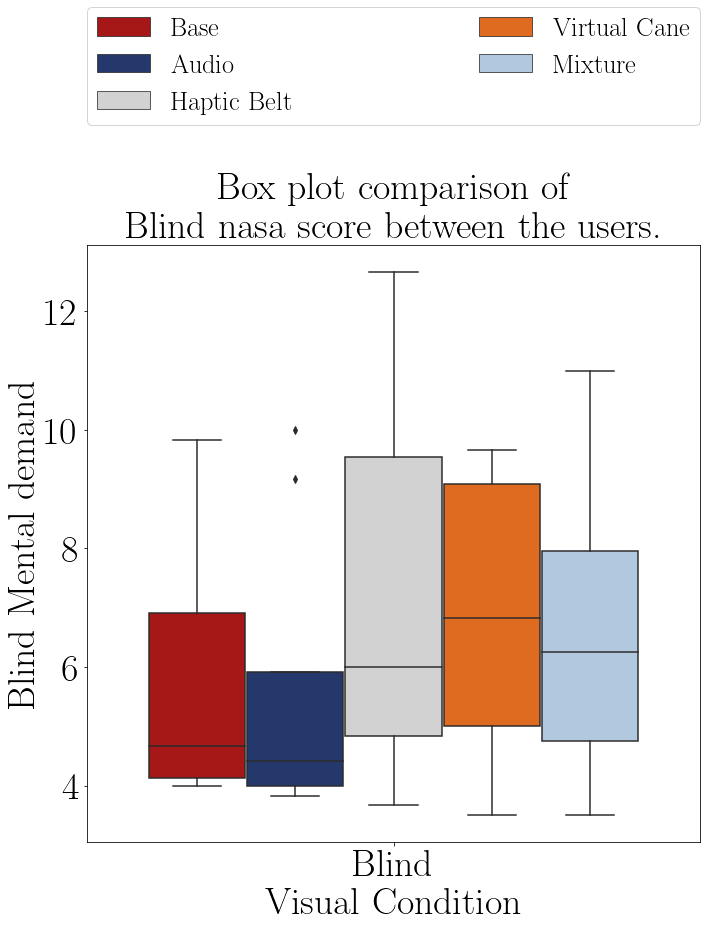
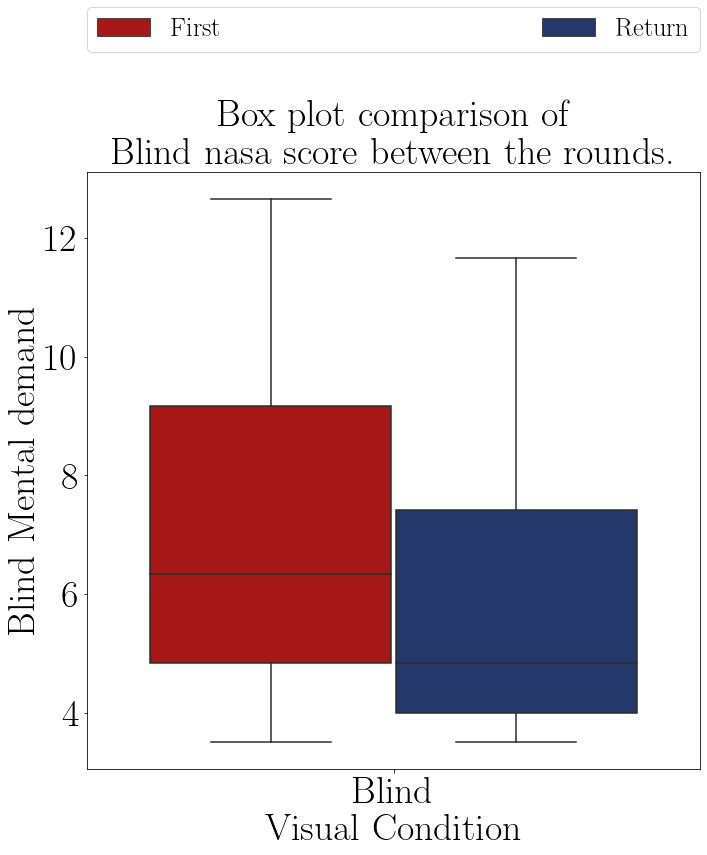
FIGURE 8.8 – Barplot of the average NASA-TLX score of the blind participants on each method.

The Table 8.7 shows the average NASA-TLX score in the“blind”sample and is possible to notice how the average score by the “blind” sample was lower during the “Audio” and the “Base” methods.

TABLE 8.7 – Average NASA-TLX score of the blind participants

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 5.79 | 5.58 | 7.31 | 6.85 | 6.688 |

The Figures 8.11 and 8.12 shows the distribution and variance of the Table 8.6. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.8 shows the Anova test p-value of the NASA-TLX score of the ”blind”sample between the guidance methods. The p-values indicates that some methods

 FIGURE 8.10 – Residual plot of the NASAFIGURE 8.9 – QQ plot of the NASA-TLX score TLX score the blind participants on each of the blind participants on each method. method.

have influence on the NASA-TLX score and that the rounds also influences the score. On the other way, their interaction, has no influence on the score.

TABLE 8.8 – Anova p-value for the NASA-TLX score on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 211.041 | 3 | 70.347 | 51.869 |  |
| Methods | 17.185 | 4 | 4.296 | 3.168 | 0.029\*\* |
| Rounds | 7.951 | 1 | 7.951 | 5.862 | 0.022\*\* |
| Interaction | 2.115 | 4 | 0.529 | 0.390 | 0.814 |
| Experimental Error | 36.619 | 27 | 1.356 |  |  |
| Total | 274.910 | 39 |  |  |  |

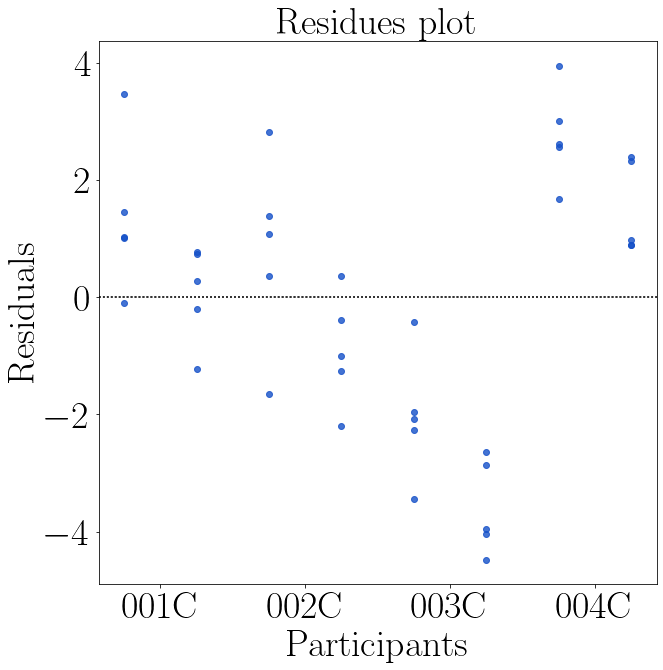
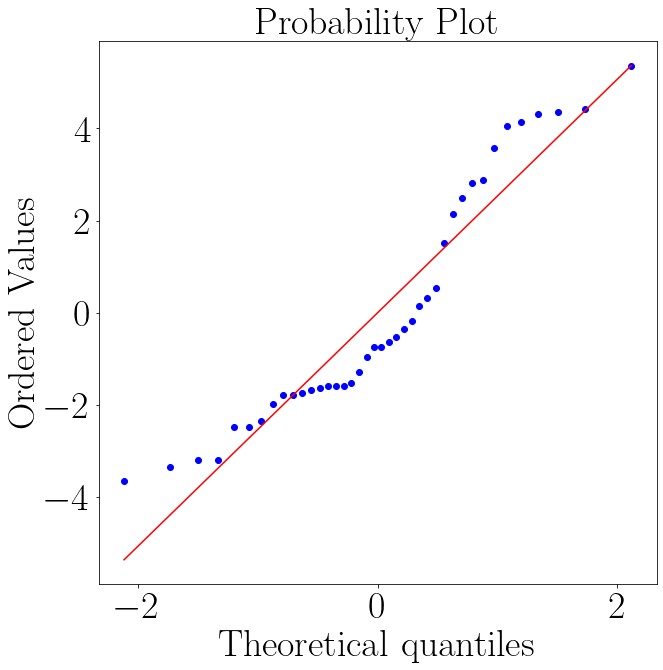


FIGURE 8.11 – QQ plot of the NASA-TLX FIGURE 8.12 – Residual plot of the NASAscore variation of the blind participants on each TLX score variation the blind participants on method. each method.

The Table 8.9 presents the conclusion of a pairwise Fisher LSD test of the blind NASATLX score between all the guidance methods. The results show that only the ”Audio” has a similar NASA-TLX score as the ”Base” method, as it was also posible to notice at Figure 8.9.

TABLE 8.9 – Cross validation p-value for the NASA-TLX score on each method for blinded users.

|  |  |  |  |
| --- | --- | --- | --- |
| Method | | | Analysis |
| Base | *X* | Audio | *H*0 : *µBase* = *µAudio* |
| Base | *X* | Haptic Belt | *H*1 : *µBase* ̸= *µHapticBelt* ∗∗ |
| Base | *X* | Virtual Cane | *H*1 : *µBase* ̸= *µV irtualCane* ∗∗ |
| Base | *X* | Mixture | *H*1 : *µBase* ̸= *µMixture* ∗∗ |
| Audio | *X* | Haptic Belt | *H*1 : *µAudio* ̸= *µHapticBelt* ∗∗ |
| Audio | *X* | Virtual Cane | *H*1 : *µAudio* ̸= *µV irtualCane* ∗∗ |
| Audio | *X* | Mixture | *H*1 : *µAudio* ̸= *µMixture* ∗∗ |
| Haptic Belt | *X* | Virtual Cane | *H*1 : *µHapticBelt* ̸= *µV irtualCane* ∗∗ |
| Haptic Belt | *X* | Mixture | *H*1 : *µHapticBelt* ̸= *µMixture* ∗∗ |
| Virtual Cane | *X* | Mixture | *H*0 : *µV irtualCane* = *µMixture* |

The Table 8.10 shows the average of the NASA-TLX score variation between the rounds. This table shows that the variation from the “Audio” was the lowest variation and the highest variation was the ”Virtual Cane”.

TABLE 8.10 – NASA-TLX score grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | -0.92 | -0.25 | -1.21 | -1.54 | -0.54 |

The Figures 8.13 and 8.14 shows the distribution and variance of the NASA-TLX score variation of the Table 8.6. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.11 shows the Anova test p-value of the NASA-TLX score of the ”blind” sample between the guidance methods. The p-value indicates that there are no difference between the variation of any method.

TABLE 8.11 – Anova p-value for the NASA-TLX score variation on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (blocks) | 0.660 | 3 | 1.058 | 0.228 |  |
| Method | 4.231 | 4 | 0.220 | 1.097 | 0.402 |
| Experimental error | 11.569 | 12 | 0.964 |  |  |
| Total | 16.460 | 19 |  |  |  |

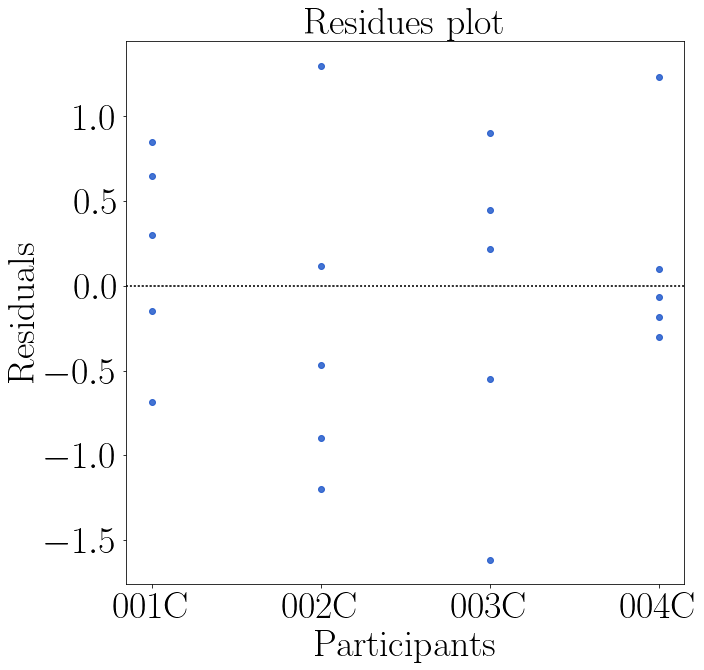
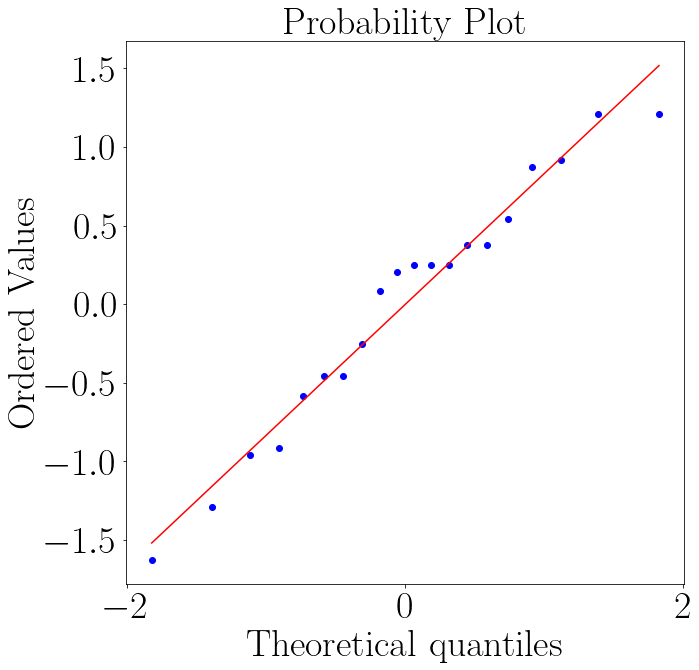


FIGURE 8.13 – Bar plot of the average NASA- FIGURE 8.14 – Bar plot of the average NASATLX score of the blind participants on each TLX score of the sighted participants on each method. method.

To close up, according to the LSD test at Table 8.9 only the ”Audio” method has a NASA-TLX score that could be said to be similar to the ”Base” method, which indicates that the existance of an haptic device increased the NASA-TLX score and that the round has some impact on the score, which means that there was a learning effect from the ”First” to the ”Return” round. Probably this effect was reflected in the other dimensions of the NASA-TLX.

The 8.8 concludes that the rounds and the interaction between the rounds and the methods have no influence on the variation of the NASA-TLX score.

#### 8.1.1.2 Adapted SAGAT

In this subsection, the SAGAT questionnaire is analyzed. Its result may give an idea of the mental map the participant is drawing. For each question a participant could score 1 point or a fraction of it. The total score of each blind participant is presented on the Table 8.12 and they are plotted in the Figures 8.15, where it is visually noticeable that the performance better the second time they visit the room.

The boxplot in the Figure 8.16 shows that there are two groups of scores one with the “Base”, “Haptic Belt” and the “Mixture” methods, and the second group with the “Audio” and the “Virtual Cane” methods. The first group scored higher than the second one. The Figure 8.17 shows a noticible difference between the scores when grouped by their corresponding round.

The Table 8.13 shows the average SAGAT score in the “blind” sample and is possible to notice how the average score by the “blind” sample was lower during the “Audio” and the “Base” methods.

The Figures 8.18 and 8.19 shows the distribution and variance of the Table 8.12. These

TABLE 8.12 – SAGAT global score felled by the blinded participants.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Round |  |  |  |  |  |
| 001C | First | 6.25 | 5.50 | 5.33 | 5.83 | 3.500 |
|  | Return | 6.25 | 6.50 | 8.50 | 5.50 | 5.500 |
| 002C | First | 6.75 | 4.50 | 3.99 | 4.50 | 6.250 |
|  | Return | 5.25 | 5.00 | 4.00 | 6.50 | 8.500 |
| 003C | First | 7.25 | 7.50 | 7.49 | 4.66 | 9.000 |
|  | Return | 10.00 | 10.00 | 8.50 | 9.00 | 9.000 |
| 004C | First | 7.50 | 6.00 | 7.66 | 4.99 | 6.500 |
|  | Return | 9.00 | 6.00 | 9.25 | 7.25 | 9.000 |

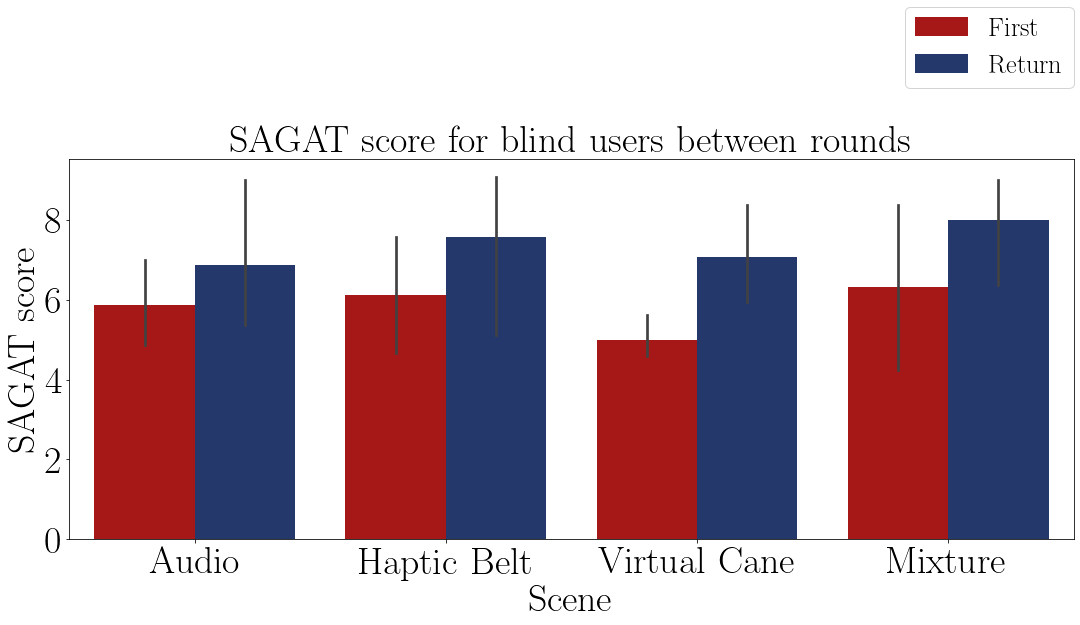


FIGURE 8.15 – Barplot of the average SAGAT score of the blind participants on each method.

TABLE 8.13 – SAGAT score average grouped by participant and visual condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 7.28 | 6.38 | 6.84 | 6.03 | 7.156 |

Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.14 shows the Anova test p-value of the SAGAT score of the ”blind” sample. The round’s p-values indicates that some have influence on the SAGAT score. Meaning that the participants did learn information about the room between the ”First” and ”Return” round. The method and the interaction between it and the round has no influence on the SAGAT score.

The Table 8.15 shows the average of the SAGAT score variation between the rounds.

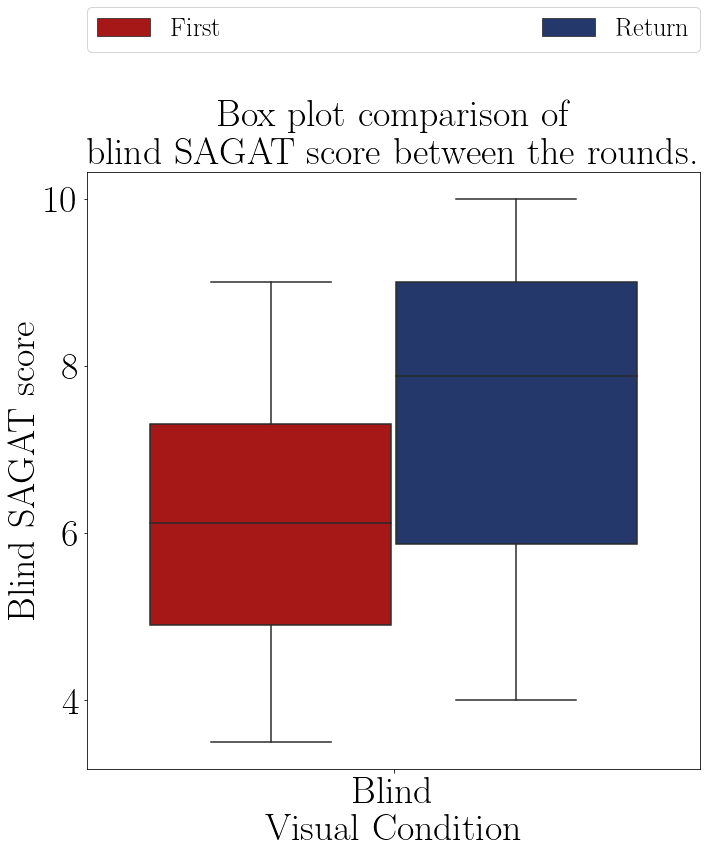
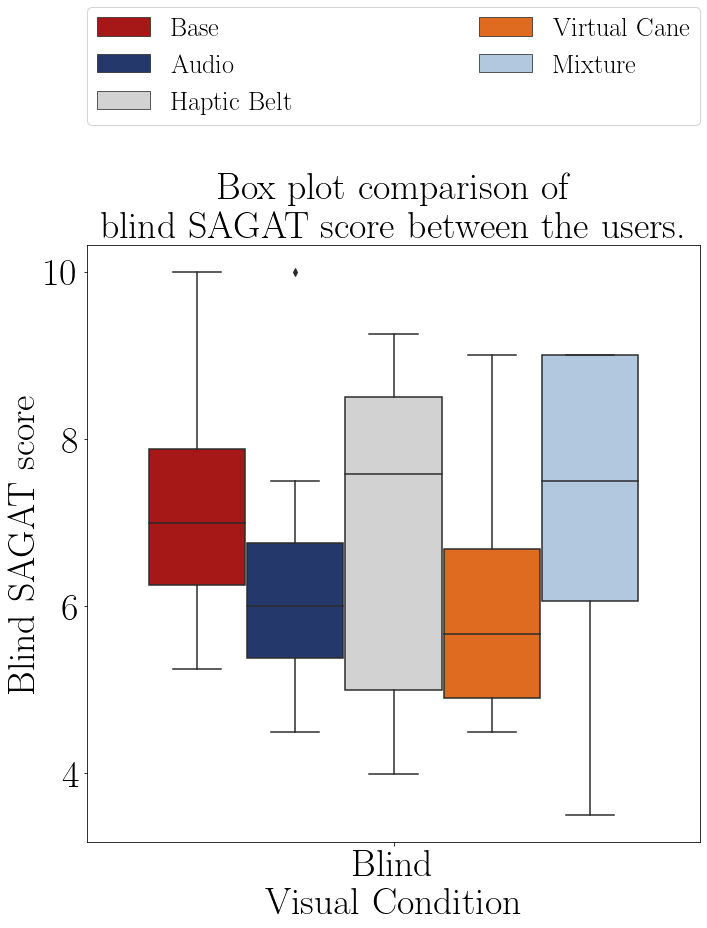


FIGURE 8.17 – Boxplot of the SAGAT score of FIGURE 8.16 – Boxplot of the SAGAT score of the blind participants grouped by round.

the blind participants grouped by method.

TABLE 8.14 – Anova p-value for the SAGAT score on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 48.231 | 3 | 16.077 | 9.731 |  |
| Methods | 8.922 | 4 | 2.230 | 1.350 | 0.277 |
| Rounds | 18.975 | 1 | 18.975 | 11.485 | 0.002\*\* |
| Interaction | 2.391 | 4 | 0.598 | 0.362 | 0.834 |
| Experimental Error | 44.608 | 27 | 1.652 |  |  |
| Total | 123.127 | 39 |  |  |  |

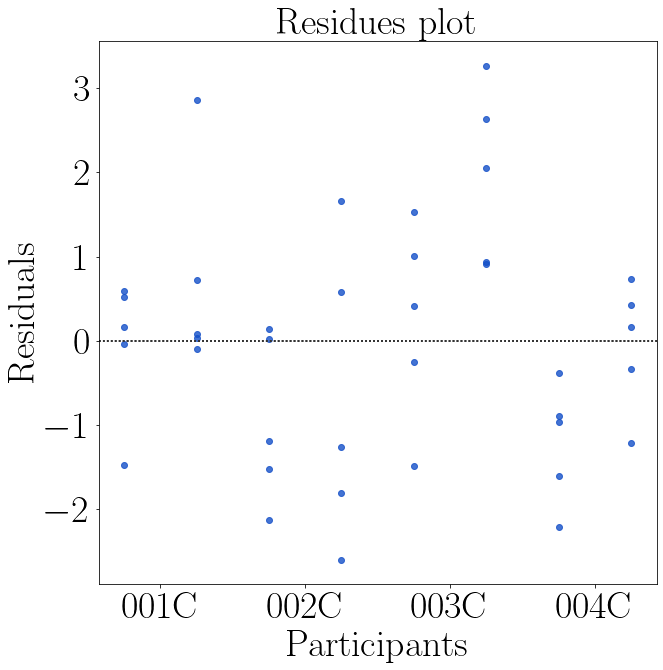
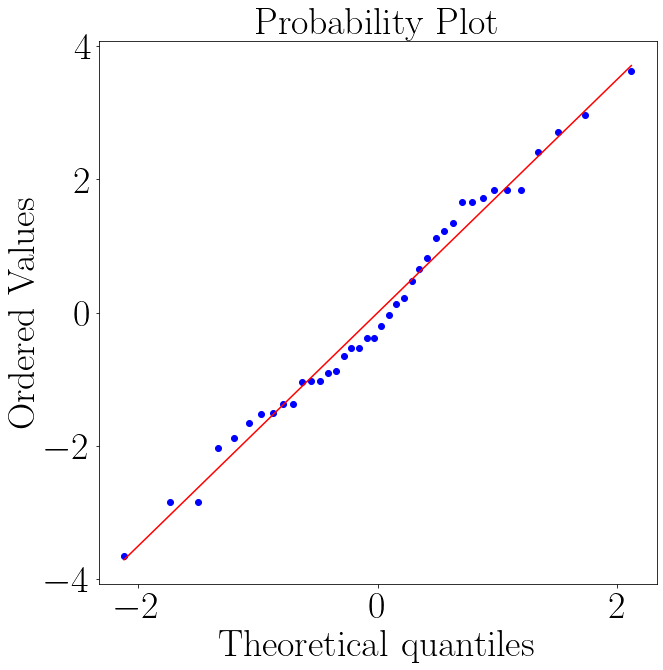


FIGURE 8.18 – QQ plot of the SAGAT score FIGURE 8.19 – Residual plot of the SAGAT of the blind participants on each method. score the blind participants on each method.

This table shows that the variation from the ”Base” and the ”Audio” was the lowest variation and the highest variation was the ”Virtual Cane”.

The Figures 8.20 and 8.21 shows the distribution and variance of the SAGAT score

TABLE 8.15 – Adapted Sagat global score variation grouped by participant and visual Condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 8.93 | 15.66 | 23.49 | 44.30 | 32.90 |

variation of the Table 8.12. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.16 shows the Anova test p-value of the SAGAT score of the ”blind” sample between the guidance methods. The p-value indicates that there are no difference between the variation in any method.

TABLE 8.16 – Anova p-value for the SAGAT score variation on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (blocks) | 1176.902 | 3 | 782.885 | 0.473 |  |
| Method | 3131.542 | 4 | 392.301 | 0.944 | 0.472 |
| Experimental error | 9956.458 | 12 | 829.705 |  |  |
| Total | 14264.902 | 19 |  |  |  |

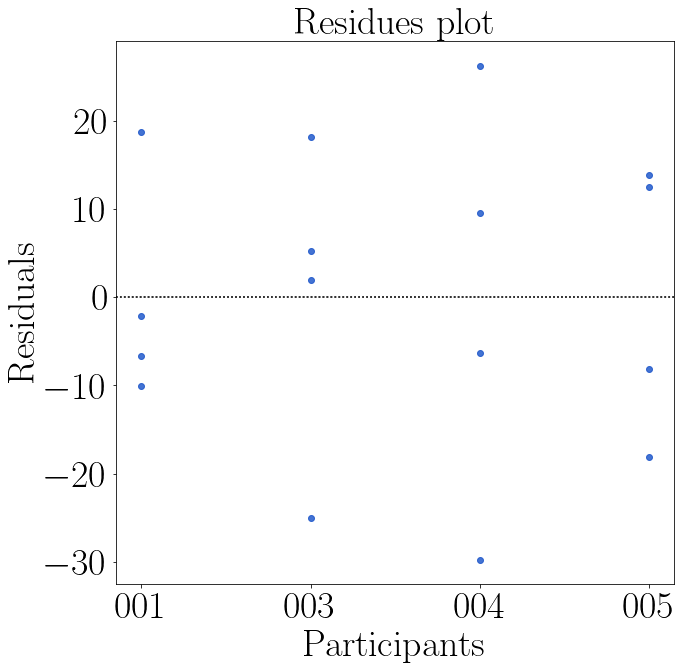
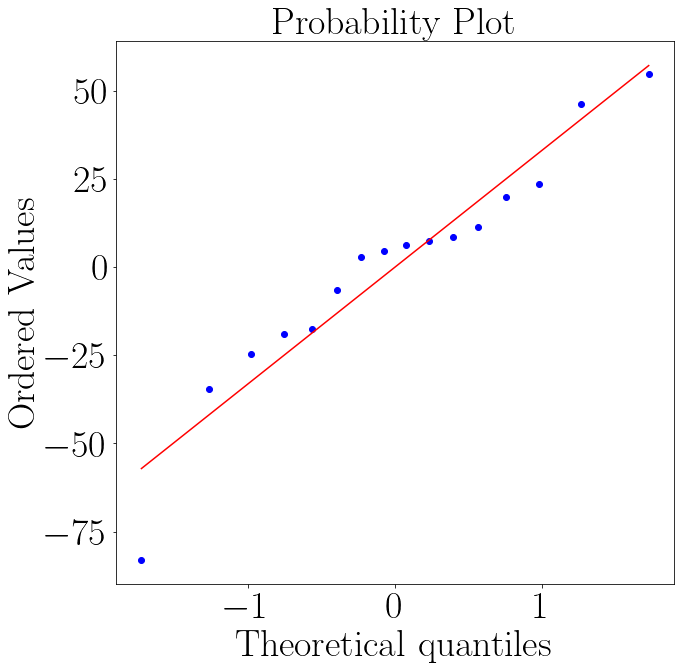


FIGURE 8.20 – QQ plot of the SAGAT score FIGURE 8.21 – Residual plot of the SAGAT variation of the blind participants on each score variation of the blind participants on each method. method.

To close up, according to the ANOVA test at Table 8.14 the methods caused no reaction on the SAGAT score, but the rounds did. That means that the participants were able in all methods to learn a little about their environment and that learning impacted their environmental perception in the next round. The fact that the test has not found any influence of the methods on the SAGAT score may be because of the small sample size, since it is posible to notice a difference between the methods at Figure 8.16. Also the interaction between method and round caused no influence in the Sagat score. According to the ANOVA test at Table 8.16, the methods did not influenced the SAGAT score.

8.1.1.3 Guidance method’s questionnaire.

Finally, the Questionnaire is analyzed to give an idea about the impressions of the users with each device. This is an important evaluation to seek their impressions of each method. The higher the score, the more the user was satisfaction with that method. The Table 8.17 shows the score of each method and they are plotted in the Figure 8.22. The Figure show a disatisfaction with the haptic devices alone.

TABLE 8.17 – Guidance method questionnaire score felled by the blinded participants.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Participant | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| 001C | 0.774 | 0.543 | 0.629 | 0.865 |
| 002C | 0.857 | 0.743 | 0.543 | 0.935 |
| 003C | 0.929 | 0.571 | 0.543 | 0.745 |
| 004C | 0.881 | 0.486 | 0.400 | 0.730 |

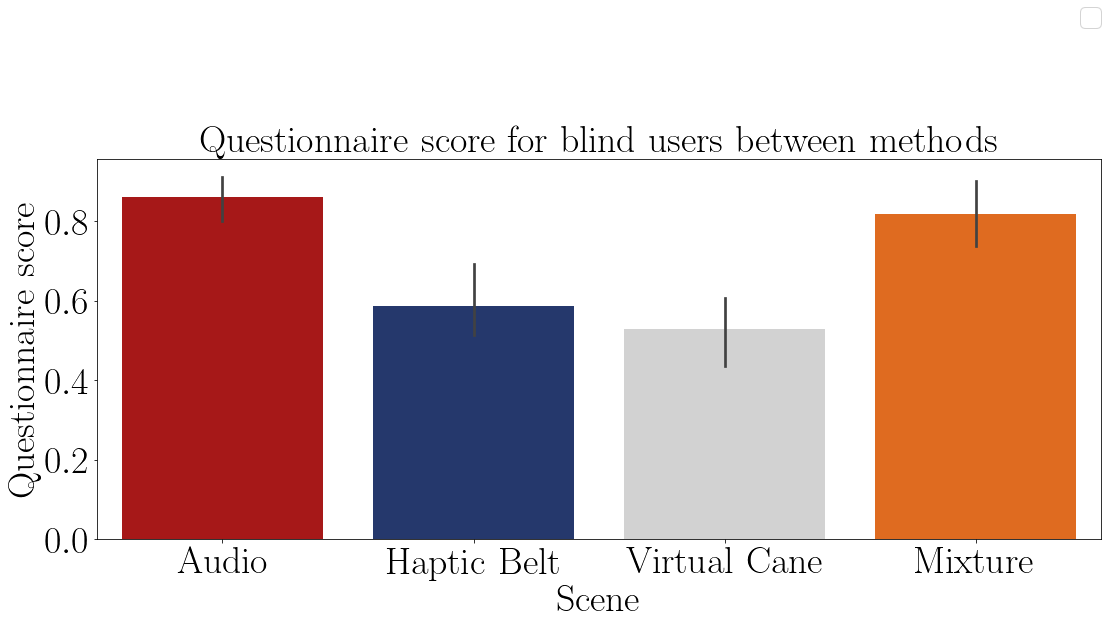


FIGURE 8.22 – Barplot of the average questionaire score of the blind participants on each method.

The Table 8.18 show the the average questionnaire score on each method. It also shows a disatisfaction with the haptic devices alone.

TABLE 8.18 – Guidance method questionnaire average score grouped by visual condition.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Visual Condition | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 0.86 | 0.59 | 0.53 | 0.82 |

The Figures 8.24 and 8.25 shows the distribution and variance of the Table 8.17.

These Figures shows that the data are normally distributed and that the methods have a

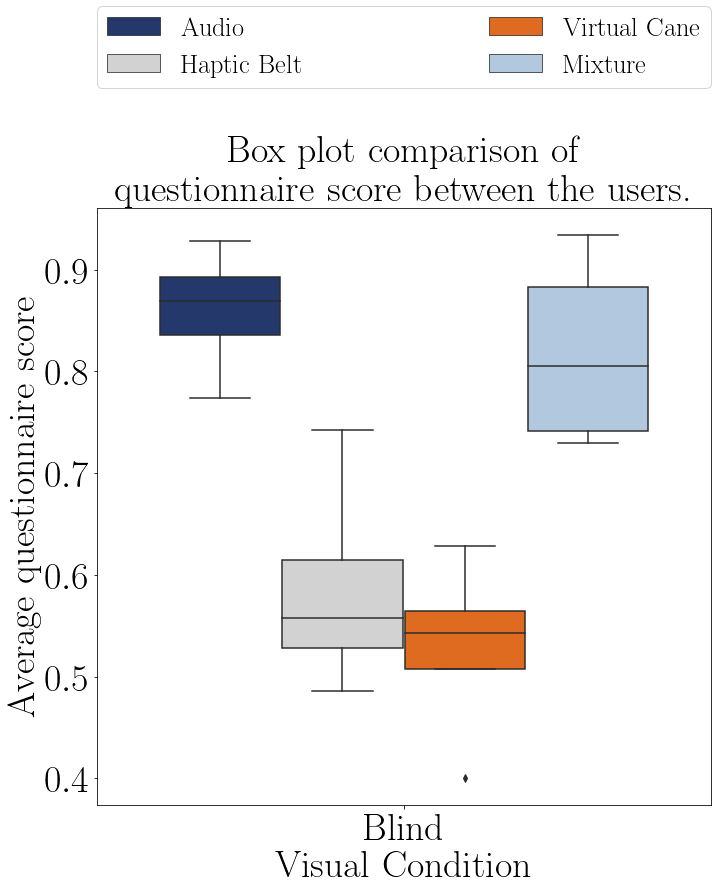


FIGURE 8.23 – Boxplot of the questionaire score of the blind participants grouped by method.

similar variance. The Table 8.19 shows the Anova test p-value of the questionnaire score of the ”blind”sample. The p-values indicates that the method have influence on the score.

Meaning that the participants had differents level os satisfaction about each method.

TABLE 8.19 – Anova p-value for the questionnaire score on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (blocks) | 0.042 | 3 | 0.110 | 2.014 |  |
| Method | 0.329 | 3 | 0.014 | 15.677 | 0.001\*\* |
| Experimental error | 0.063 | 9 | 0.007 |  |  |
| Total | 0.434 | 15 |  |  |  |

The Table 8.20 presents the conclusion of a pairwise Fisher LSD test of the blind NASA-TLX score between all the guidance methods. The results show that only the ”Audio” and ”Mixture” have the same statistically result and that there is a difference between the both ”Haptic Belt” and ”Virtual Cane”.

The LSD Table 8.20 confirms the information of the Figure 8.23 that the“Audio”and the ”Mixture”methods were the most favorite by the blind participants, whilst the“Haptic

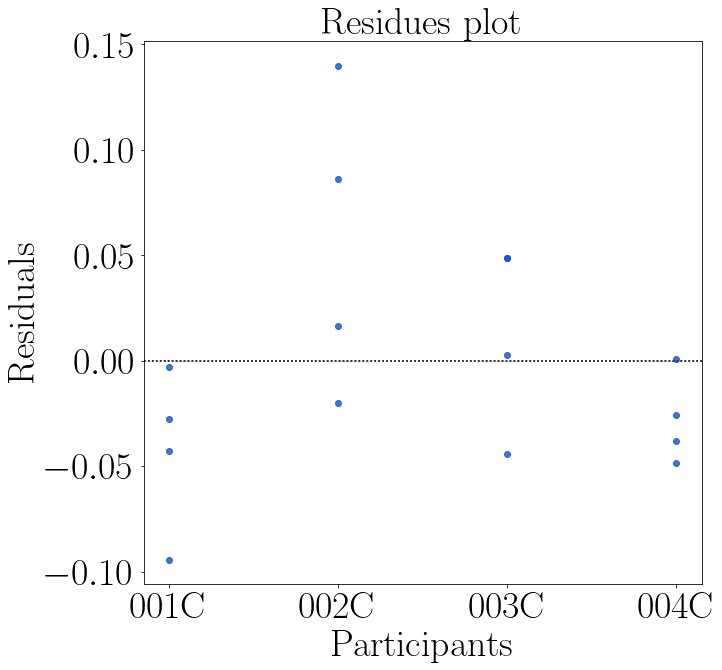
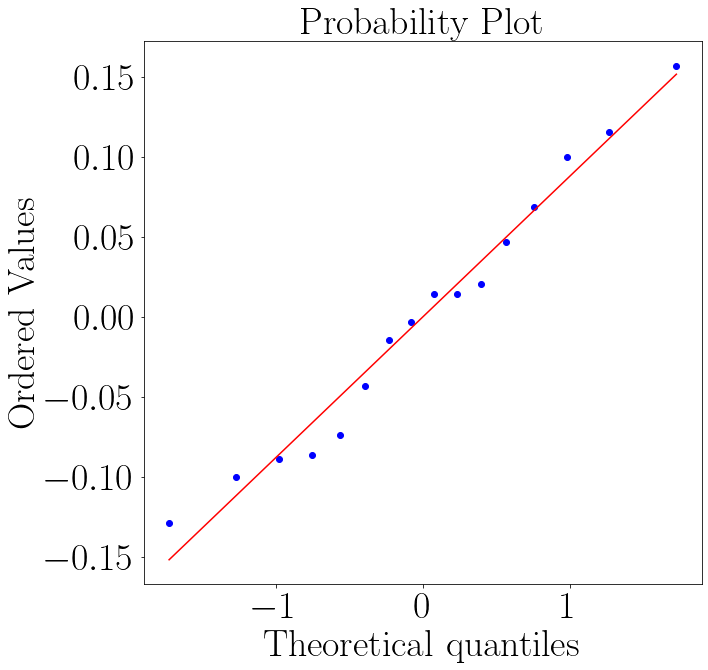


FIGURE 8.25 – Residual plot of the ques-

FIGURE 8.24 – QQ plot of the questionnaire tionnaire score the blind participants on each

score of the blind participants on each method. method.

TABLE 8.20 – Cross validation p-value for the questionnaire score on each method for blinded users.

|  |  |  |  |
| --- | --- | --- | --- |
| Method | | | Analysis |
| Audio | *X* | Haptic Belt | *H*1 : *µAudio* ̸= *µHapticBelt* ∗∗ |
| Audio | *X* | Virtual Cane | *H*1 : *µAudio* ̸= *µV irtualCane* ∗∗ |
| Audio | *X* | Mixture | *H*0 : *µAudio* = *µMixture* |
| Haptic Belt | *X* | Virtual Cane | *H*1 : *µHapticBelt* ̸= *µV irtualCane* ∗∗ |
| Haptic Belt | *X* | Mixture | *H*1 : *µHapticBelt* ̸= *µMixture* ∗∗ |
| Virtual Cane | *X* | Mixture | *H*1 : *µV irtualCane* ̸= *µMixture* ∗∗ |

Belt”and“Virtual Cane”were the most unfavorite devices. The participants did comment about those two last devices, saying that they were not precise enough, confusing and very different from what they are used to use.

### 8.1.2 Physiological data

There were 3 different sensors in this experiment, 2 that collected physiological data and the one left collected temperature. The last one was used to eliminate the temperature influence on the GSR sensor. These were all used to assess Mental Workload.

* Electrocardiogram (ECG) data;

Two features are extracted from the ECG, heartrate (BPM) and heartrate variance (SDNN).

Is expected that the heartrate slight decrease from the ”First”to the ”Return”round. The heartrate variance is expected to slight increase from the ”First”to the ”Return” round.

* Galvanic skin reaction and temperature data;;

Is expected that the GSR average to increase at every “First” round and then a slight decrease in the next round.

#### 8.1.2.1 Electrocardiogram (ECG) data

The ECG analysis is divided into two different types

* Heart rate;

This analysis checks the heartbeat frequency;

* Heart rate variance.

This analysis checks the heartbeat frequency variance and it is done by analyzing the variation of the interval between beats.

At the beginning of each experience, a baseline data was gathered to establish a comparison between the normal state of the user and the scenes’ induced state. After the data gathering, an algorithm in Python was used to read the data and separate it accordingly to each participant, method and round. The algorithm followed the steps above: • Outliers remotion; Since the participants moved during the whole experience a lot of noise was collected by the sensors

* Normalization between -1 and 1;
* Peak detection; If the results were appropriate:
  + Heartbeat interval calculation;
  + File save to be used in Kubius HRV Standard.

If the results were not appropriate:

* + Tune peak detection method’s parameters;
  + Heartbeat interval calculation;
  + File save to be used in the next software.

This judgment was made by analyzing the plotted ECG signal and the detected peaks. Kubios HRV Standard is a heart rate variability (HRV) analysis software for personal noncommercial use. The Kubios HRV Standard makes it possible to use your HR monitor to examine the health of the cardiovascular system or to evaluate stress and recovery (KUBIUS..., ). At Kubius, the file with the intervals was analyzed and the results were saved in a report file to be read in python again. Back in python the results were plotted, tabled and statistically tested as the other data. In Appendix D there is a diagram with a pseudo-algorithm of this process.

This analysis was made by comparing the baseline values with the values of each round individually and between the round values themselves.

##### 8.1.2.1.1 Analysis of the heartbeat frequency (BPM)

The Table 8.21 presents the average heart rate by each blind participant on each scenes. It is possible to see that the previous expectation cannot be proven, since there is no sistematic pattern in the heartrate variation between the rounds.

TABLE 8.21 – Average BPM felled by the blinded participants.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Round |  |  |  |  |  |
| 001C | First | 75.75 | 60.71 | 71.17 | 59.07 | 68.24 |
|  | Return | 71.05 | 58.61 | 66.22 | 64.20 | 70.76 |
| 002C | First | 48.69 | 38.67 | 48.74 | 46.89 | 52.23 |
|  | Return | 52.46 | 47.58 | 58.97 | 56.75 | 58.25 |
| 003C | First | 68.37 | 69.89 | 70.95 | 69.41 | 66.94 |
|  | Return | 67.34 | 67.44 | 69.68 | 68.82 | 67.37 |
| 004C | First | 75.09 | 73.55 | 73.70 | 71.94 | 74.03 |
|  | Return | 74.74 | 74.79 | 74.02 | 72.69 | 67.34 |

In the Figure 8.26 is plotted the average data presentend in the previoes table. There is a slight increase in the heartrate between the rounds, with the exception of the ”Base” method. That means that, in the average, the participants felt more demandful in the ”Return” round.

The Table 8.22 show the average heartbeat frequency variation between the rounds of each group. As it was shown in the Figure 8.26, only the ”Base” method has a negative average variaton between the rounds. It is also posible to see that the Virtual Cane variation was the highest, hence it was also the highest mental workload.

TABLE 8.22 – ECG average BPM for each method of the blind participants.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 66.69 | 61.40 | 66.68 | 63.72 | 65.65 |

The Figure 8.27 show a comparison between the methods. There is no big difference

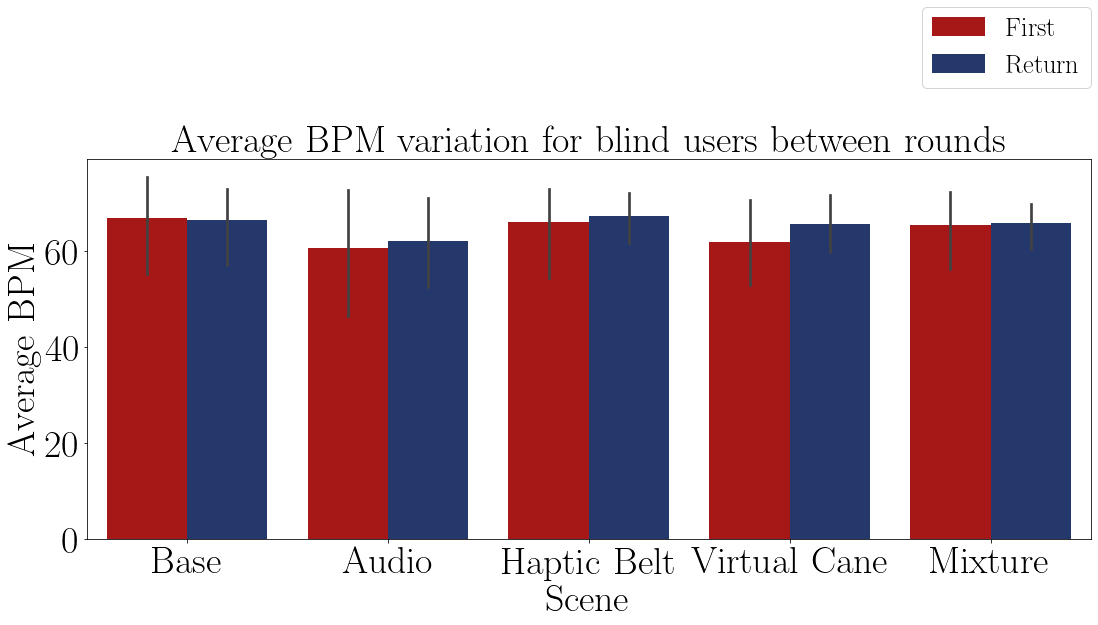


FIGURE 8.26 – Barplot of the average BPM of the blind participants on each method.

between them, but it is posible to separate them in two groups based on their similarity. One with “Base”, “Haptic Belt” and “Mixture” methods and the other with “Audio” and

“Virtual Cane”. The Figure 8.28 presents the average heartreate frequency grouped by round.

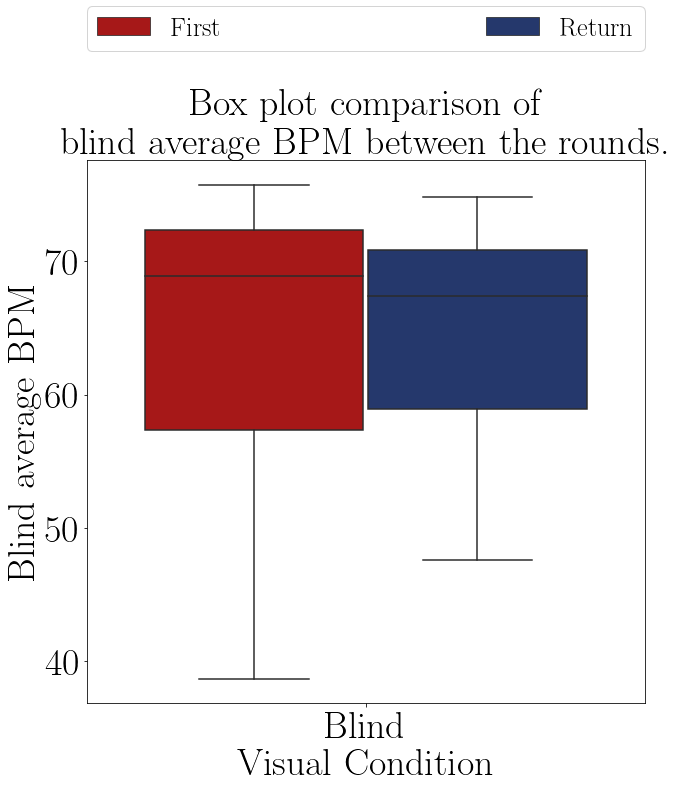
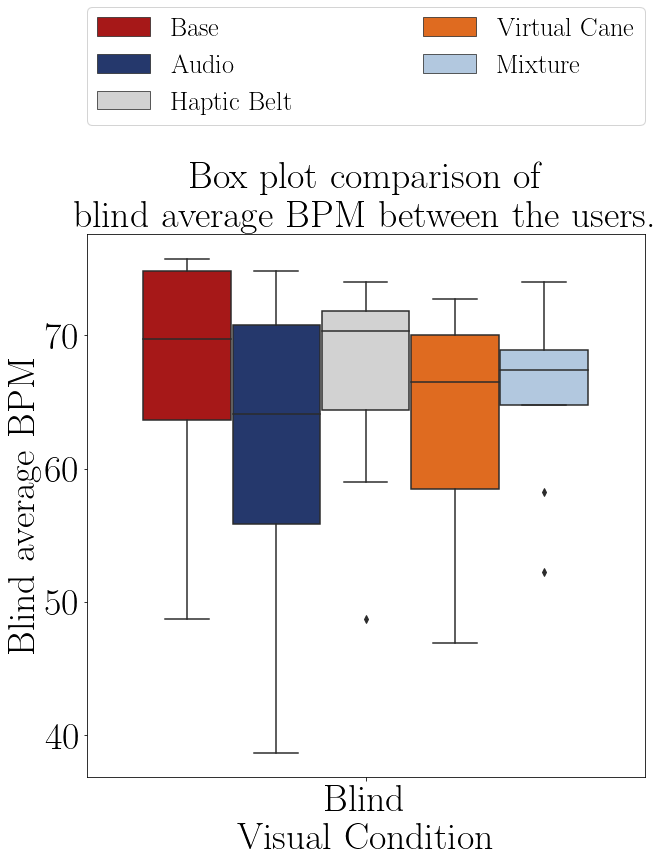


FIGURE 8.28 – Boxplot of the BPM of the FIGURE 8.27 – Boxplot of the BPM of the blind participants grouped by round. blind participants grouped by method.

The Figures 8.29 and 8.30 shows the distribution and variance of the Table 8.21. These Figures shows that the data are normally distributed but the participants had different that the methods have a similar variance. The Table 8.23 shows the ANOVA test p-value of the heart rate frequency of the “blind” sample. The p-value indicates that there is no effect of the methods, rounds and neither their interaction in the heartrate frequency.

According to the ANOVA test at Table 8.23, there is no effect from the method, the

TABLE 8.23 – Anova p-value for the BPM on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 2807.274 | 3 | 935.758 | 49.361 |  |
| Methods | 164.045 | 4 | 41.011 | 2.163 | 0.100 |
| Rounds | 15.693 | 1 | 15.693 | 0.828 | 0.371 |
| Interaction | 20.606 | 4 | 5.152 | 0.272 | 0.894 |
| Experimental Error | 511.853 | 27 | 18.958 |  |  |
| Total | 3519.471 | 39 |  |  |  |

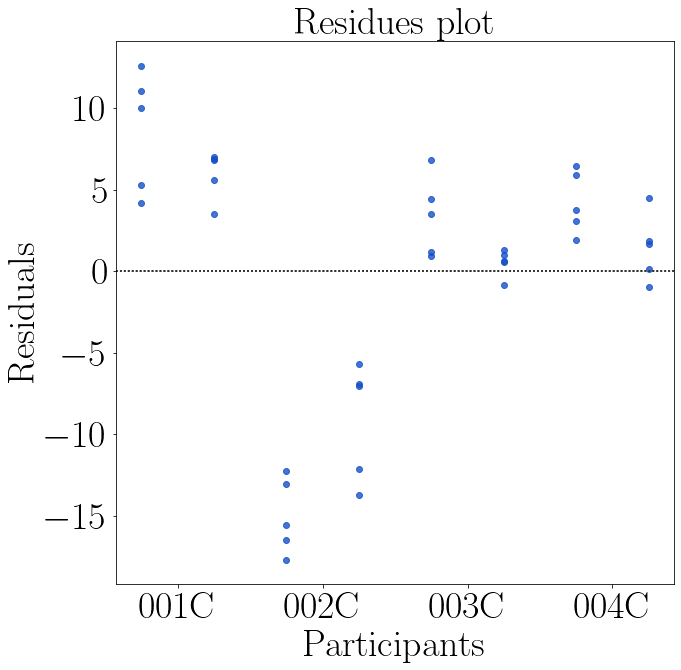
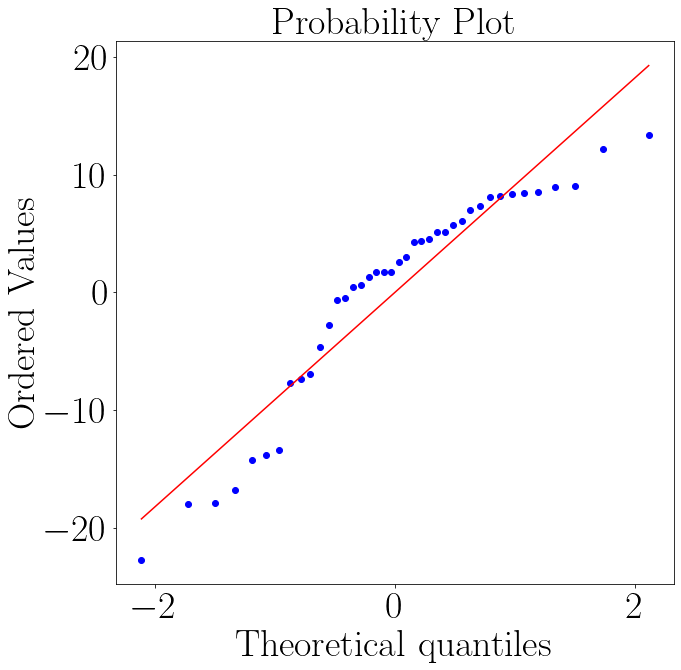


FIGURE 8.29 – QQ plot of the BPM of the FIGURE 8.30 – Residual plot of the BPM score blind participants on each method. the blind participants on each method.

round or the interaction between them in the heartrate frequency. It is posible to notice some small difference in the Figure 8.27 but maybe because of the small sample size, it was no sensitive enough to be proved by the ANOVA test.

##### 8.1.2.1.2 Analysis of the heartbeat variance (SDNN)

The Table 8.24 presents the standard deviation of the interbeat interval by each participant on each scenes. As it was with the Table 8.21, it is not posible to draw a pattern inside this Table. Different participant had increase, or decrease, with different methods.

Inside the barplot Figure 8.31 shows the average SDNN in each method. It is posible to notice that some method had an increase and some a decrease in the SDNN. The ones that indicate an increase would mean that the participant felt a lesser mental workload in the ”Return” round, whilst the deacrese means the opposite.

The Table 8.25 presents the average SDNN variation between the rounds. It shows that only the ”Audio” and the ”Haptic Belt” methods shown a increase in the mental workload.

The Figures 8.32 presents the distribution of each method SDNN. It noticeable that the ”Base” method has a different SDNN than the rest. The ”Virtual Cane” also has a

TABLE 8.24 – Average SDNN of the blind participants during the each round and method.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Round |  |  |  |  |  |
| 001C | First | 81.292 | 107.061 | 124.737 | 163.968 | 129.054 |
|  | Return | 120.719 | 130.885 | 131.590 | 157.589 | 124.786 |
| 002C | First | 73.761 | 98.863 | 81.140 | 33.977 | 79.289 |
|  | Return | 108.940 | 49.627 | 42.815 | 114.057 | 107.545 |
| 003C | First | 36.870 | 38.325 | 35.101 | 42.392 | 43.692 |
|  | Return | 52.750 | 41.196 | 44.256 | 42.602 | 46.145 |
| 004C | First | 70.728 | 86.827 | 62.560 | 85.900 | 70.472 |
|  | Return | 71.950 | 74.895 | 70.017 | 66.089 | 104.040 |

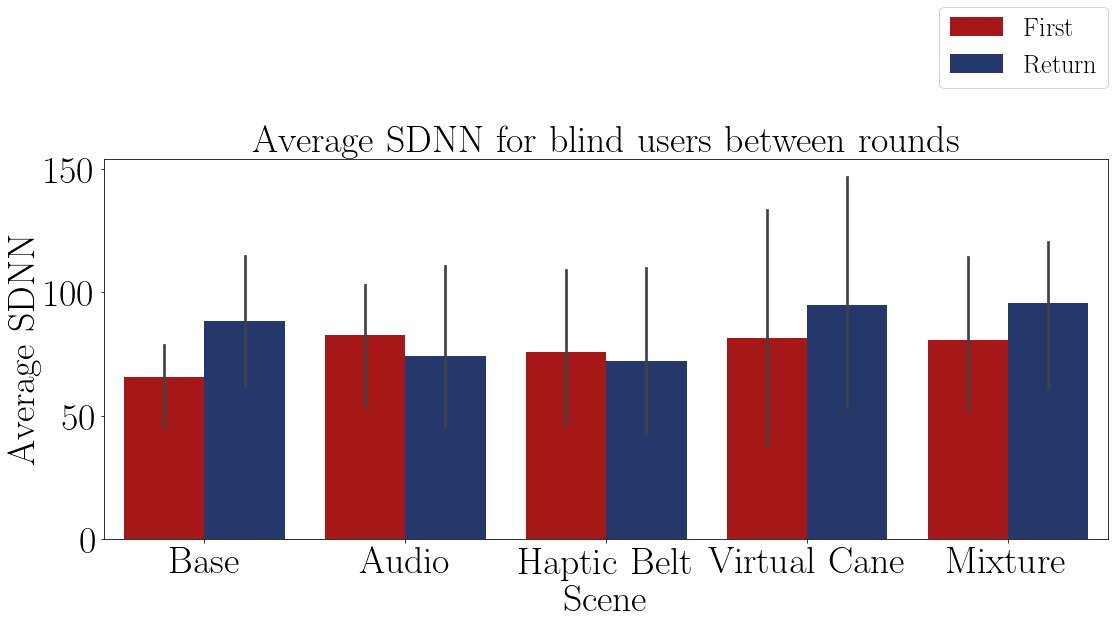


FIGURE 8.31 – Barplot of the average SDNN of the blind participants on each method.

TABLE 8.25 – ECG average SDNN for each method of the blind participants.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 77.13 | 78.46 | 74.03 | 88.32 | 88.13 |

different distribution from the rest. The Figure 8.33 presents the SDNN grouped by the rounds. It shows a slight difference between the rounds.

The Figures 8.34 and 8.35 shows the distribution and variance of the Table 8.24. These Figures shows that the data are normally distributed but the participants had different that the methods have a similar variance. The Table 8.26 shows the ANOVA test p-value of the heartbeat interval variance of the “blind” sample. The p-value indicates that there is no effect of any factor.

The Table 8.26 does not prove that any method or round has some influence in the

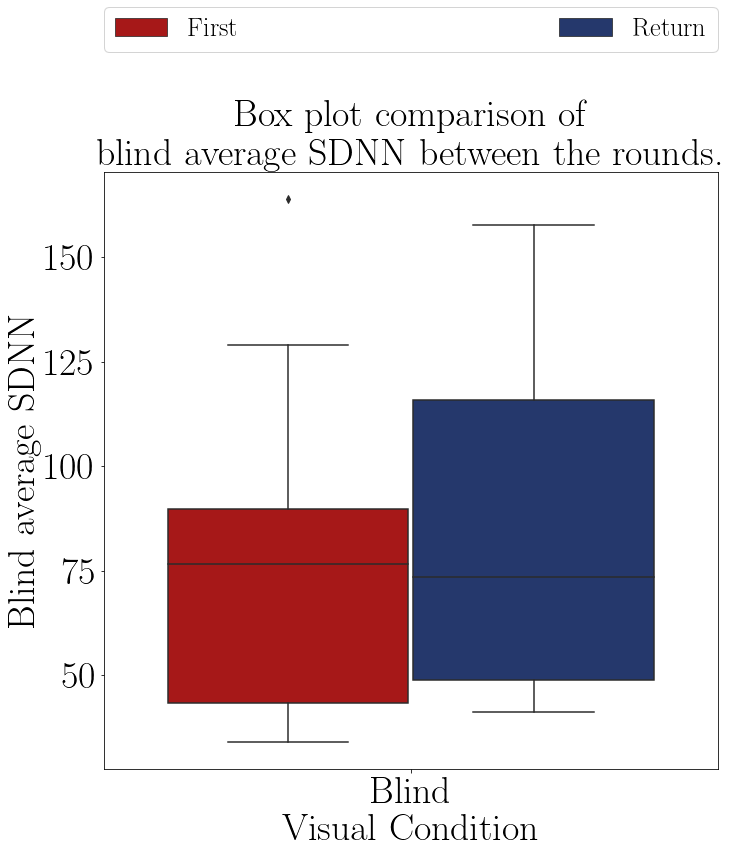
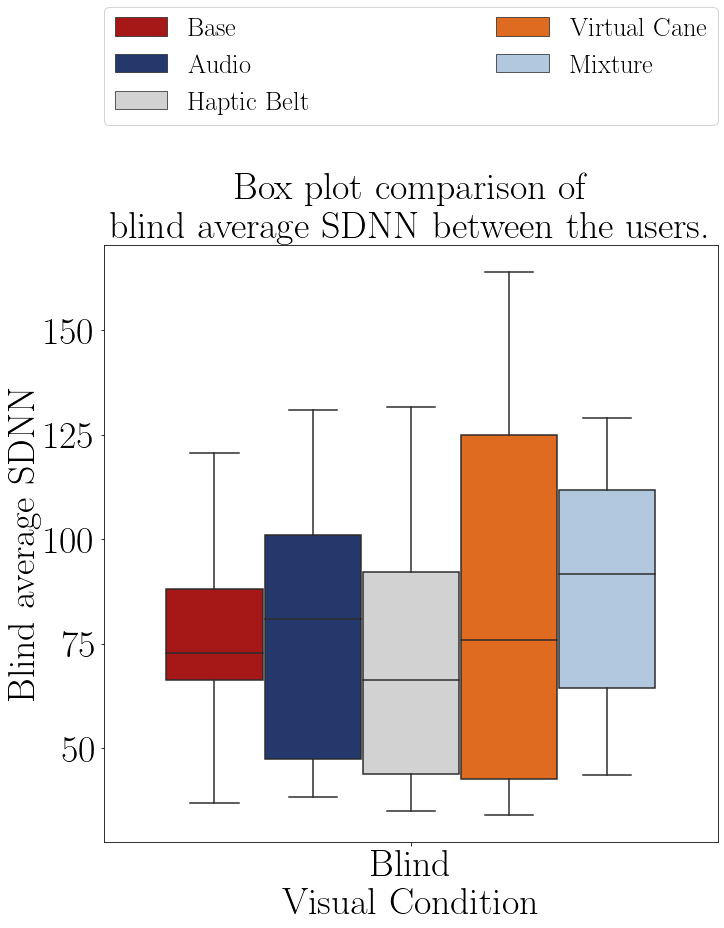


FIGURE 8.33 – Boxplot of the SDNN of the FIGURE 8.32 – Boxplot of the SDNN of the blind participants grouped by round. blind participants grouped by method.

TABLE 8.26 – Anova p-value for the average SDNN on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 36520.955 | 3 | 12173.652 | 30.932 |  |
| Methods | 1394.166 | 4 | 348.542 | 0.886 | 0.486 |
| Rounds | 612.182 | 1 | 612.182 | 1.555 | 0.223 |
| Interaction | 1431.284 | 4 | 357.821 | 0.909 | 0.473 |
| Experimental Error | 10626.244 | 27 | 393.565 |  |  |
| Total | 50584.831 | 39 |  |  |  |

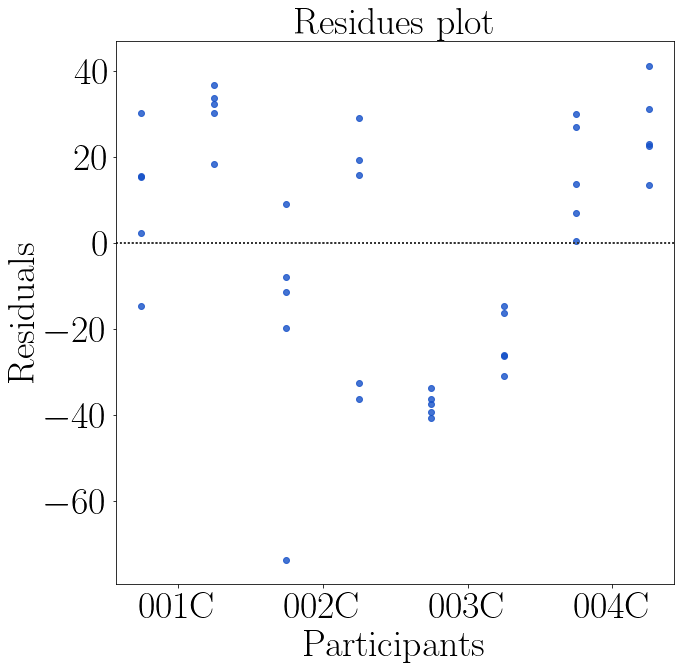
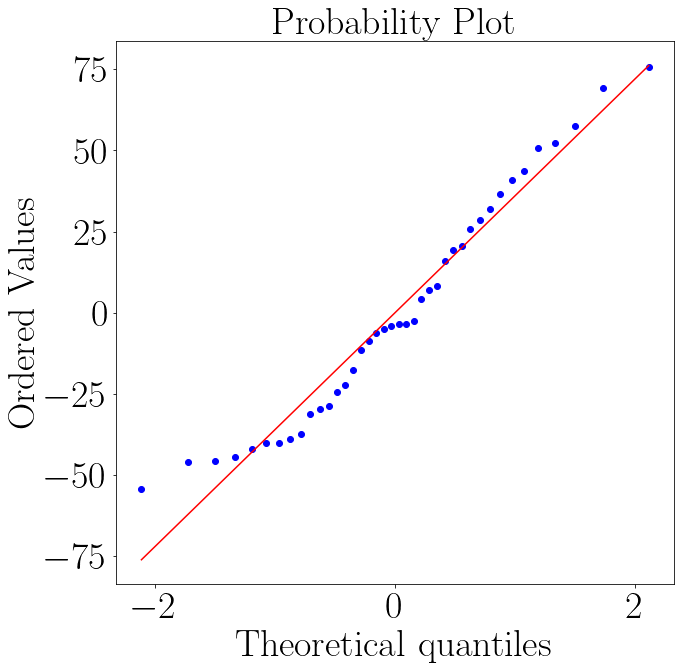


FIGURE 8.34 – QQ plot of the SDNN of the FIGURE 8.35 – Residual plot of the SDNN of blind participants on each method. the blind participants on each method.

heartbeat interval variance, thus in the Mental Workload. Although, in the Figure 8.32 it is posible to notice that the ”Base”method has a different distribution. As it has already commented before, maybe the result of the anova test is a conseguence of a small sample size.

#### 8.1.2.2 Galvanic skin reaction and temperature data;

The GSR analysis is made by analyzing its average and the accumulated value and comparing both features between the baseline and each round. The temperature was analyzed with the GSR to see if there is some influence and by a graphical analysis there was none. For the experiment, the GSR sensor was worn on the left hand for right-handed participant and on the right hand for left-handed participants.

Two participants, one blind and one sighted user, had to have their GSR data removed because the sensor was not fixed accordingly.

The Table 8.27 presents the standard deviation of the interbeat interval by each participant on each scenes. As it was with the Table 8.21, it is not posible to draw a pattern inside this Table. Different participant had increase, or decrease, with different methods.

The Table 8.27 presents the average skin conductance by each blind participant on their baseline and on each scene and their respectivily variation is inside Table 8.28. In the majority of times the skin conductance has risen from the ”First” to the ”Return” round, which mean that the participant was more aroused or with a higher mental workload.

TABLE 8.27 – Average GSR felled by the blind participants [*µ*S].

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Baseline | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Round |  |  |  |  |  |  |
| 001C | First | 0.37 | 0.48 | 1.03 | 3.14 | 3.79 | 3.90 |
|  | Return |  | 0.83 | 1.58 | 2.81 | 4.04 | 4.57 |
| 003C | First | 0.30 | 0.56 | 0.56 | 0.62 | 0.85 | 1.09 |
|  | Return |  | 0.62 | 0.63 | 0.65 | 0.92 | 1.06 |
| 004C | First | 1.24 | 2.34 | 3.07 | 3.49 | 2.28 | 2.23 |
|  | Return |  | 2.57 | 2.95 | 3.20 | 2.21 | 2.24 |

TABLE 8.28 – Average GSR variation in relation to the baseline in each round of the blind participants

[*µ*S].

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Round |  |  |  |  |  |
| 001C | First | 30.58% | 176.54% | 746.10% | 920.72% | 951.71% |
|  | Return | 125.29% | 327.42% | 656.99% | 988.93% | 1132.39% |
| 003C | First | 85.36% | 84.23% | 104.19% | 182.35% | 258.80% |
|  | Return | 105.34% | 109.23% | 112.95% | 202.35% | 249.72% |
| 004C | First | 89.62% | 148.53% | 182.84% | 84.33% | 80.69% |
|  | Return | 108.22% | 138.64% | 159.00% | 78.73% | 81.61% |

The Figure 8.36 presents the average GSR variation on each method and one can say that the presence of a haptic device causes an increase in the skin conductance, hence its mental workload. Also it is posible to realize that the average skin conductance of the blind participants had incresed between the ”First” and ”Return” round, with the exception of the ”Base” method and the ”Haptic Belt” method.

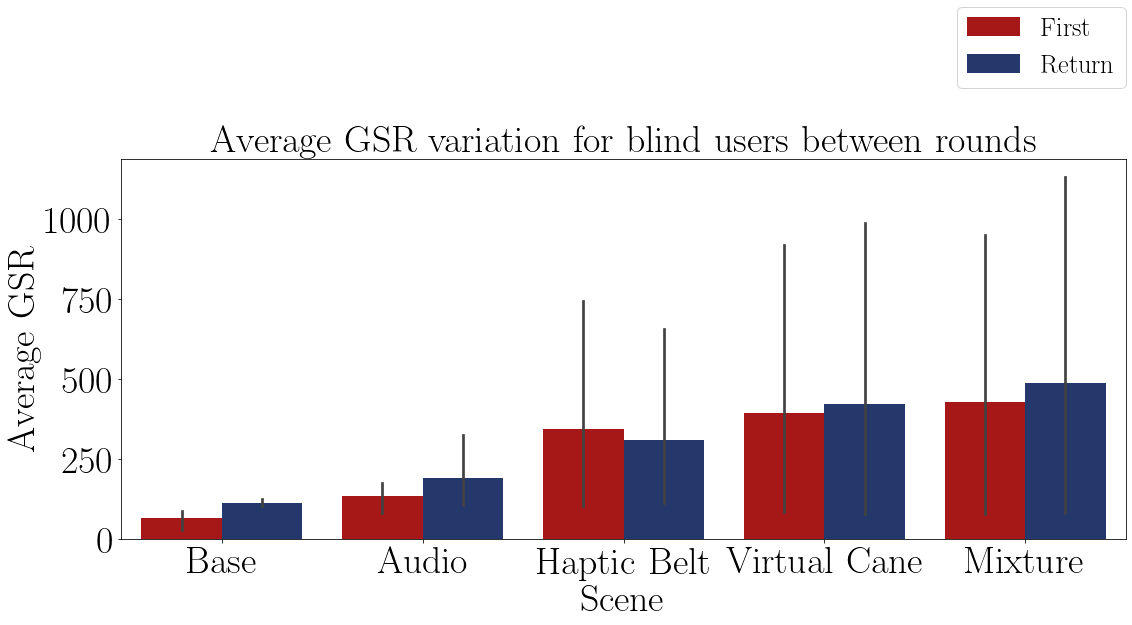


FIGURE 8.36 – Barplot of the average SDNN of the blind participants on each method.

The Table 8.29 presents the average GSR variation presented in the table 8.28. It shows that the ”Audio”method presented the lesser GSR, that could be a combination of the fact that during the ”Audio”method the hands was not used and that the participants felt less strange to the method, since it is based a common daily activity.

TABLE 8.29 – Average GSR variation by the blind participants

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 90.73% | 164.10% | 327.01% | 409.57% | 459.155 |

The Figures 8.37 presents the distribution of the skin conductance on each method. It noticeable that the ”Base” method has the lowest variation of all methods and that the presence of a haptic device increases its variance. The Figure 8.38 presents the GSR grouped by the rounds and their are virtually the same.

The Figures 8.39 and 8.40 shows the distribution and variance of the Table 8.28. These Figures shows that the data are normally distributed but the participants had different that the methods have a similar variance. The Table 8.30 shows the ANOVA test p-value of the heartbeat interval variance of the “blind” sample. The p-value indicates that there is no effect of any factor in the skin conductance.

The Table 8.30 does not prove that any method or round has some influence in the

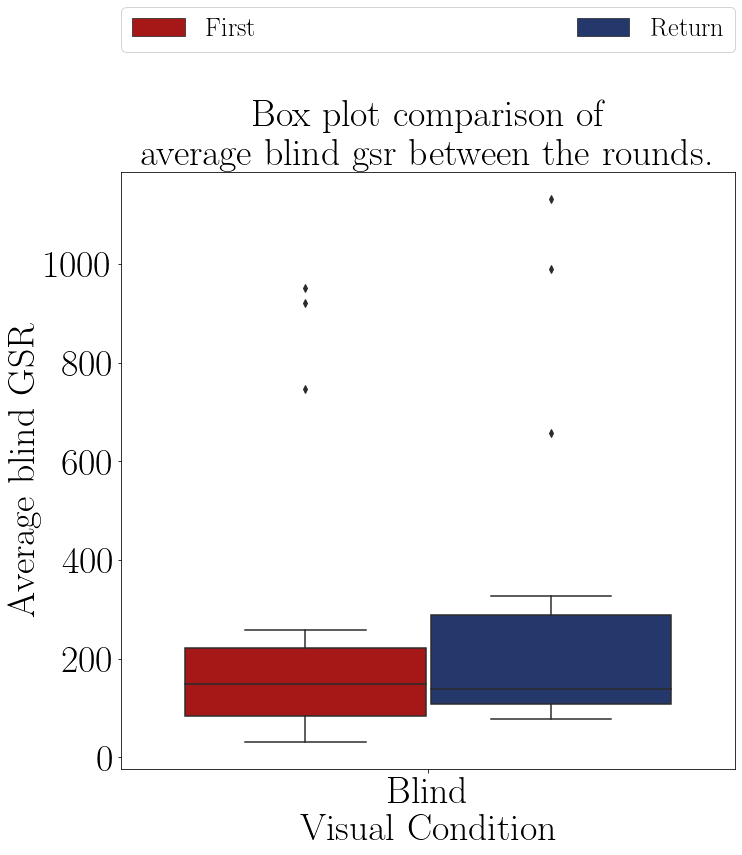
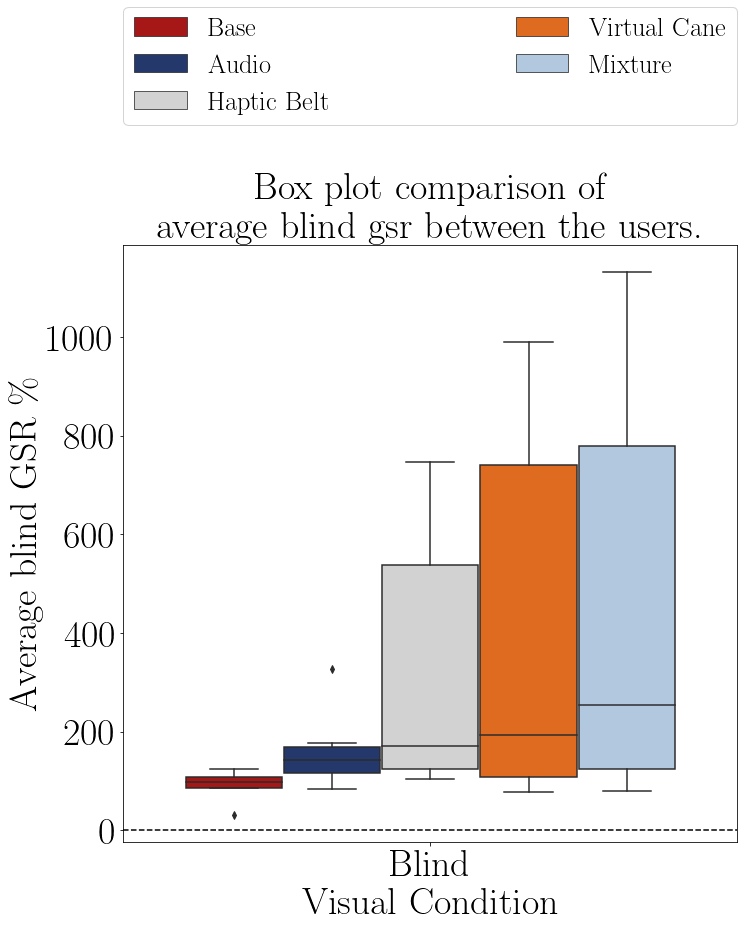


FIGURE 8.38 – Boxplot of the GSR of the blind FIGURE 8.37 – Boxplot of the GSR of the blind participants grouped by round. participants grouped by method.

TABLE 8.30 – Anova p-value for the mental demand average on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 1499470.825 | 2 | 749735.412 | 14.528 |  |
| Methods | 599028.542 | 4 | 149757.136 | 2.902 | 0.051 |
| Rounds | 6756.031 | 1 | 6756.031 | 0.131 | 0.722 |
| Interaction | 8702.285 | 4 | 2175.571 | 0.042 | 0.996 |
| Experimental Error | 928919.342 | 18 | 51606.630 |  |  |
| Total | 3042877.025 | 29 |  |  |  |

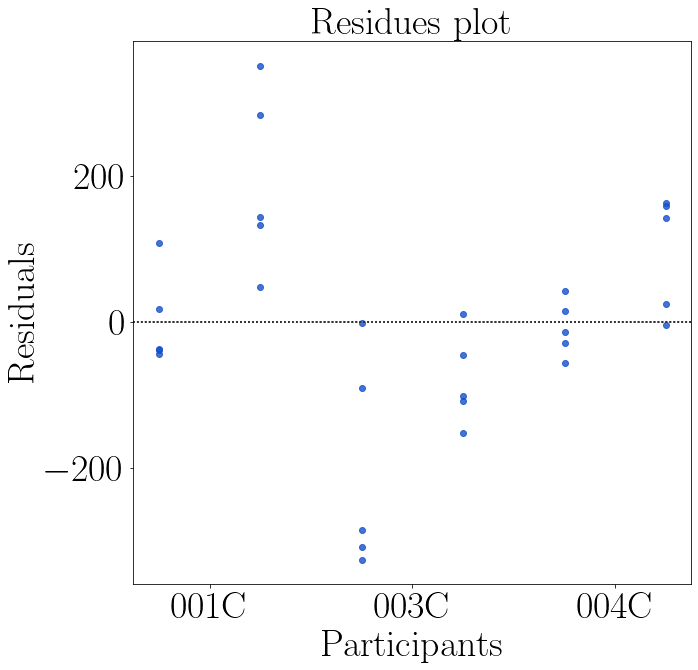
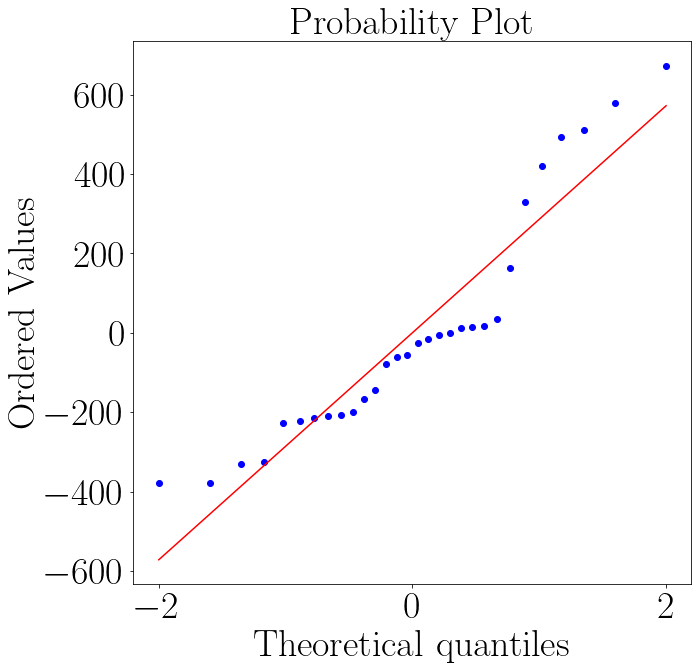


FIGURE 8.39 – QQ plot of the SDNN of the FIGURE 8.40 – Residual plot of the SDNN of blind participants on each method. the blind participants on each method.

skin conductance variation, thus in the Mental Workload. Although, in the Figure 8.37 it is posible to notice that the ”Base”and the ”Audio”method have a different distribution. As it has already commented before, maybe the result of the anova test is a conseguence of a small sample size.

### 8.1.3 Final Remarks

The “Audio” method showed a higher performance among the other methods and the use of a haptic device decreased the performance of all methods. This probably happened because the participants are already used to use sound to guide themselves, especially environmental sounds. The environment sounds used inside the scenes that gave hints about locations where always the same (telephone ringing, laptop keyboard sounds, exterior noise, door opening and closing). It is likely that the participants felt more secure when it only had to focus on the sounds around him/her. This is reinforced by the fact that, during the“Audio”only guidance, half of the participants did not called for any command, or used only a few times the audio command option.

The fact that the haptic devices caused a higher average and a higher variation is probably due to the fact that the users had to learn and get used with them. Besides, for being just conceptual, their precision was not as big as they were expecting. That explains why their results were not as good as the “Base” or “Audio” methods and these results are correctly related to the satisfaction questionnaires, which scored them as the unsatisfied devices.

The ANOVA test from the mental demand did not prove any influence of the method nor the rounds, but the same test for the NASA-TLX score proved a influence of these both factors. That means that the methods influenced the score in other NASA-TLX dimension.

The SAGAT’s ANOVA proved that the round did influenced the participants average score, meaning that they did learn from one round to another and that effect was a natural thing, not an effect caused by the devices.

The other ANOVA tests were inconclusive, but most of their boxplots most showed a difference between the methods. In these cases the reason is the small sample size and the sample’s variety. The blind participants age range was from 26 to 56, with an average of 43.5 years, and the education range was from High School to 2 graduations. That may impact the user experience as well in the questionnaires’ answer.

But all the participants showed a great enthusiasm before, during and after the research. They also recommend some modifications that would bring more realism for they.

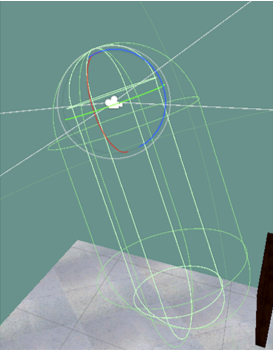
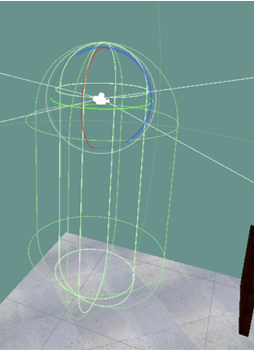
And of course, they made some complaints, such as:

* The speakers inside the HMD were not could enough for some to give them the precise location of its origin;
* The HMD was big enough to cover have of the participant’s face and that gave them a strange sensation, since some of them use the air or the wind feeling on the face

to give them hints about the location of walls or other high obstacles;

* As said before, the precision of the vibration was not good for them to use the devices. That is mainly because of how the HMD position the user inside the virtual environment.

The user is represented as a vertical capsule, and the HMD is positioned on the top end of that capsule. If the user tilts his/her head down, as if they were facing the ground, the capsule rotates in relation to the HMD point making the virtual body of the user occupy a total different space from the reality. The Figure 8.41 represents that situation.



(b) The user’s capsule while the participant is straight (a) The user’s capsule while the participant is straight but looking down. and looking forward.

FIGURE 8.41 – Two different capsule positions based on the user’s head position.

* The vibration from the haptic belt was not intense enough sometimes.

## 8.2 Comparison between BVI users and sighted users

In this section, the second goal of this experiment, “do non-BVI users, when deprived from their vision, evaluate assistive devices in a similar way as BVI users?”, will be linked with the gathered data and then compared with the results of the first goal’s section. It is expected that both results would be different. As was the last section, this section will also be divided in the same subsections.

### 8.2.1 Subjective data

Only two of the questionnaires will be analyzed, the NASA-TLX and the Adapted SAGAT, and it is expected that for:

* NASA-TLX;

There will be a noticeable difference between the sight sample mental workload and the blind sample mental workload.

* Adapted SAGAT;

Is expected to notice a difference between the“blind”sample and the“sight”sample.

#### 8.2.1.1 NASA-TLX

##### 8.2.1.1.1 Analysis of the mental demand scale

The Table 8.31 presents the mental demand averages of all participants on each scene and their average are plotted in the Figures from 8.42 to 8.44.

TABLE 8.31 – Mental demand felled by the participants.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual  Condition | Round |  |  |  |  |
| 001 | Sight | First | 12 | 11 | 5 | 9 |
|  |  | Return | 13 | 13 | 5 | 10 |
| 001C | Blind | First | 1 | 14 | 3 | 6 |
|  |  | Return | 1 | 10 | 2 | 6 |
| 002C | Blind | First | 1 | 1 | 10 | 12 |
|  |  | Return | 1 | 1 | 10 | 3 |
| 003 | Sight | First | 18 | 18 | 16 | 10 |
|  |  | Return | 12 | 15 | 11 | 8 |
| 003C | Blind | First | 5 | 5 | 8 | 1 |
|  |  | Return | 1 | 1 | 2 | 1 |
| 004 | Sight | First | 17 | 20 | 12 | 20 |
|  |  | Return | 12 | 15 | 10 | 15 |
| 004C | Blind | First | 10 | 15 | 10 | 10 |
|  |  | Return | 10 | 14 | 8 | 10 |
| 005 | Sight | First | 4 | 12 | 10 | 13 |
|  |  | Return | 6 | 10 | 6 | 12 |

The Figures 8.42 and 8.43 show a systematic reduction on the perceived mental demand

in all methods between the rounds for both groups. But the Figure 8.44 shows that the average of each method was very different between the two groups.

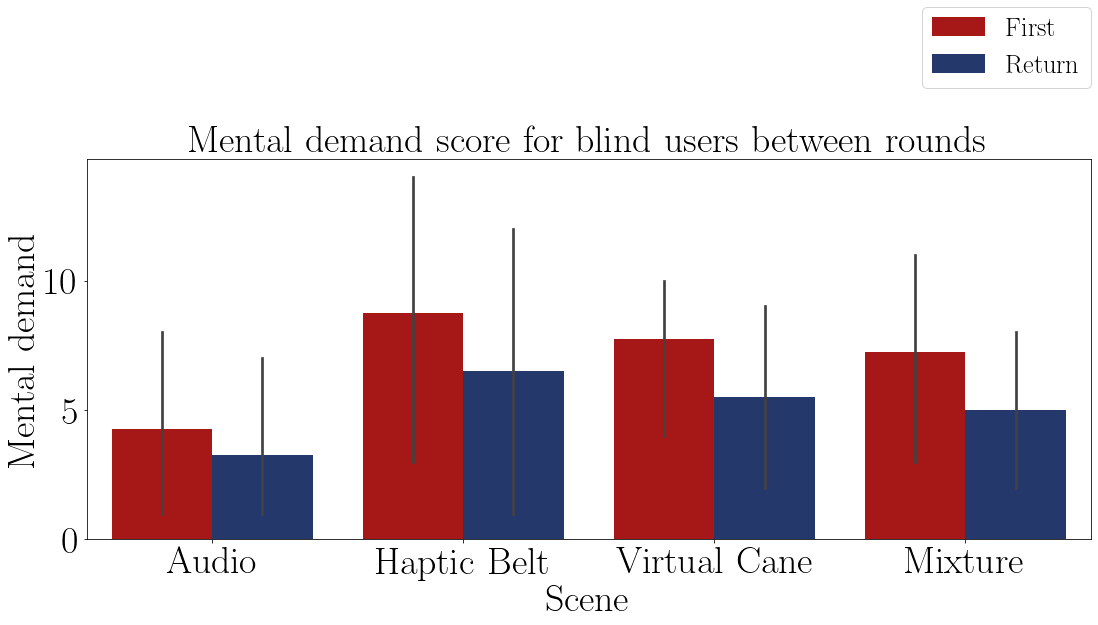


FIGURE 8.42 – Barplot of the average mental demand of the blind participants on each method and round.

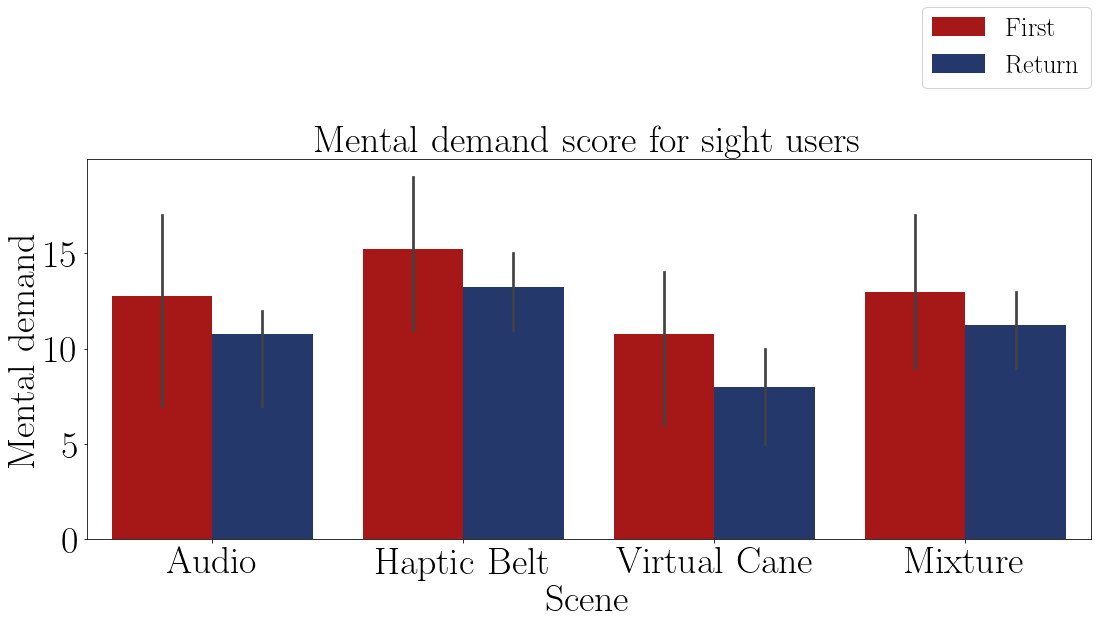


FIGURE 8.43 – Barplot of the average mental demand of the sight participants on each method and round.

The Figure 8.45 and 8.46 presents a box plot with the mental demand of both groups by method. These figures show that the reaction of each group is completelly different between the methods and rounds.

The Table 8.32 shows the average mental demand of both samples and is possible to notice how the average perceived mental demand by the sight sample was higher in every method.

The Figures 8.47 and 8.48 shows the distribution and variance of sighted participants in the Table 8.31. These Figures shows that the data are normally distributed and that

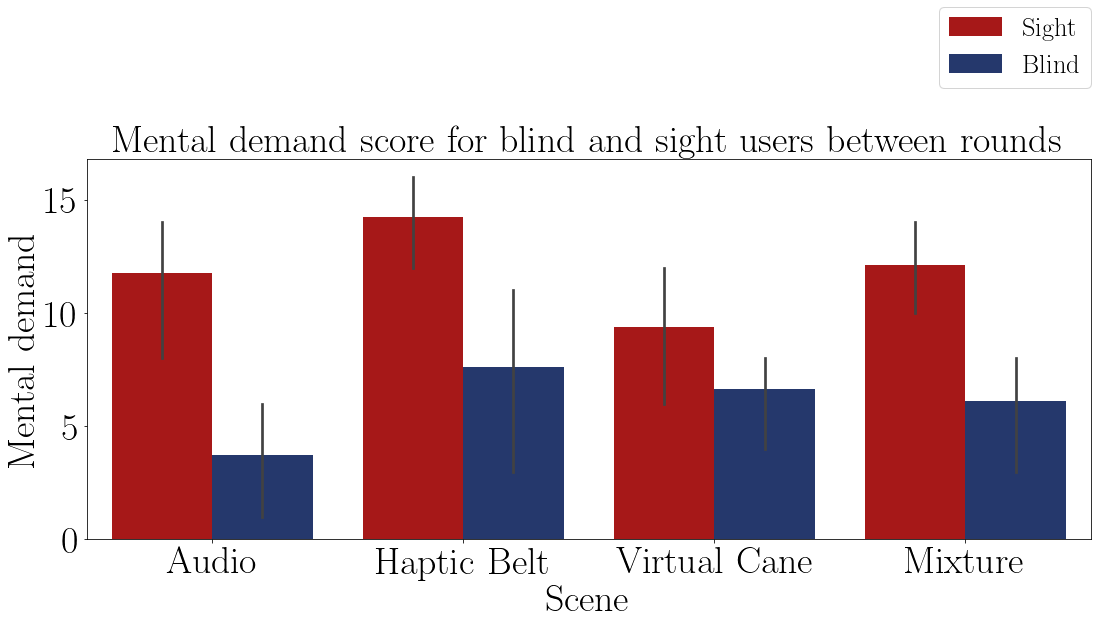


FIGURE 8.44 – Barplot of the average mental demand of both participants on each method.

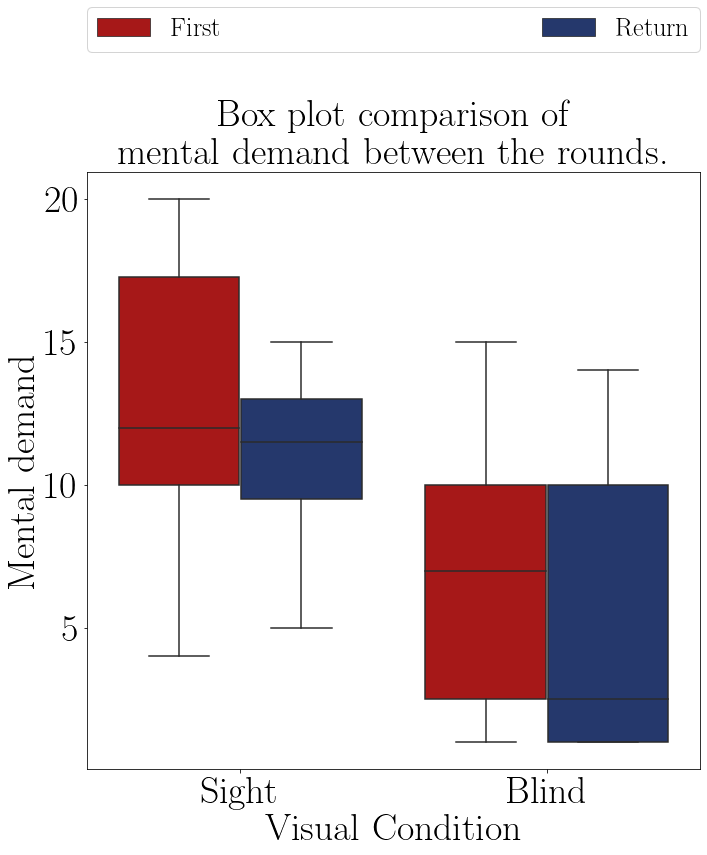
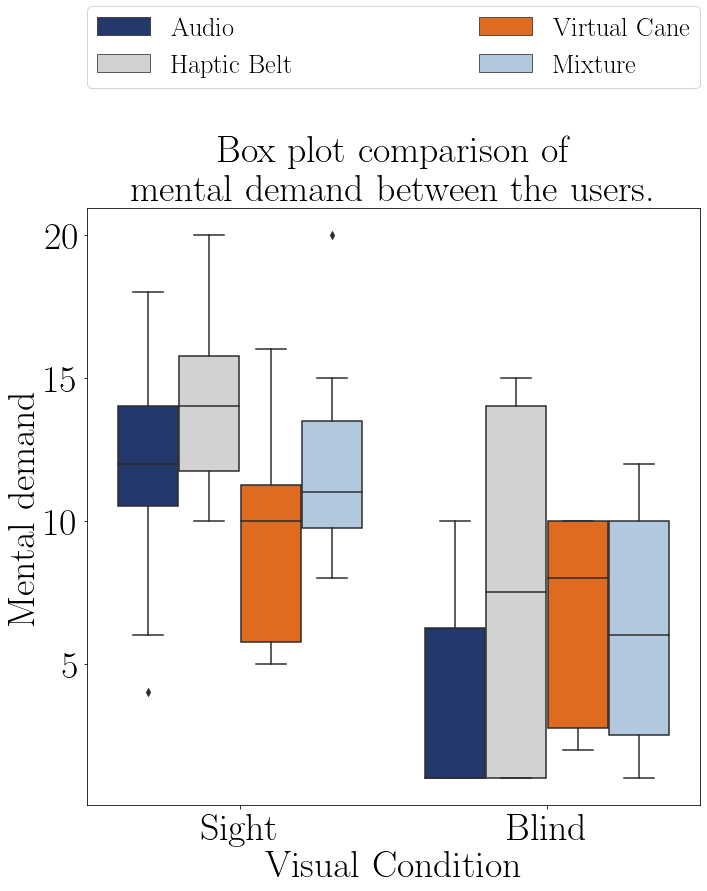


FIGURE 8.45 – Boxplot of the mental demand FIGURE 8.46 – Boxplot of the mental demand of the participants grouped by method. of the participants grouped by round.

TABLE 8.32 – Mental demand average grouped by participant and visual condition

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Visual Condition | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 3.75 | 7.62 | 6.62 | 6.125 |
| Sight | 11.75 | 14.25 | 9.38 | 12.125 |

the methods have a similar variance. The Table 8.33 shows the Anova test p-values of the mental demand of the ”sight” sample between the guidance methods. The method’s and the round’s p-values indicates that there is some influence of the method in the mental demand but no influence from the round or the interaction between them.

TABLE 8.33 – Anova p-value for the mental demand average on each method for sighted users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 202.250 | 3 | 67.417 | 6.547 |  |
| Methods | 95.750 | 3 | 31.917 | 3.099 | 0.049\*\* |
| Rounds | 36.125 | 1 | 36.125 | 3.508 | 0.075 |
| Interaction | 1.125 | 3 | 0.375 | 0.036 | 0.990 |
| Experimental Error | 216.250 | 21 | 10.298 |  |  |
| Total | 551.500 | 31 |  |  |  |

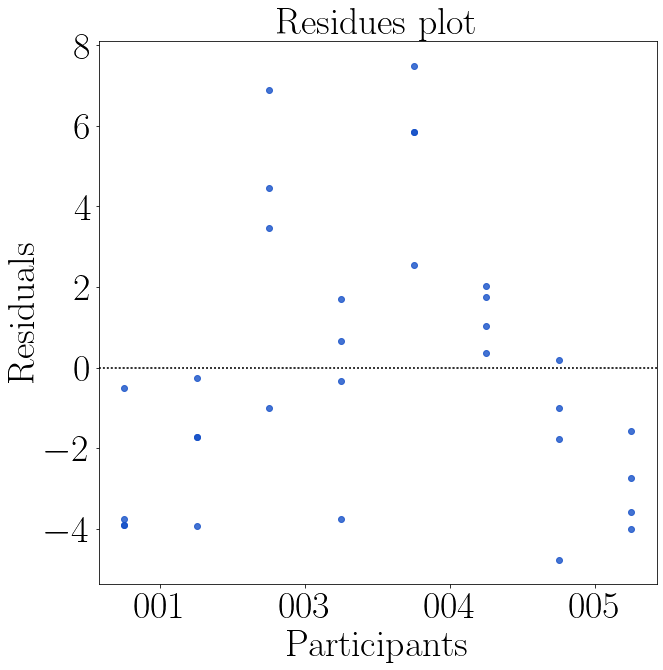
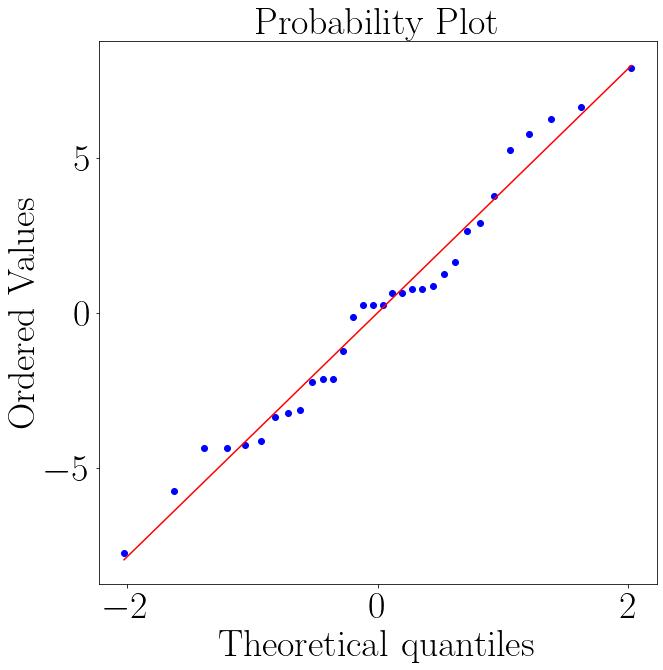


FIGURE 8.48 – Residual plot of the mental

FIGURE 8.47 – QQ plot of the mental demand demand score the sighted participants on each

of the sight participants on each method.

method.

The Table 8.34 presents the conclusion of a pairwise Fisher LSD test of the previous ANOVA test. The results show that only the ”Audio”has a similar mental demand as the ”Mixture” method.

TABLE 8.34 – Cross validation p-value for the mental demand average on each method for sighted users.

|  |  |  |  |
| --- | --- | --- | --- |
| Method | | | Analysis |
| Audio | *X* | Haptic Belt | *H*1 : *µAudio* ̸= *µHapticBelt* ∗∗ |
| Audio | *X* | Virtual Cane | *H*1 : *µAudio* ̸= *µV irtualCane* ∗∗ |
| Audio | *X* | Mixture | *H*0 : *µAudio* = *µMixture* |
| Haptic Belt | *X* | Virtual Cane | *H*1 : *µHapticBelt* ̸= *µV irtualCane* ∗∗ |
| Haptic Belt | *X* | Mixture | *H*1 : *µHapticBelt* ̸= *µMixture* ∗∗ |
| Virtual Cane | *X* | Mixture | *H*1 : *µV irtualCane* ̸= *µMixture* ∗∗ |

The Table 8.35 shows the average of the mental demand variation between the rounds. This table shows that the mental demand variation from the “Audio” has the lower variation, and the rest are similar variations.

The Figures 8.49 and 8.50 shows the distribution and variance of the mental demand variation of the Table 8.1. These Figures shows that the data are normally distributed and

TABLE 8.35 – Mental demand variation grouped by participant and visual condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | -2.5 | -1.0 | -2.2 | -2.2 | -2.2 |
| Sight | -1.0 | -2.0 | -2.0 | -2.8 | -1.8 |

that the methods have a similar variance. The Table 8.36 shows the Anova test p-value of the mental demand of the ”sight” sample between the guidance methods. The p-value indicates that there is no influence of the methods in the variation of mental demand between the rounds.

TABLE 8.36 – Anova p-value for the mental demand variation on each method for sighted users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (blocks) | 74.250 | 3 | 0.750 | 6.319 |  |
| Method | 2.250 | 3 | 24.750 | 0.191 | 0.900 |
| Experimental error | 35.250 | 9 | 3.917 |  |  |
| Total | 111.750 | 15 |  |  |  |

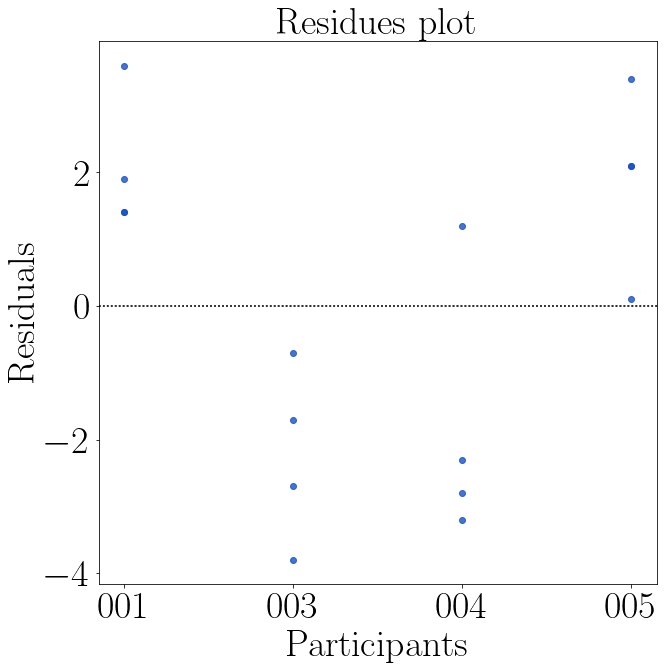
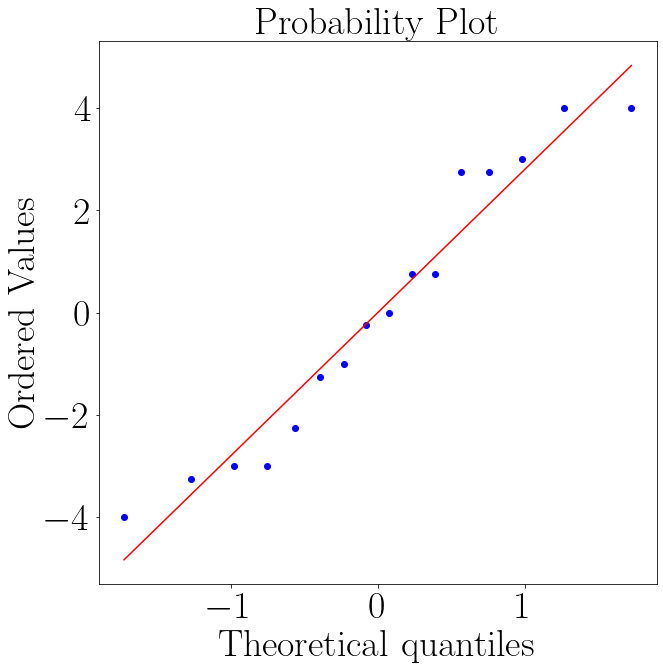


FIGURE 8.49 – Residual plot of the mental de- FIGURE 8.50 – Residual plot of the mental demand variation of the blind participants on each mand variation of the sighted participants on method. each method.

To close up, according to the ANOVA test at Table 8.34 the method do have influence on the mental demand of the sighted participant and that the ”Audio”and the ”Mixture” method have the same mental demand for them. This differs from the result of the previous section that was the ANOVA did not prove any effect and that the ”Audio”and ”Mixture” methods could not be said to be similar. Although for the ”blind” users, they were also the methods that caused the lowest mental demand.

There is no influence in the tested methods in the participants mental demand variation, as shown in the Table 8.36.

##### 8.2.1.1.2 Analysis of the NASA-TLX score

The Table 8.37 presents the NASA-TLX score of all participants on each scene and their average are plotted in the Figures from 8.51 to 8.53.

TABLE 8.37 – NASA-TLX score felled by the participants.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual  Condition | Round |  |  |  |  |
| 001 | Sight | First | 10.167 | 9.833 | 7.000 | 9.000 |
|  |  | Return | 11.000 | 10.833 | 6.167 | 9.333 |
| 001C | Blind | First | 4.000 | 8.833 | 5.167 | 6.333 |
|  |  | Return | 4.000 | 6.667 | 4.500 | 6.167 |
| 002C | Blind | First | 4.833 | 4.833 | 9.000 | 7.000 |
|  |  | Return | 4.833 | 4.833 | 7.000 | 5.167 |
| 003 | Sight | First | 9.833 | 10.167 | 9.500 | 6.500 |
|  |  | Return | 6.667 | 9.667 | 7.833 | 4.833 |
| 003C | Blind | First | 4.000 | 5.333 | 6.667 | 3.500 |
|  |  | Return | 3.833 | 3.667 | 3.500 | 3.500 |
| 004 | Sight | First | 14.833 | 13.667 | 11.500 | 15.833 |
|  |  | Return | 11.833 | 11.833 | 10.833 | 12.167 |
| 004C | Blind | First | 10.000 | 12.667 | 9.667 | 11.000 |
|  |  | Return | 9.167 | 11.667 | 9.333 | 10.833 |
| 005 | Sight | First | 7.667 | 9.000 | 8.000 | 9.667 |
|  |  | Return | 7.667 | 8.667 | 7.667 | 6.000 |

The Figures 8.51 and 8.52 also show a decrease of the score on in all methods between the rounds for both groups and the Figure 8.53 shows that the average of each method was very different between the two groups, as it was with the mental demand.

The Figure 8.54 and 8.55 presents a box plot with the NASA-TLX score of both groups by method. These figures show that the reaction of each group is also different between the methods and rounds.

The Table 8.38 shows the average NASA-TLX score of both samples and is possible to notice how the average perceived NASA-TXL average by the sight sample was also higher in every method.

The Figures 8.56 and 8.57 shows the distribution and variance of sighted participants in the Table 8.37. These Figures shows that the data are normally distributed and that

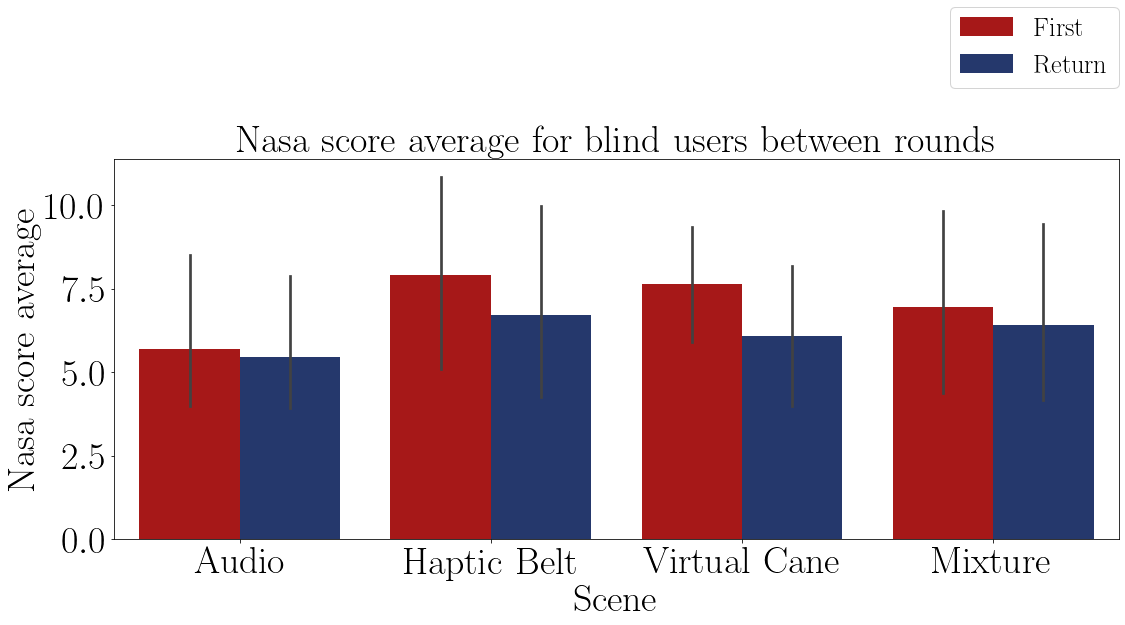


FIGURE 8.51 – Barplot of the NASA-TLX score of the blind participants on each method and round.

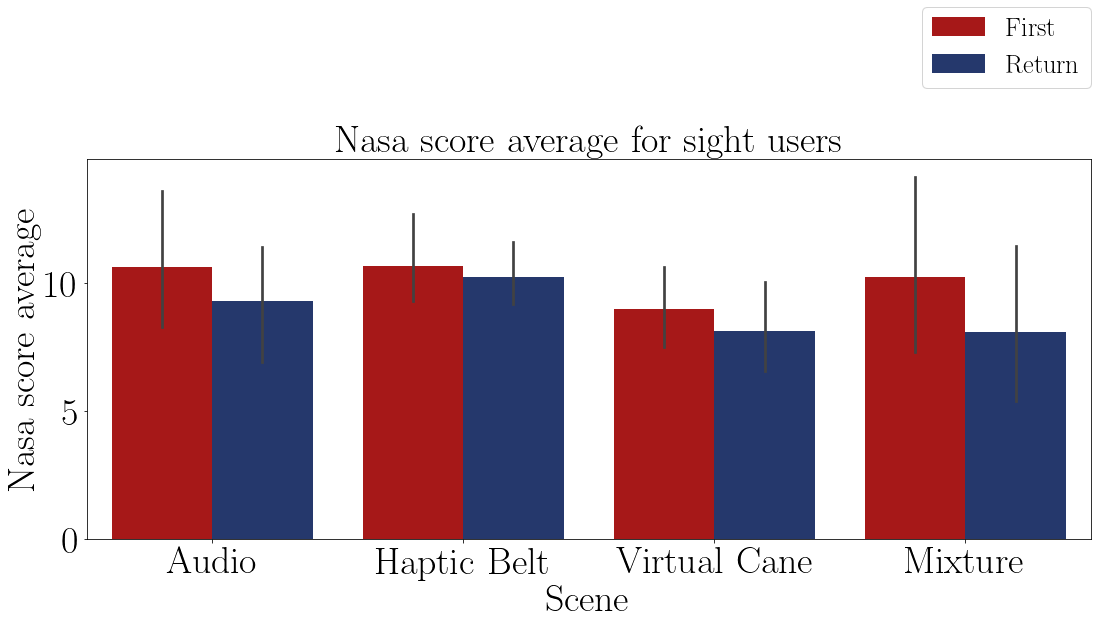


FIGURE 8.52 – Barplot of the NASA-TLX score of the sight participants on each method and round.

TABLE 8.38 – Average NASA-TLX score grouped by participant and visual condition

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Visual Condition | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 5.58 | 7.31 | 6.85 | 6.688 |
| Sight | 9.96 | 10.46 | 8.56 | 9.167 |

the methods have a similar variance. The Table 8.39 shows the ANOVA test p-values of the NASA-TLX score of the ”sight”sample between the guidance methods and they show that the round has an effect on the score.

The Table 8.40 shows the average of the NASA-TLX score variation between the rounds. This table shows that the score variation from the“Audio”has the lower variation, and the rest are similar variations.

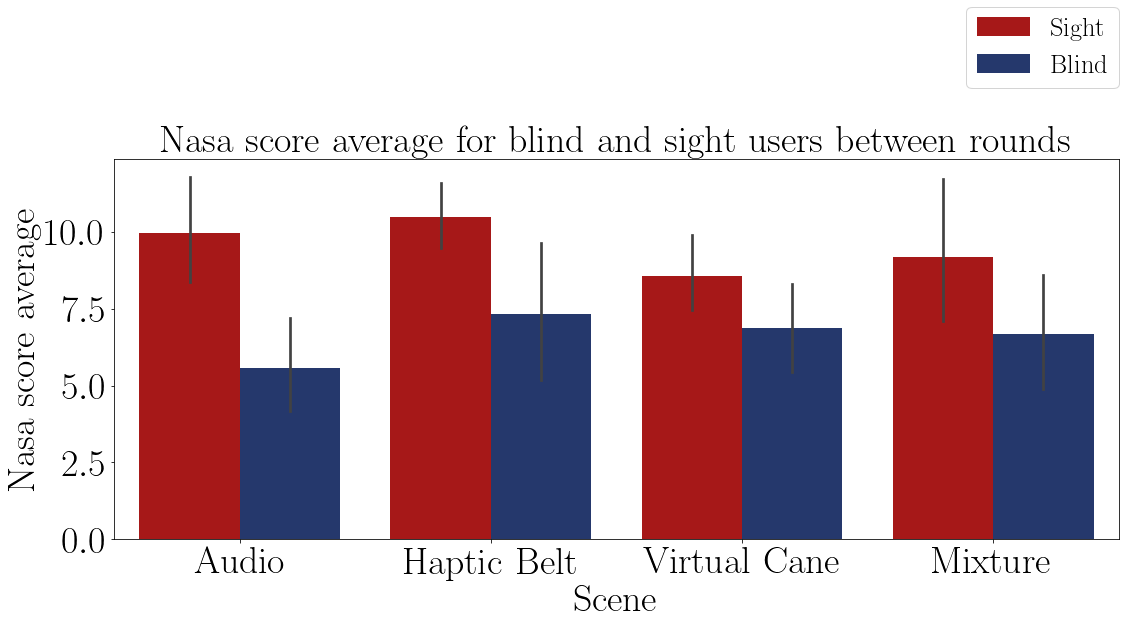


FIGURE 8.53 – Barplot of the NASA-TLX score of both participants on each method.

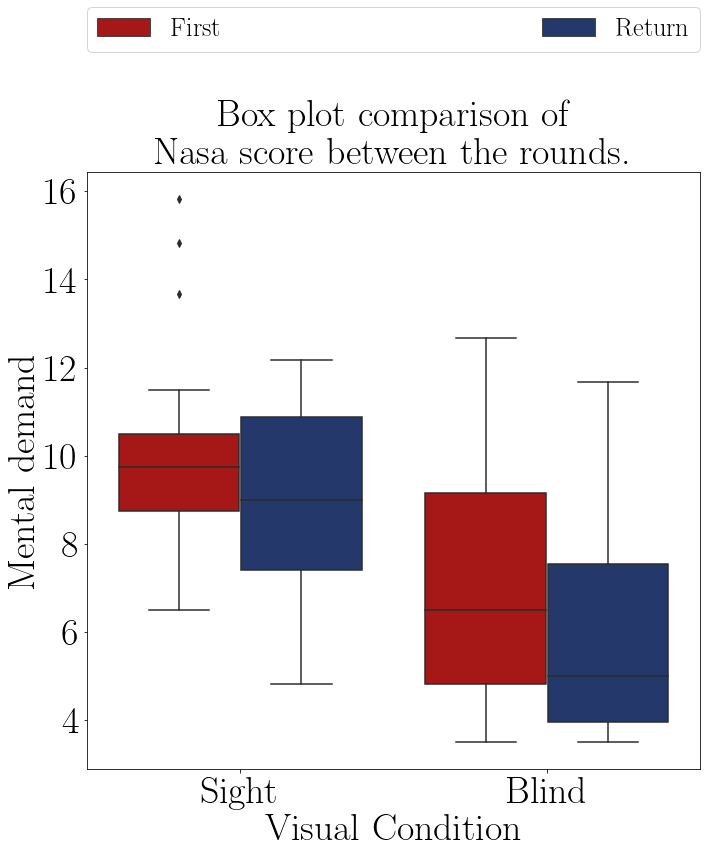
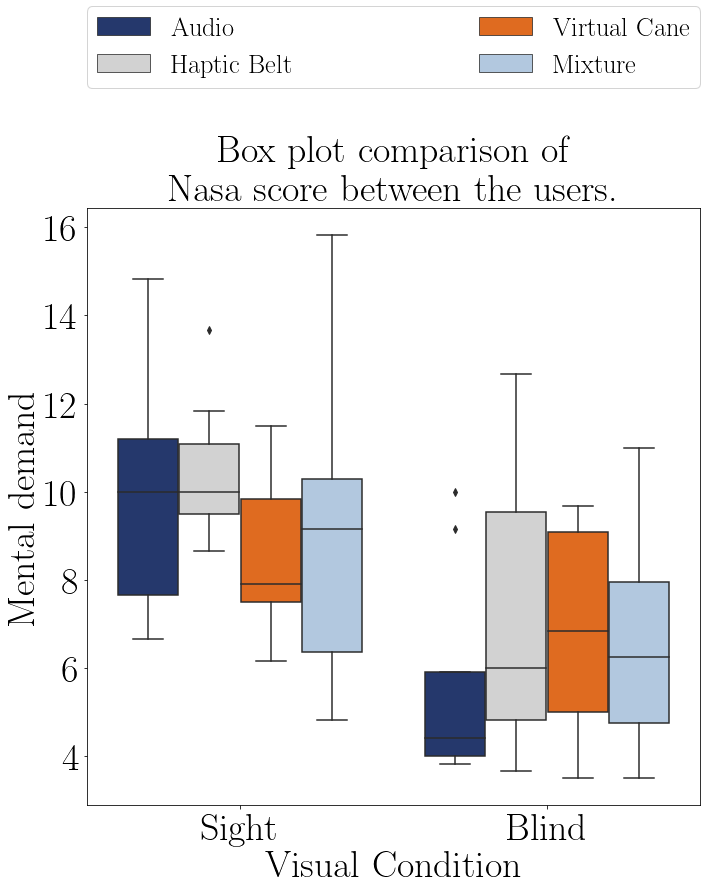


FIGURE 8.54 – Boxplot of the NASA-TLX FIGURE 8.55 – Boxplot of the NASA-TLX score of the participants grouped by method. score of the participants grouped by round.

TABLE 8.39 – Anova p-value for the NASA-TLX score on each method for sighted users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 120.766 | 3 | 40.255 | 17.948 |  |
| Methods | 16.905 | 3 | 5.635 | 2.512 | 0.086 |
| Rounds | 11.480 | 1 | 11.480 | 5.118 | 0.034\*\* |
| Interaction | 3.343 | 3 | 1.114 | 0.497 | 0.688 |
| Experimental Error | 47.102 | 21 | 2.243 |  |  |
| Total | 199.596 | 31 |  |  |  |

The Figures 8.58 and 8.59 shows the distribution and variance of the NASA-TLX score variation of the Table 8.1. These Figures shows that the data are normally distributed and

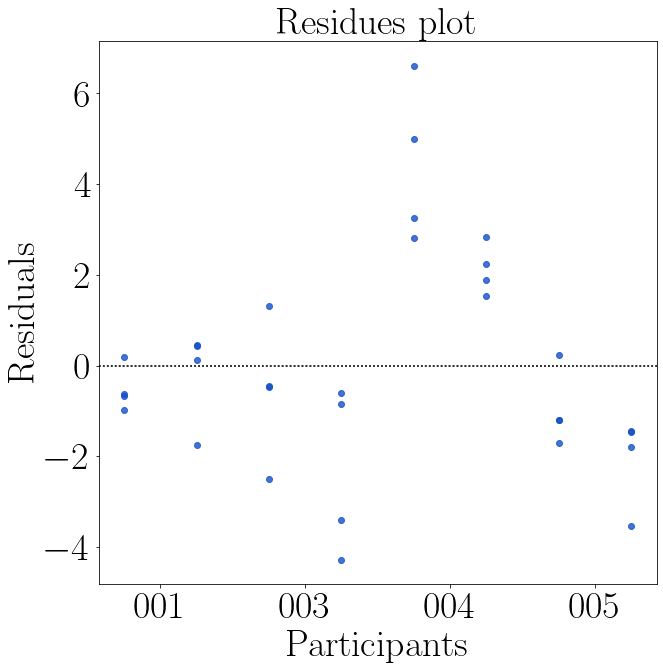
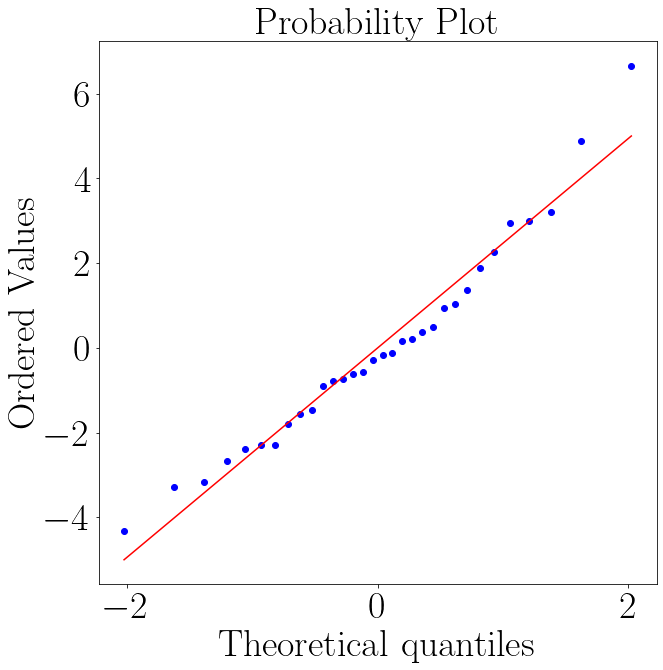


FIGURE 8.57 – Residual plot of the NASAFIGURE 8.56 – QQ plot of the NASA-TLX

TLX score the sight participants on each

score of the sight participants on each method. method.

TABLE 8.40 – NASA-TLX score grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | -0.92 | -0.25 | -1.21 | -1.54 | -0.54 |
| Sight | -0.04 | -1.33 | -0.42 | -0.87 | -2.17 |

that the methods have a similar variance. The Table 8.41 shows the Anova test p-value of the NASA-TLX score of the ”sight” sample between the guidance methods and it proves that there is no influence of the methods in the variation of score between the rounds.

TABLE 8.41 – Anova p-value for the NASA score variation on each method for sighted users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (blocks) | 15.436 | 3 | 2.229 | 3.517 |  |
| Method | 6.686 | 3 | 5.145 | 1.523 | 0.274 |
| Experimental error | 13.168 | 9 | 1.463 |  |  |
| Total | 35.290 | 15 |  |  |  |

To close up, according to the ANOVA test at Table 8.39 the methods do not an effect on the score, but rounds do. The blind users felt an impact on both the method and the round.

There is no influence in the tested methods in the participants NASA-TLX score variation, as shown in the Table 8.41.

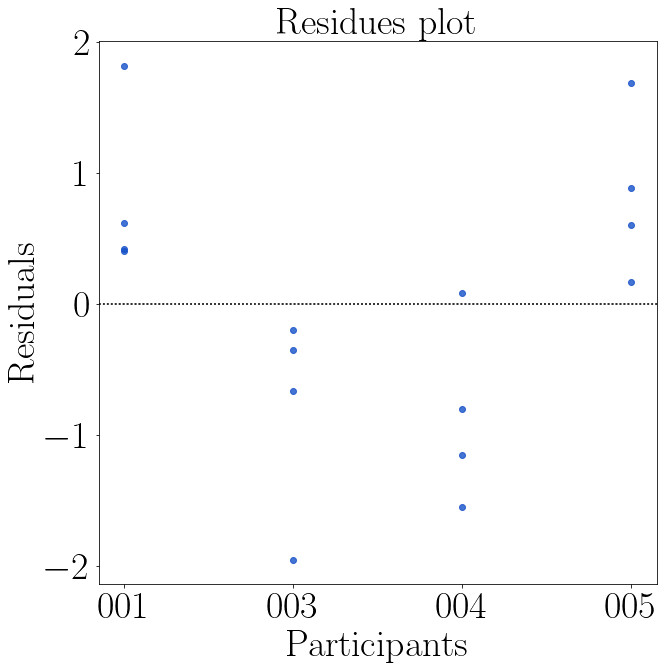
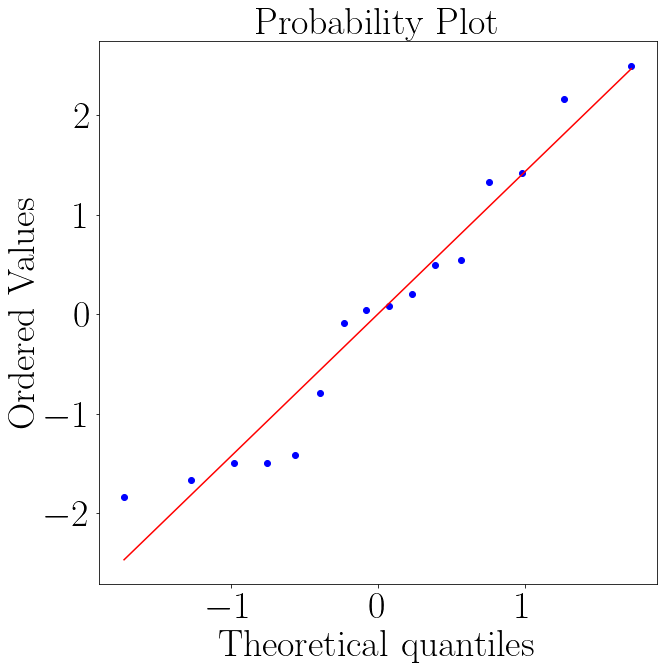


FIGURE 8.58 – Residual plot of the variation FIGURE 8.59 – Residual plot of the variation NASA-TLX score of the blind participants on NASA-TLX score of the sighted participants on each method. each method.

#### 8.2.1.2 Adapted SAGAT

The Table 8.42 presents the SAGAT score of all participants on each scene and their average are plotted in the Figures from 8.60 to 8.62.

TABLE 8.42 – SAGAT global score felled by the participants.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual  Condition | Round |  |  |  |  |
| 001 | Sight | First | 4.500 | 4.330 | 2.660 | 6.500 |
|  |  | Return | 6.000 | 5.000 | 5.000 | 4.500 |
| 001C | Blind | First | 5.500 | 5.330 | 5.830 | 3.500 |
|  |  | Return | 6.500 | 8.500 | 5.500 | 5.500 |
| 002C | Blind | First | 4.500 | 3.990 | 4.500 | 6.250 |
|  |  | Return | 5.000 | 4.000 | 6.500 | 8.500 |
| 003 | Sight | First | 6.750 | 5.990 | 3.990 | 6.750 |
|  |  | Return | 6.000 | 7.250 | 6.250 | 7.500 |
| 003C | Blind | First | 7.500 | 7.490 | 4.660 | 9.000 |
|  |  | Return | 10.000 | 8.500 | 9.000 | 9.000 |
| 004 | Sight | First | 7.250 | 7.990 | 5.990 | 8.250 |
|  |  | Return | 7.750 | 9.500 | 8.250 | 7.000 |
| 004C | Blind | First | 6.000 | 7.660 | 4.990 | 6.500 |
|  |  | Return | 6.000 | 9.250 | 7.250 | 9.000 |
| 005 | Sight | First | 3.000 | 3.160 | 3.990 | 4.000 |
|  |  | Return | 3.750 | 3.000 | 2.000 | 6.000 |

The Figures 8.60 and 8.61 also show a increase of the score on in all methods between the rounds for both groups, with only the exception of the ”Mixture” method with the sighted users, and the Figure 8.62 shows that the average the blind users were higher than the sighted users.

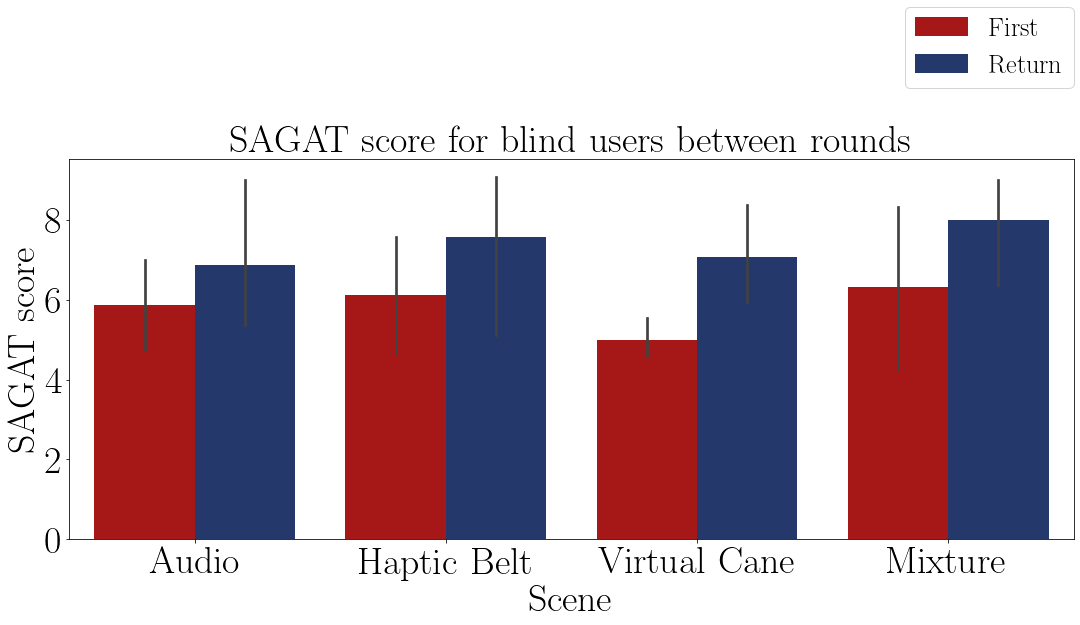


FIGURE 8.60 – Barplot of the SAGAT score of the blind participants on each method and round.

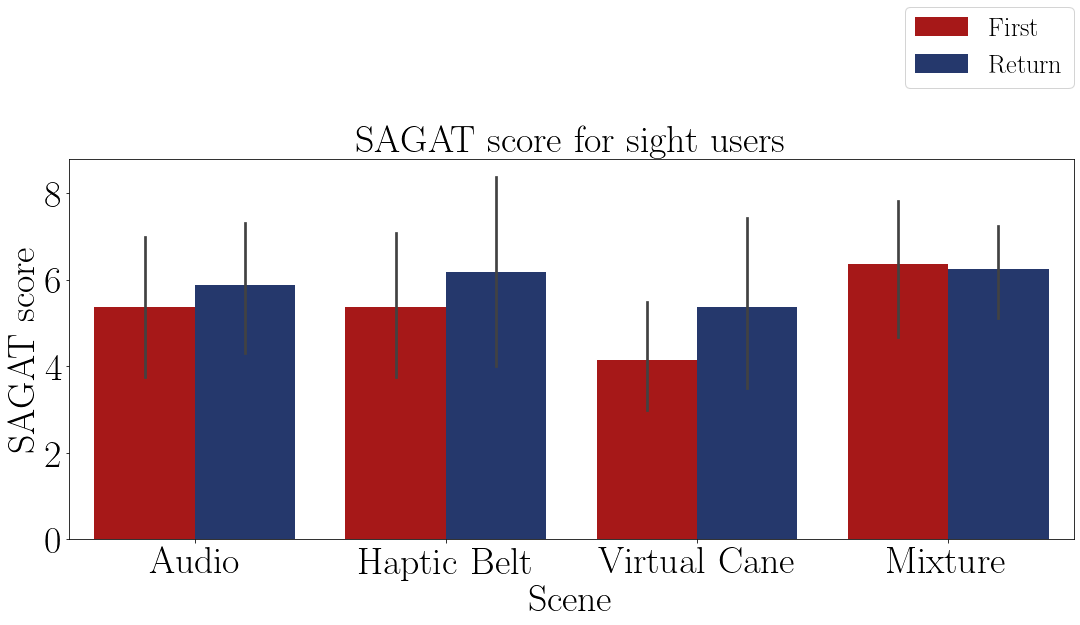


FIGURE 8.61 – Barplot of the SAGAT score of the sight participants on each method and round.

The Figure 8.63 and 8.64 presents a box plot with the SAGAT score of both groups by method and rounds in that order. These figures show that the reaction of each group is also different between the methods and rounds, with the ”blind”.

The Table 8.43 shows the average SAGAT score of both samples and is possible to notice how the average score by the blind users was higher in every method.

The Figures 8.65 and 8.66 shows the distribution and variance of sighted participants in the Table 8.42. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.44 shows the ANOVA test p-values of the SAGAT score of the ”sight” sample between the guidance methods and they show that the methods had an effect on the score.

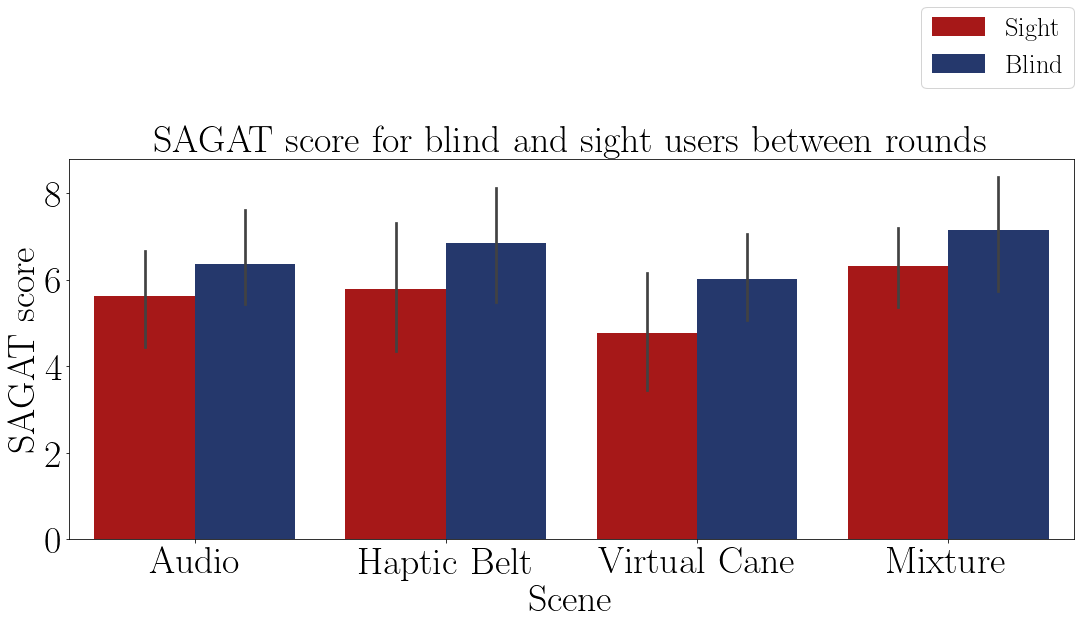


FIGURE 8.62 – Barplot of the SAGAT score of both participants on each method.

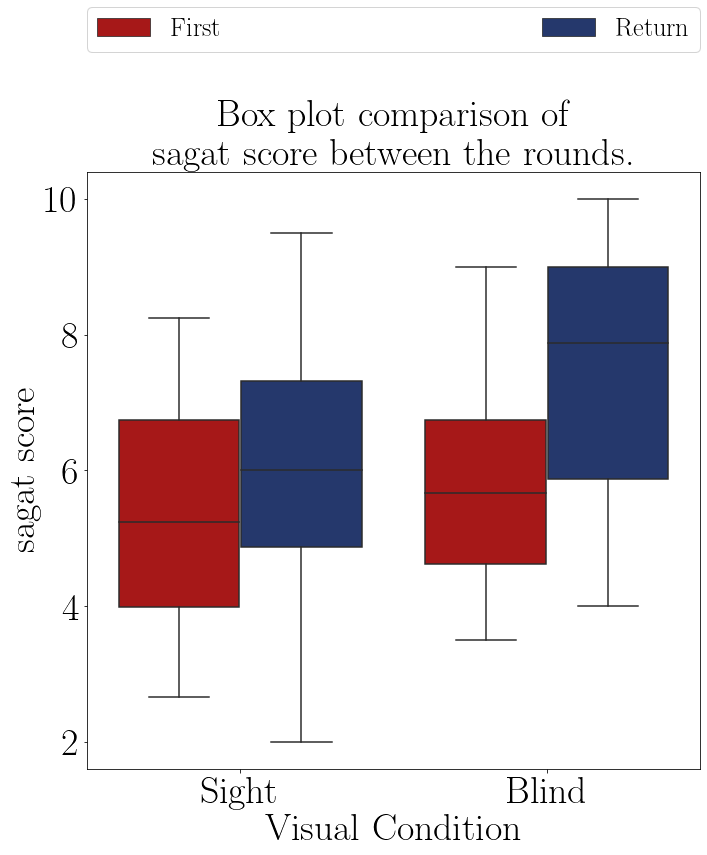
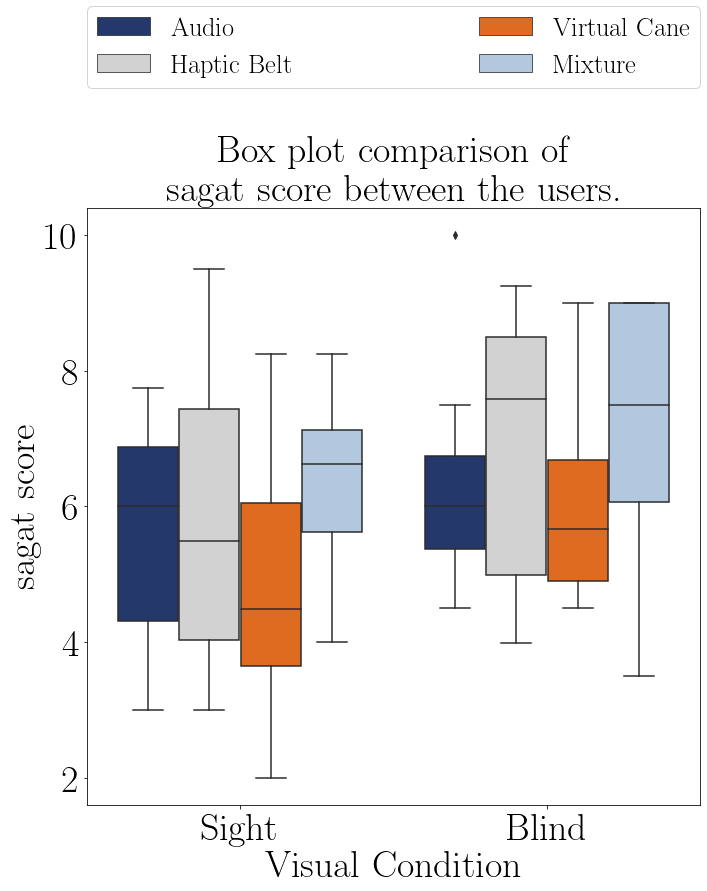


FIGURE 8.63 – Boxplot of the NASA-TLX FIGURE 8.64 – Boxplot of the NASA-TLX score of the participants grouped by method. score of the participants grouped by round.

TABLE 8.43 – Adapted Sagat average global score grouped by participant and visual Condition.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Visual Condition | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 6.38 | 6.84 | 6.03 | 7.156 |
| Sight | 5.62 | 5.78 | 4.77 | 6.312 |

The Table 8.45 presents the conclusion of a pairwise Fisher LSD test of the previous ANOVA test. The results show that only the ”Audio”and the ”Haptic Belt”had a similar SAGAT score. This is different than the result from the ANOVA of the blind users, which indicated for them that the rounds had an effect.

TABLE 8.44 – Anova p-value for the SAGAT score on each method for sighted users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 77.492 | 3 | 25.831 | 27.053 |  |
| Methods | 9.866 | 3 | 3.289 | 3.444 | 0.035\*\* |
| Rounds | 2.910 | 1 | 2.910 | 3.048 | 0.095 |
| Interaction | 1.931 | 3 | 0.644 | 0.674 | 0.578 |
| Experimental Error | 20.051 | 21 | 0.955 |  |  |
| Total | 112.250 | 31 |  |  |  |

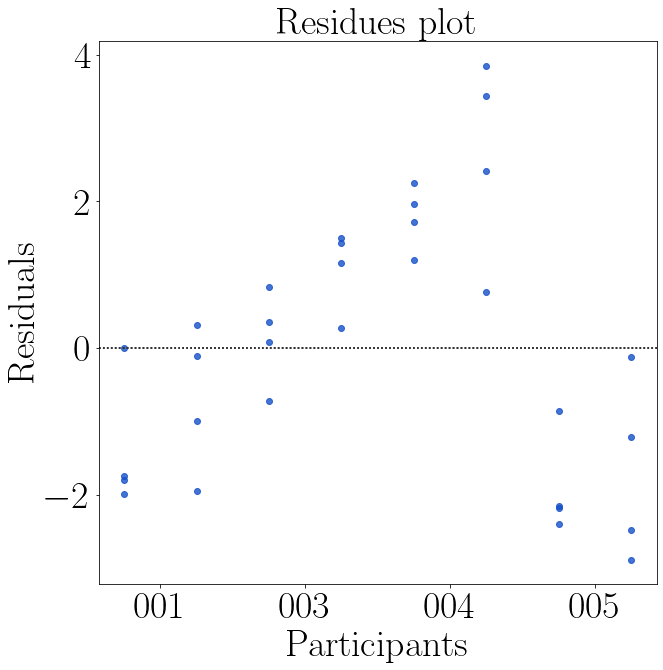
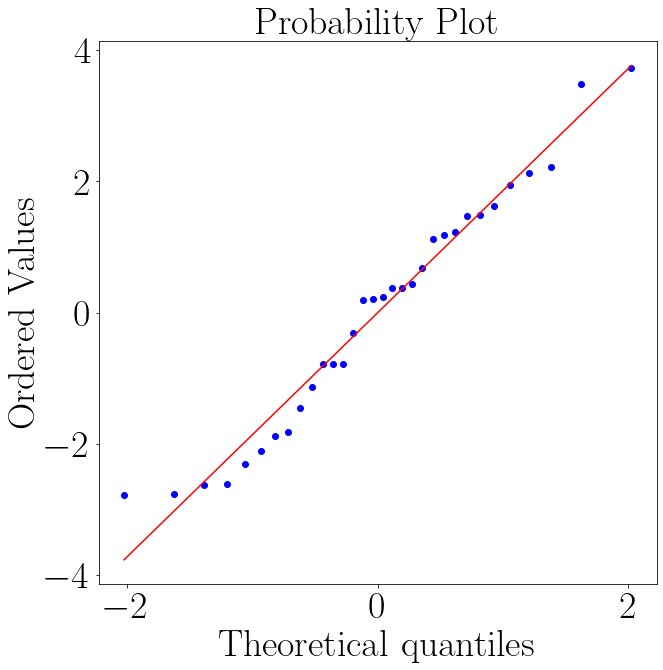


FIGURE 8.66 – Residual plot of the mental

FIGURE 8.65 – QQ plot of the mental demand demand score the sight participants on each

of the sight participants on each method. method.

TABLE 8.45 – Cross validation p-value for the SAGAT score on each method for sighted users.

|  |  |  |  |
| --- | --- | --- | --- |
| Method | | | Analysis |
| Audio | *X* | Haptic Belt | *H*0 : *µAudio* = *µHapticBelt* |
| Audio | *X* | Virtual Cane | *H*1 : *µAudio* ̸= *µV irtualCane* ∗∗ |
| Audio | *X* | Mixture | *H*1 : *µAudio* ̸= *µMixture* ∗∗ |
| Haptic Belt | *X* | Virtual Cane | *H*1 : *µHapticBelt* ̸= *µV irtualCane* ∗∗ |
| Haptic Belt | *X* | Mixture | *H*1 : *µHapticBelt* ̸= *µMixture* ∗∗ |
| Virtual Cane | *X* | Mixture | *H*1 : *µV irtualCane* ̸= *µMixture* ∗∗ |

The Table 8.46 shows the average of the SAGAT score variation between the rounds. This table and the Figure 8.64 show that, besides the higher average score, the blind users also had a higher variation between the rounds.

The Figures 8.67 and 8.68 shows the distribution and variance of the mental demand variation of the Table 8.12. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.47 shows the Anova test p-value of the SAGAT score of the ”sight” sample between the guidance methods and it proves that there is no influence of the methods in the variation of mental demand

TABLE 8.46 – Adapted Sagat global score variation grouped by participant and visual Condition

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Visual Condition | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 15.66 | 23.49 | 44.30 | 32.90 |
| Sight | 13.53 | 12.59 | 33.12 | 3.80 |

between the rounds.

TABLE 8.47 – Anova p-value for the SAGAT score variation on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (blocks) | 1030.664 | 3 | 612.533 | 0.209 |  |
| Method | 1837.598 | 3 | 343.555 | 0.373 | 0.775 |
| Experimental error | 14788.556 | 9 | 1643.173 |  |  |
| Total | 17656.818 | 15 |  |  |  |

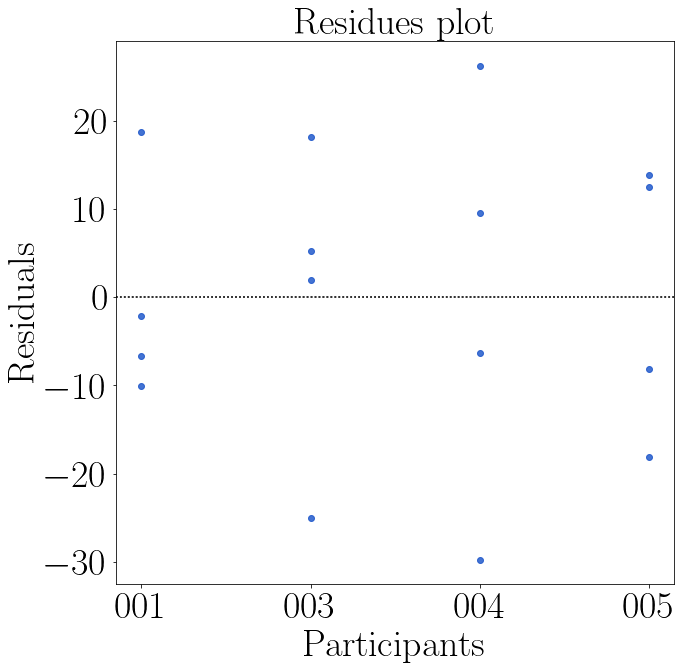
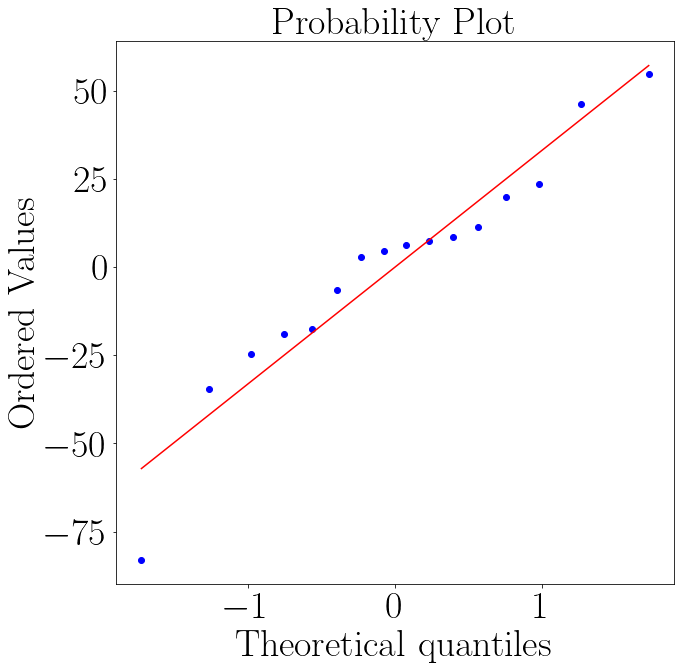


FIGURE 8.67 – Residual plot of the variation FIGURE 8.68 – Residual plot of the variation SAGAT score of the blind participants on each SAGAT score of the sighted participants on method. each method.

To close up, according to the Tables 8.43 and 8.46 with the Figures 8.63 and 8.64 the blind user scored a higher SAGAT score than the sight user with the same conditions and devices. Besides that, the ANOVA and the LSD Fisher Test at Tables 8.44 and 8.45 show that for the sight user the methods impact more their score, whilst the blind user were affected more with the rounds.

There is no influence in the tested methods in the participants mental demand variation, as shown in the Table 8.47.

### 8.2.2 Physiological data

The same sensors used for the first objective are used for the second objective. The expectations for all of the results is a difference between the“blind”sample and the“sight” sample. This subsection was divided in the same way as before:

* Electrocardiogram (ECG) data;

Two features are extracted from the ECG, heartrate (BPM) and heartrate variance (SDNN).

Is expected that the heartrate increases at every “First” round and then a slight decrease in the next round. The heartrate variance is expected to decrease in the “First” round and a slight increase in the next round.

* Galvanic skin reaction and temperature data;;

Is expected that the GSR average to increase at every “First” round and then a slight decrease in the next round.

#### 8.2.2.1 Electrocardiogram (ECG) data

##### 8.2.2.1.1 Analysis of the heartbeat frequency (BPM)

The Table 8.48 presents the average heart rate by each participant on each scenes and they are plotted in the Figures 8.69 to 8.71.

The Figures 8.69 show and increase between all methods, whilst the Figure 8.70 also presents a decrease in two methods. The Figure 8.71 shows that in most methods, the average BPM of the sight users was slight higher than the blind users.

The Figure 8.72 and 8.73 presents a box plot with the average BPM of both groups by method and rounds in that order. These figures show the reaction of the sight user was very different from the blind users, in all methods and rounds.

The Table 8.49 shows the average heartrate of both samples and is possible to notice how the average score by the blind users was higher in every method, apart of the ”Haptic

Belt”.

The Figures 8.74 and 8.75 shows the distribution and variance of sighted participants of the Table 8.48. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.50 shows the ANOVA test p-values of the average heartrate of the ”sight”sample between the guidance methods and they show that the methods had an effect on the score.

TABLE 8.48 – ECG average BPM felled by the participants using the proposed methods.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Part. | Visual  Condition | Round |  |  |  |  |
| 001 | Sight | First | 71.23 | 63.02 | 64.85 | 58.77 |
|  |  | Return | 73.18 | 61.18 | 66.78 | 66.26 |
| 001C | Blind | First | 60.71 | 71.17 | 59.07 | 68.24 |
|  |  | Return | 58.61 | 66.22 | 64.20 | 70.76 |
| 002C | Blind | First | 38.67 | 48.74 | 46.89 | 52.23 |
|  |  | Return | 47.58 | 58.97 | 56.75 | 58.25 |
| 003 | Sight | First | 63.47 | 71.80 | 70.90 | 72.76 |
|  |  | Return | 72.75 | 71.23 | 67.49 | 73.01 |
| 003C | Blind | First | 69.89 | 70.95 | 69.41 | 66.94 |
|  |  | Return | 67.44 | 69.68 | 68.82 | 67.37 |
| 004 | Sight | First | 66.85 | 62.45 | 65.94 | 67.86 |
|  |  | Return | 69.48 | 65.65 | 64.58 | 71.86 |
| 004C | Blind | First | 73.55 | 73.70 | 71.94 | 74.03 |
|  |  | Return | 74.79 | 74.02 | 72.69 | 67.34 |
| 005 | Sight | First | 71.34 | 66.93 | 66.46 | 67.06 |
|  |  | Return | 69.57 | 65.97 | 67.00 | 65.47 |

TABLE 8.49 – ECG average BPM for each method grouped by visual condition.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Visual Condition | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 61.40 | 66.68 | 63.72 | 65.65 |
| Sight | 69.73 | 66.03 | 66.75 | 67.88 |

TABLE 8.50 – Anova p-value for the BPM on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 98.882 | 3 | 32.961 | 2.953 |  |
| Methods | 62.635 | 3 | 20.878 | 1.870 | 0.166 |
| Rounds | 12.193 | 1 | 12.193 | 1.092 | 0.308 |
| Interaction | 19.626 | 3 | 6.542 | 0.586 | 0.631 |
| Experimental Error | 234.427 | 21 | 11.163 |  |  |
| Total | 427.763 | 31 |  |  |  |

According to the ANOVA test at Table 8.50 there was no effect of the methods neither the rounds or their interaction, despite the fact that the Figure 8.72 showed a big difference between the methods. So the methods did not influence the sighted user mental workload.

The same conclusion was driven in the section 8.1.2.1 in the BPM part.

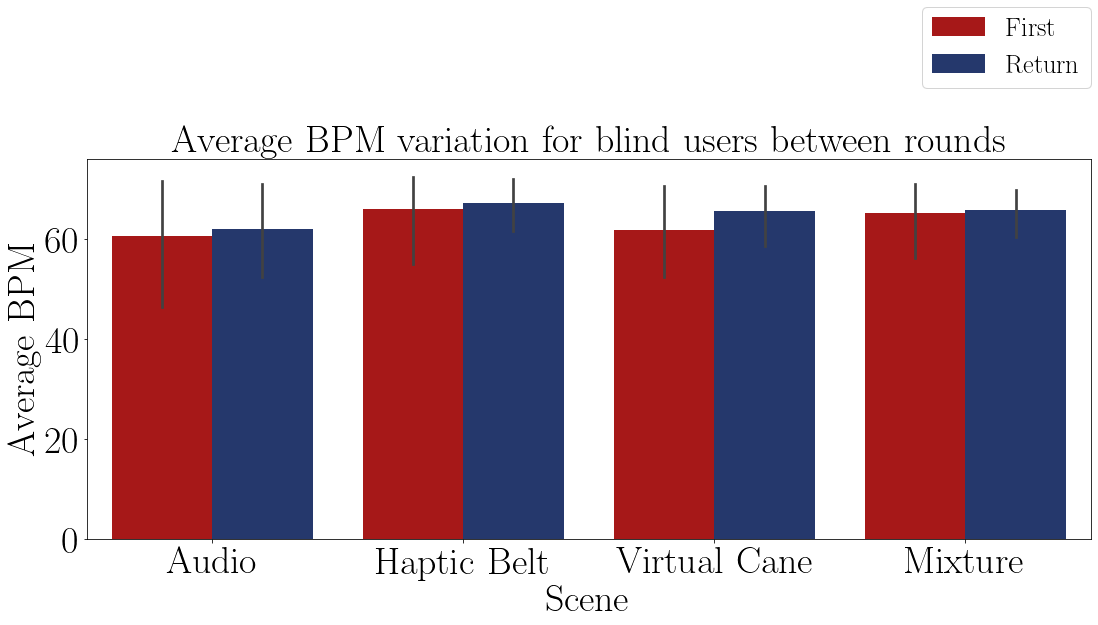


FIGURE 8.69 – Barplot of the average BPM of the blind participants on each method and round.

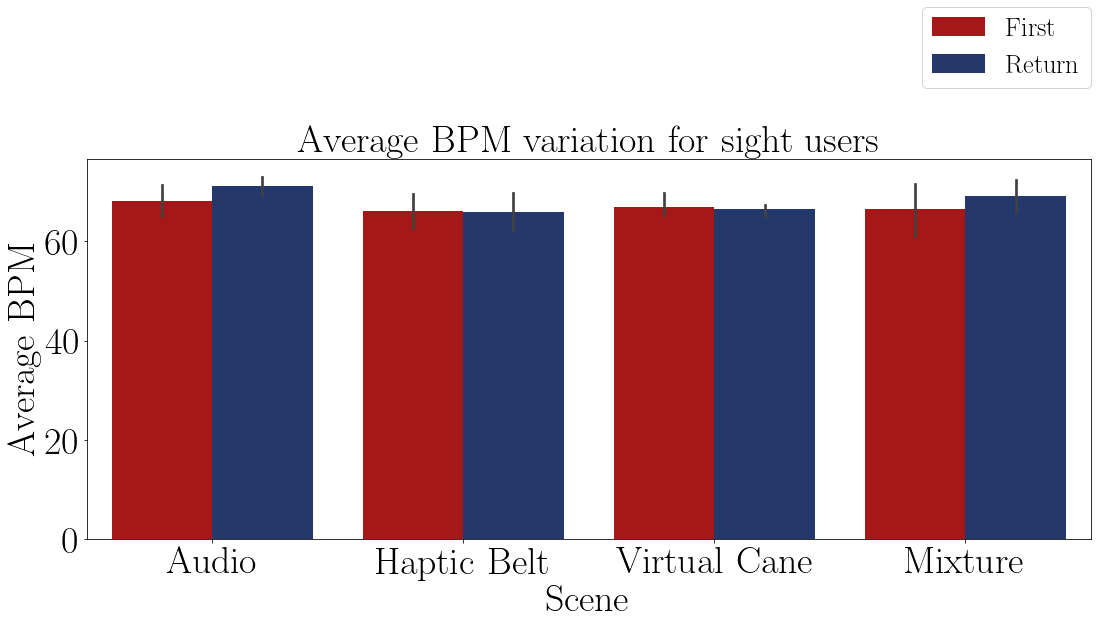


FIGURE 8.70 – Barplot of the average BPM of the sight participants on each method and round.

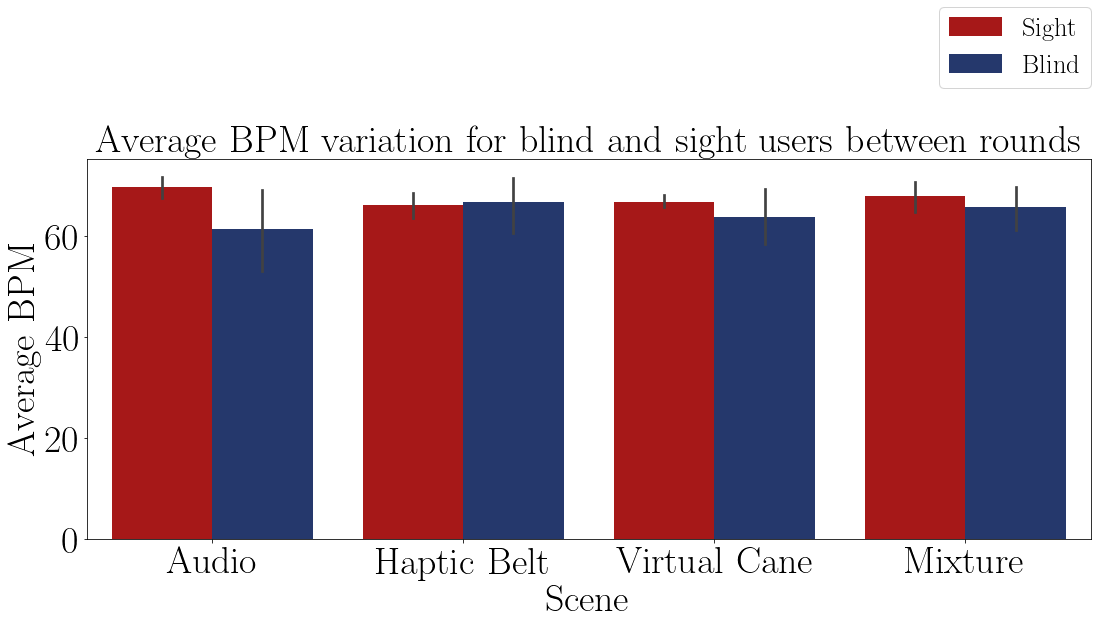


FIGURE 8.71 – Barplot of the average BPM of both participants on each method.

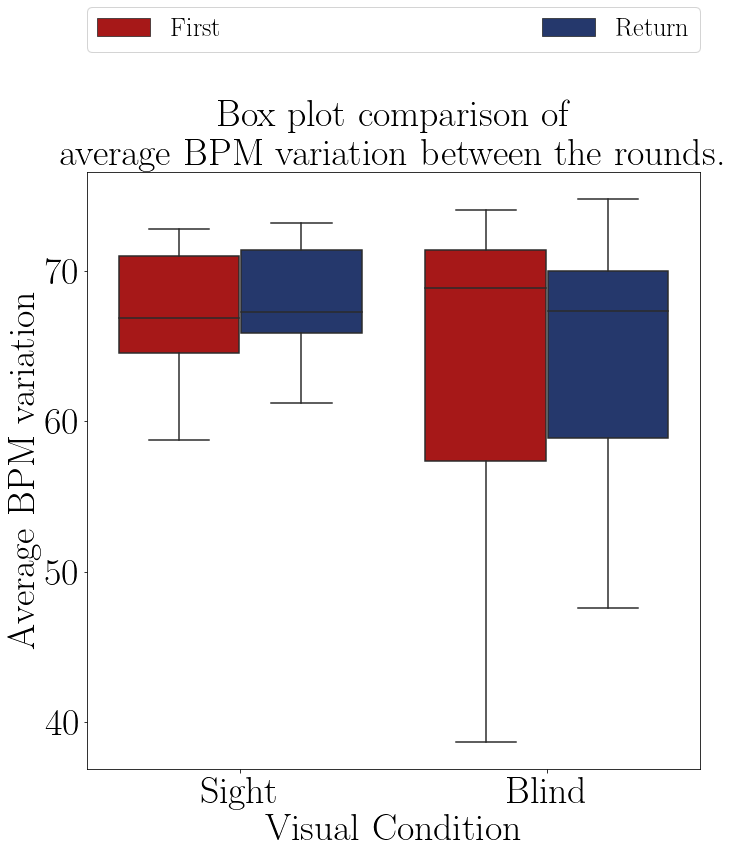
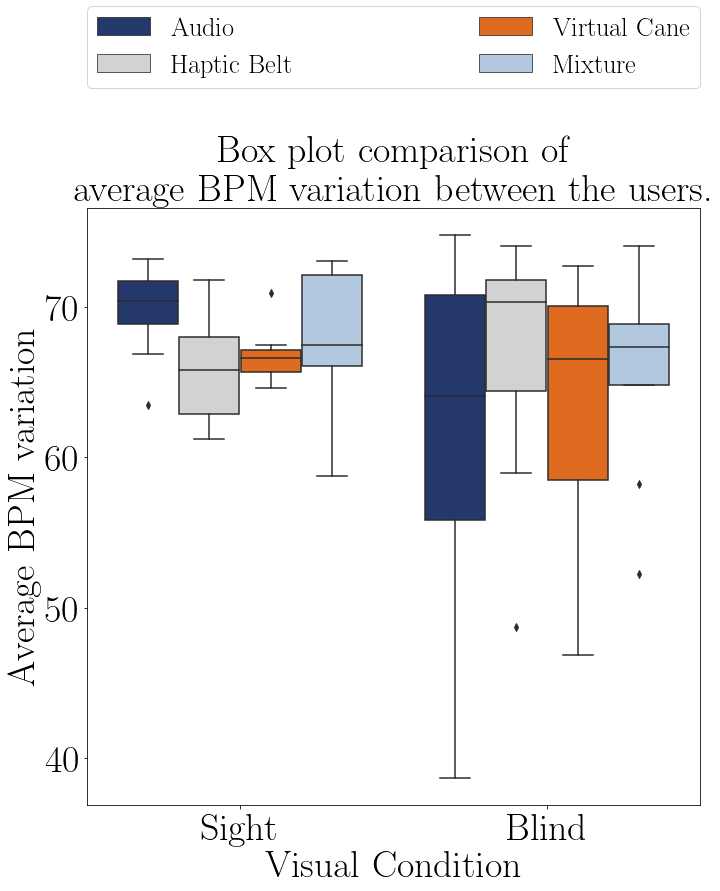


FIGURE 8.73 – Boxplot of the average BPM of

FIGURE 8.72 – Boxplot of the average BPM of the participants grouped by round.

the participants grouped by method.

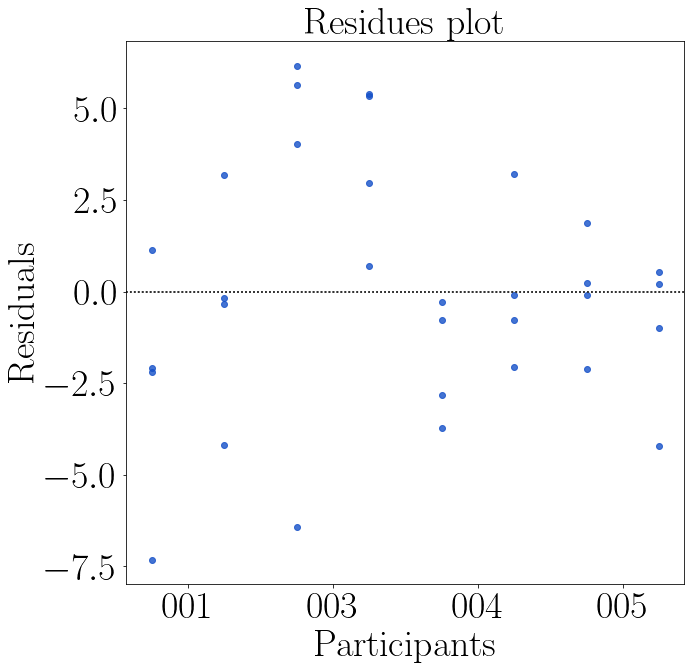
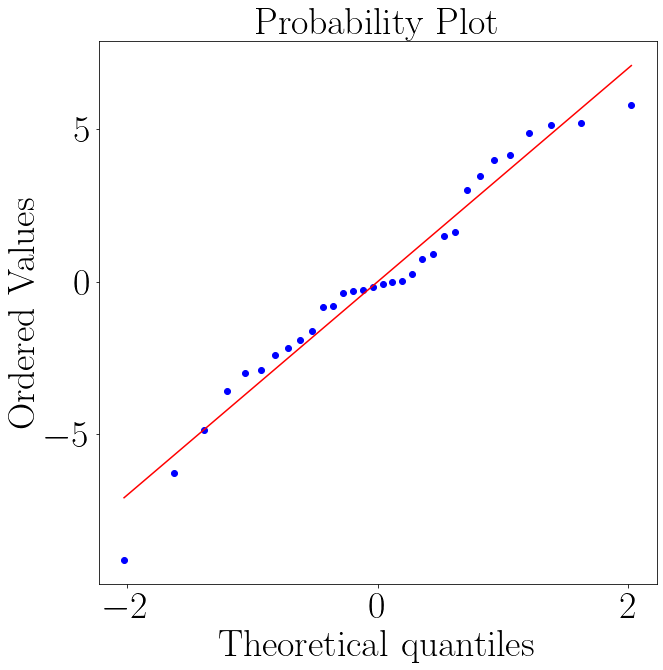


FIGURE 8.74 – QQ plot of the BPM of the FIGURE 8.75 – Residual plot of the BPM score sight participants on each method. the sight participants on each method.

##### 8.2.2.1.2 Analysis of the heartbeat variance (SDNN)

The Table 8.51 presents the average heartbeat variance by each participant on each scenes and they are plotted in the Figures 8.76 to 8.78.

TABLE 8.51 – Average SDNN by the participants during the each round and method.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Part. | Visual  Condition | Round |  |  |  |  |
| 001 | Sight | First | 82.185 | 134.530 | 134.773 | 225.408 |
|  |  | Return | 69.479 | 318.747 | 116.003 | 136.507 |
| 001C | Blind | First | 107.061 | 124.737 | 163.968 | 129.054 |
|  |  | Return | 130.885 | 131.590 | 157.589 | 124.786 |
| 002C | Blind | First | 98.863 | 81.140 | 33.977 | 79.289 |
|  |  | Return | 49.627 | 42.815 | 114.057 | 107.545 |
| 003 | Sight | First | 79.600 | 51.782 | 68.676 | 60.842 |
|  |  | Return | 45.709 | 40.927 | 66.323 | 47.823 |
| 003C | Blind | First | 38.325 | 35.101 | 42.392 | 43.692 |
|  |  | Return | 41.196 | 44.256 | 42.602 | 46.145 |
| 004 | Sight | First | 121.130 | 154.718 | 128.477 | 125.947 |
|  |  | Return | 100.366 | 122.563 | 140.115 | 119.260 |
| 004C | Blind | First | 86.827 | 62.560 | 85.900 | 70.472 |
|  |  | Return | 74.895 | 70.017 | 66.089 | 104.040 |
| 005 | Sight | First | 87.686 | 120.522 | 88.591 | 102.796 |
|  |  | Return | 93.207 | 122.839 | 141.305 | 96.035 |

The Figures 8.76 and 8.77 do not show a pattern. Some methods caused a decrease while other caused an increase on the SDNN. The Figure 8.78 that in all methods the SDNN of the sight users were higher than the blind users. That means that the sight users had a lower mental workload than the blind users.

The Figure 8.79 and 8.80 presents a box plot with the average SDNN of both groups by method and rounds in that order. These figures show the reaction of the sight user was a little different from the blind users. In all methods and rounds the SDNN from the sight users appear to be higher, hence with lower mental workload.

The Table 8.52 shows the average heartbeat variance of both samples and is possible to notice how the average score by the sight users was higher in every method, reinforcing the Figures 8.78 to 8.80 conclusions.

The Figures 8.81 and 8.82 shows the distribution and variance of sighted participants of the Table 8.51. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.53 shows the ANOVA test p-values of the average heartbeat variance of the ”sight” sample between the guidance methods and they show that the methods had an effect on the score.

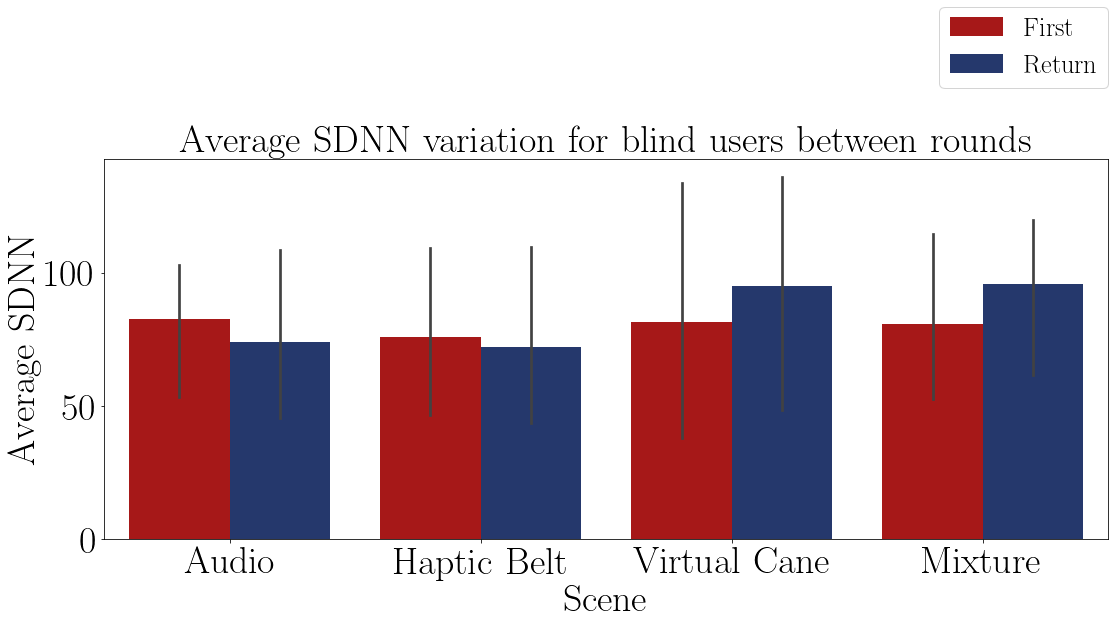


FIGURE 8.76 – Barplot of the average SDNN of the blind participants on each method and round.

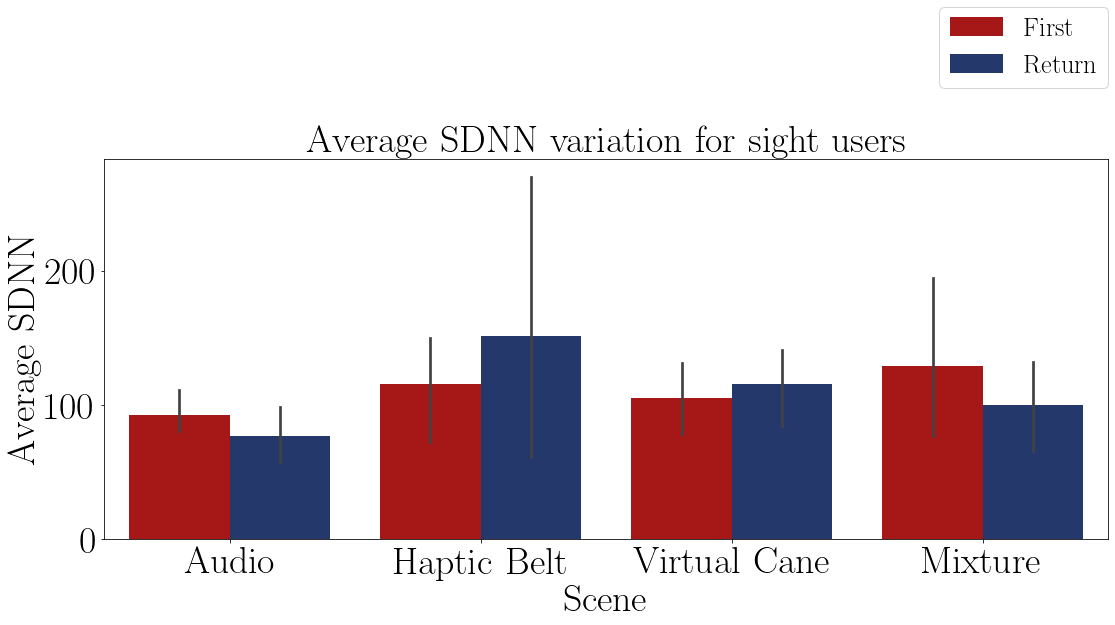


FIGURE 8.77 – Barplot of the average SDNN of the sight participants on each method and round.

TABLE 8.52 – ECG Average SDNN average in relation to the baseline grouped by participant and visual Condition.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Visual Condition | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 78.46 | 74.03 | 88.32 | 88.13 |
| Sight | 84.92 | 133.33 | 110.53 | 114.33 |

According to the ANOVA test at Table 8.53 there was no effect on the interbeat variance. So the methods did not influence the sighted user mental workload. The same conclusion was driven in the section 8.1.2.1 in the SDNN part.

Also, the sight user had a higher SDNN, which means lower Mental Workload, a unexpected result based on the expectation and on the previous notes.

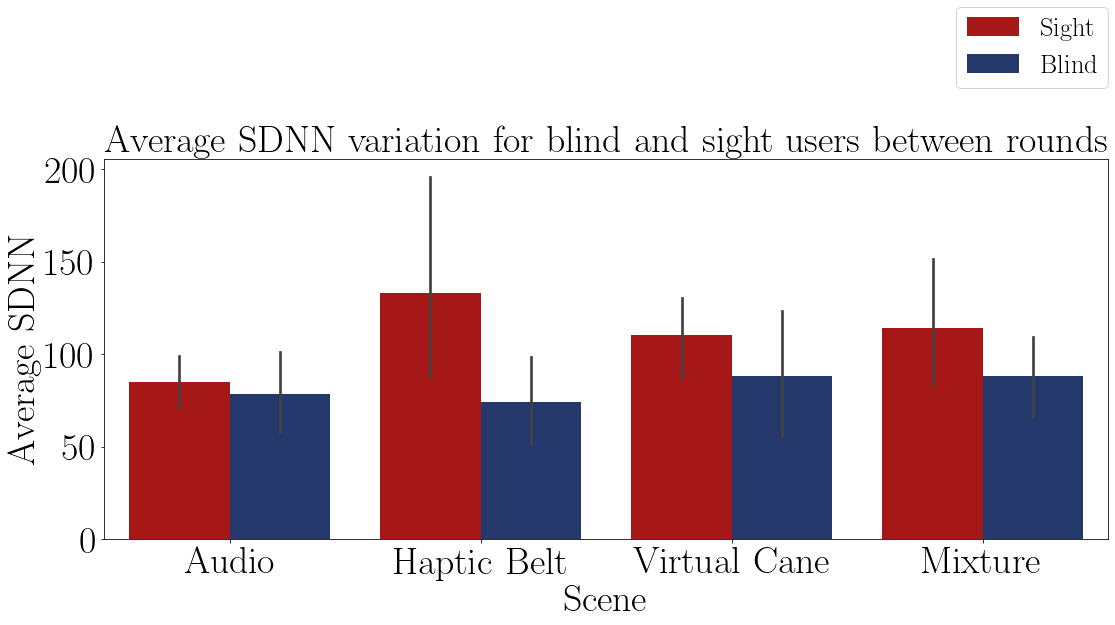


FIGURE 8.78 – Barplot of the average SDNN of both participants on each method.

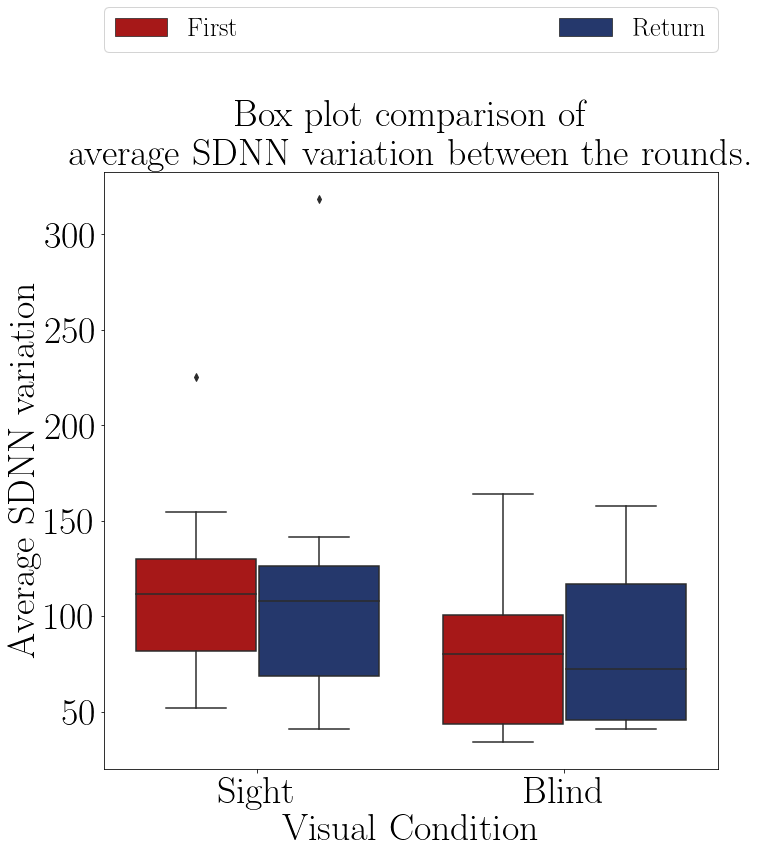
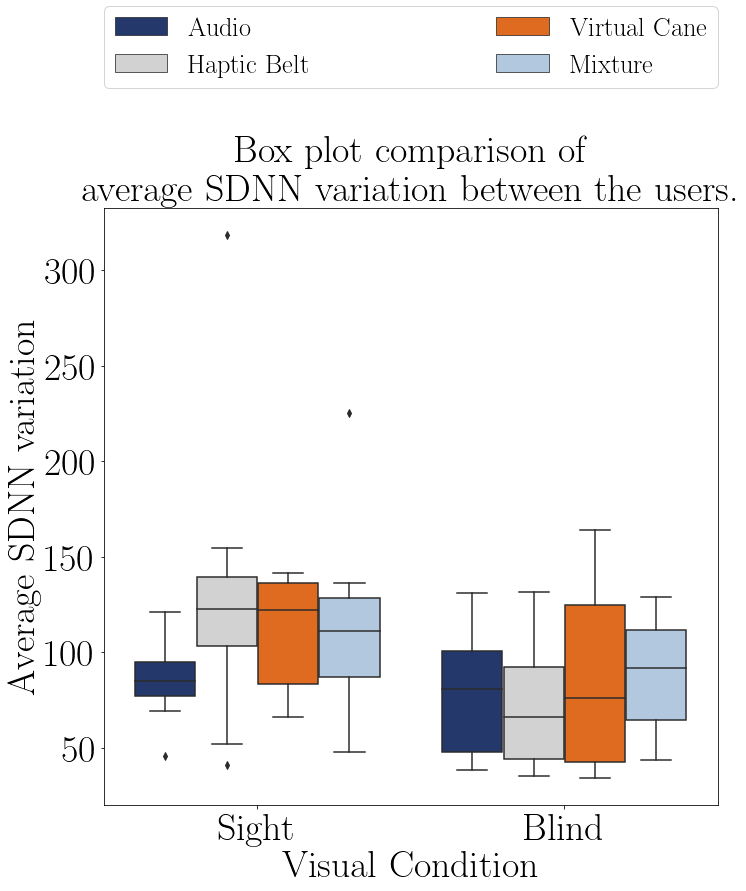


FIGURE 8.80 – Boxplot of the average SDNN

FIGURE 8.79 – Boxplot of the average SDNN

of the participants grouped by round.

of the participants grouped by method.

TABLE 8.53 – Anova p-value for the average SDNN on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 38392.134 | 3 | 12797.378 | 7.035 |  |
| Methods | 9518.457 | 3 | 3172.819 | 1.744 | 0.189 |
| Rounds | 2.846 | 1 | 2.846 | 0.002 | 0.969 |
| Interaction | 4947.394 | 3 | 1649.131 | 0.907 | 0.455 |
| Experimental Error | 38203.020 | 21 | 1819.191 |  |  |
| Total | 91063.851 | 31 |  |  |  |

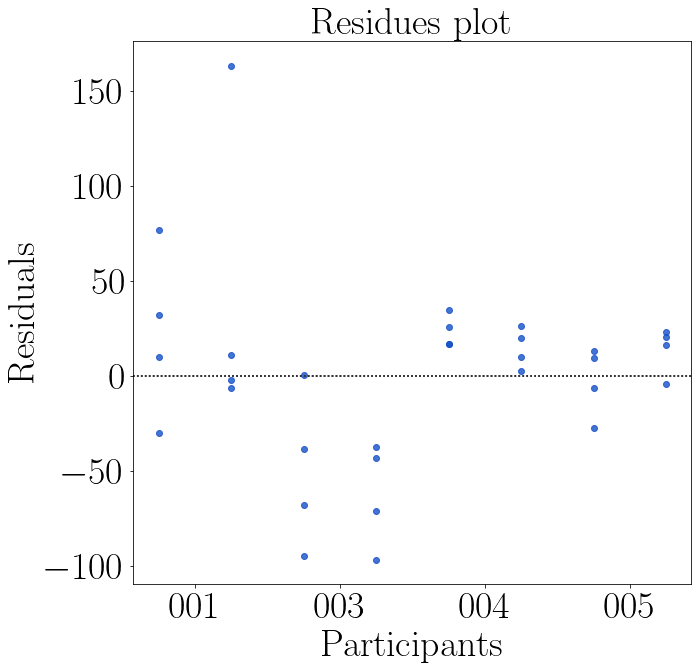
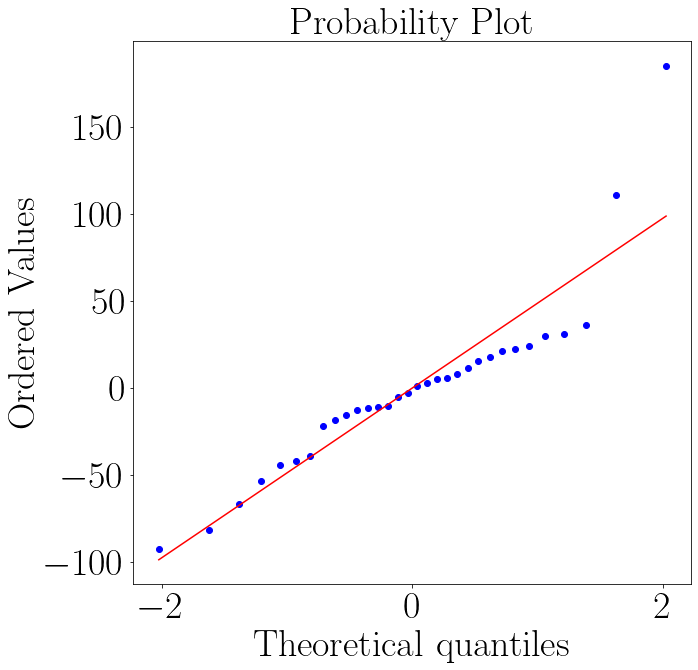


FIGURE 8.82 – Residual plot of the aver-

FIGURE 8.81 – QQ plot of the average SDNN age SDNN score the sight participants on each

of the sight participants on each method. method.

#### 8.2.2.2 Galvanic skin reaction and temperature data;

The GSR analysis is also made by analyzing its average and comparing both features between both blind and sample groups. As mentioned before, there was no influence of the temperature and the GSR sensor was worn on the left hand for right-handed participant and on the right hand for left-handed participants.

The Table 8.54 presents the average skin conductance by each participant on each scenes and they are plotted in the Figures 8.76 to 8.78.

The Table 8.55 presents the average skin conductance by each participant on their baseline and on each scene and their respectivily variation is inside Table 8.28. In the majority of times the skin conductance has risen from the ”First” to the ”Return” round, which mean that the participant was more aroused or with a higher mental workload.

TABLE 8.54 – Average GSR felled by the participants [*µ*S].

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Baseline | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual Condition | Round |  |  |  |  |  |
| 001 | Sight | First | 4.27 | 15.19 | 15.67 | 15.19 | 14.15 |
|  |  | Return |  | 14.95 | 15.09 | 15.72 | 21.52 |
| 001C | Blind | First | 0.37 | 1.03 | 3.14 | 3.79 | 3.90 |
|  |  | Return |  | 1.58 | 2.81 | 4.04 | 4.57 |
| 003C | Blind | First | 0.30 | 0.56 | 0.62 | 0.85 | 1.09 |
|  |  | Return |  | 0.63 | 0.65 | 0.92 | 1.06 |
| 004 | Sight | First | 2.60 | 11.18 | 12.60 | 12.92 | 10.34 |
|  |  | Return |  | 11.97 | 12.25 | 13.47 | 10.16 |
| 004C | Blind | First | 1.24 | 3.07 | 3.49 | 2.28 | 2.23 |
|  |  | Return |  | 2.95 | 3.20 | 2.21 | 2.24 |
| 005 | Sight | First | 0.47 | 1.58 | 1.44 | 1.37 | 1.33 |
|  |  | Return |  | 1.53 | 1.47 | 1.49 | 1.33 |

The Figures 8.83 show a pattern, that the presence of a haptic device increases the GSR variation, hence the stress or the mental workload, and 8.84 do not show a pattern, all GSR variations are basic the same. One thing in common is that the ”Haptic belt” caused a deacreased between the rounds, while the other methods caused an increase.

The Figure 8.85 reinforces the fact that the presence of a haptic device increases the GSR for the blind user. With those devices, the blind user’s GSR were higher than the sighted user. The opposite happened in the ”Audio” method.

The Figure 8.79 and 8.80 presents a box plot with the average skin conductance of both groups by method and rounds in that order. These figures show the reaction of the sight user was different from the blind users. In all methods the GSR for the sighted user appears to be more constant. The effect of the round appear to be the same for both of

TABLE 8.55 – Average GSR variation in relation to the baseline in each round [*µ*S].

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual Condition | Round |  |  |  |  |
| 001 | Sight | First | 255.76% | 266.93% | 255.69% | 231.52% |
|  |  | Return | 250.18% | 253.32% | 268.25% | 403.90% |
| 001C | Blind | First | 176.54% | 746.10% | 920.72% | 951.71% |
|  |  | Return | 327.42% | 656.99% | 988.93% | 1132.39% |
| 003C | Blind | First | 84.23% | 104.19% | 182.35% | 258.80% |
|  |  | Return | 109.23% | 112.95% | 202.35% | 249.72% |
| 004 | Sight | First | 329.08% | 383.54% | 395.83% | 297.05% |
|  |  | Return | 359.53% | 370.35% | 417.17% | 289.96% |
| 004C | Blind | First | 148.53% | 182.84% | 84.33% | 80.69% |
|  |  | Return | 138.64% | 159.00% | 78.73% | 81.61% |
| 005 | Sight | First | 239.16% | 207.74% | 193.85% | 184.71% |
|  |  | Return | 227.06% | 214.91% | 219.59% | 185.86% |

the groups, none.

The Table 8.56 shows the average skin conductance variation of both samples. It also shows that the presence of a haptic device increases the GSR, whilst the sight user had a basically constant GSR.

TABLE 8.56 – Average GSR variation grouped by participant and visual condition

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Visual Condition | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 164.10% | 327.01% | 409.57% | 459.15% |
| Sight | 276.80% | 282.80% | 291.73% | 265.50% |

The Figures 8.88 and 8.89 shows the distribution and variance of sighted participants of the Table 8.54. These Figures shows that the data are normally distributed and that the methods have a similar variance. The Table 8.57 shows the ANOVA test p-values of the average skin conductance variance of the ”sight”sample between the guidance methods and they show that nor the methods nor the rounds had an effect on the sight users.

According to the ANOVA test at Table 8.57 the methods did not impact the sight user’s arousal or their mental workload. This was the same result from the ANOVA test of the Section 8.1.2.2. The Figure 8.86 showed the same result, but the same was not said about the boxplot of the blind user.

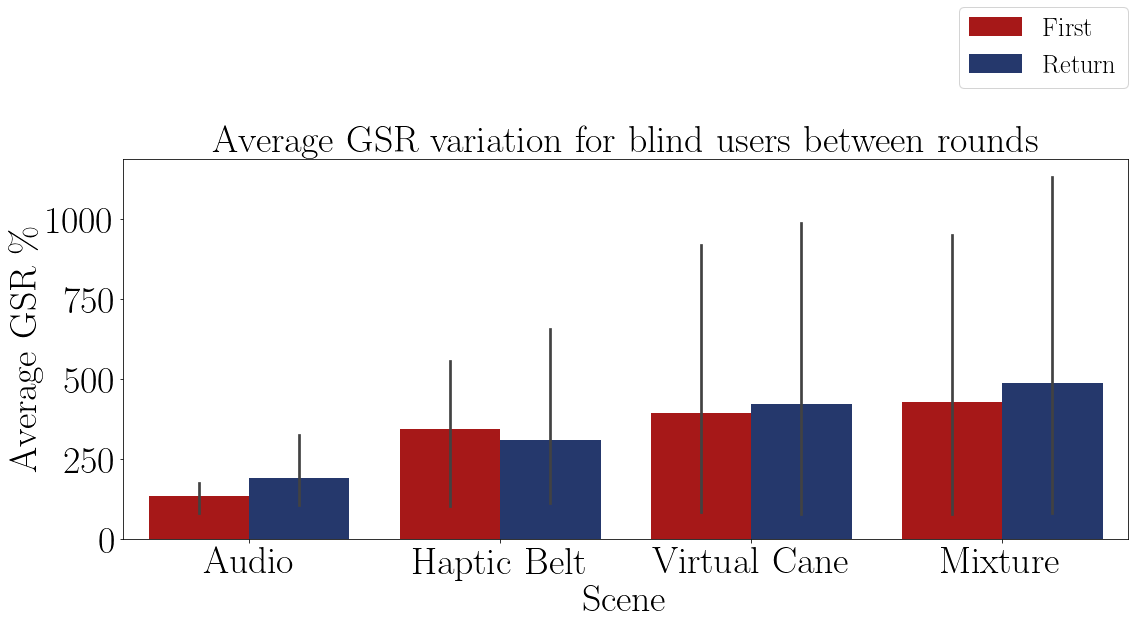


FIGURE 8.83 – Barplot of the average GSR of the blind participants on each method and round.

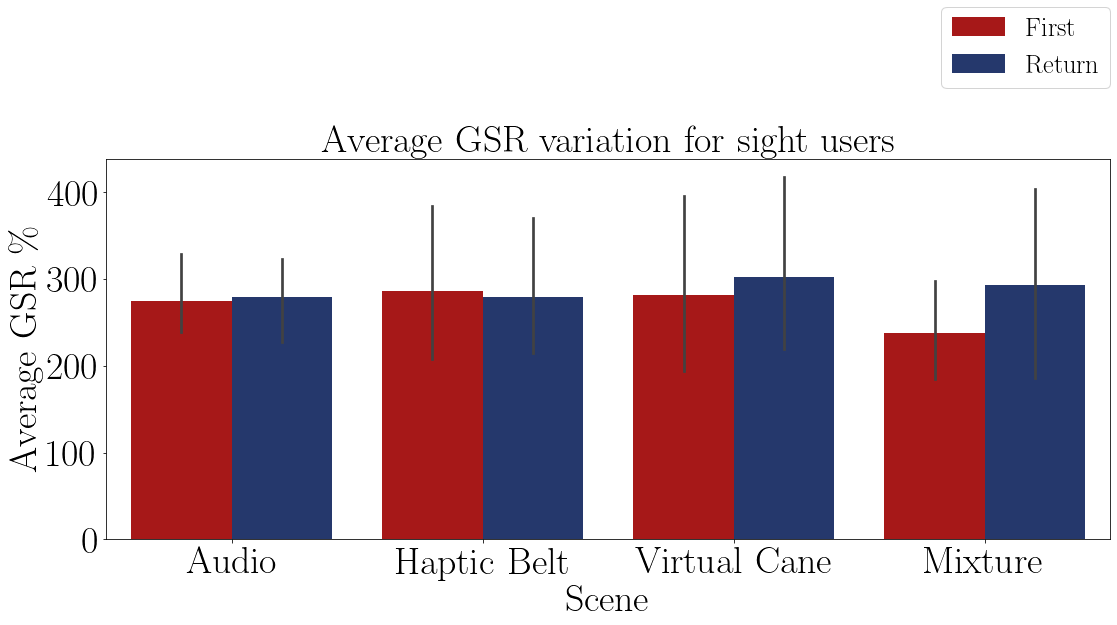


FIGURE 8.84 – Barplot of the average GSR of the sight participants on each method and round.

TABLE 8.57 – Anova p-value for the mental demand average on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Participants (Blocks) | 85935.244 | 2 | 42967.622 | 19.697 |  |
| Methods | 2180.186 | 3 | 726.729 | 0.333 | 0.802 |
| Rounds | 2002.532 | 1 | 2002.532 | 0.918 | 0.354 |
| Interaction | 3298.684 | 3 | 1099.561 | 0.504 | 0.686 |
| Experimental Error | 30539.551 | 14 | 2181.397 |  |  |
| Total | 123956.197 | 23 |  |  |  |

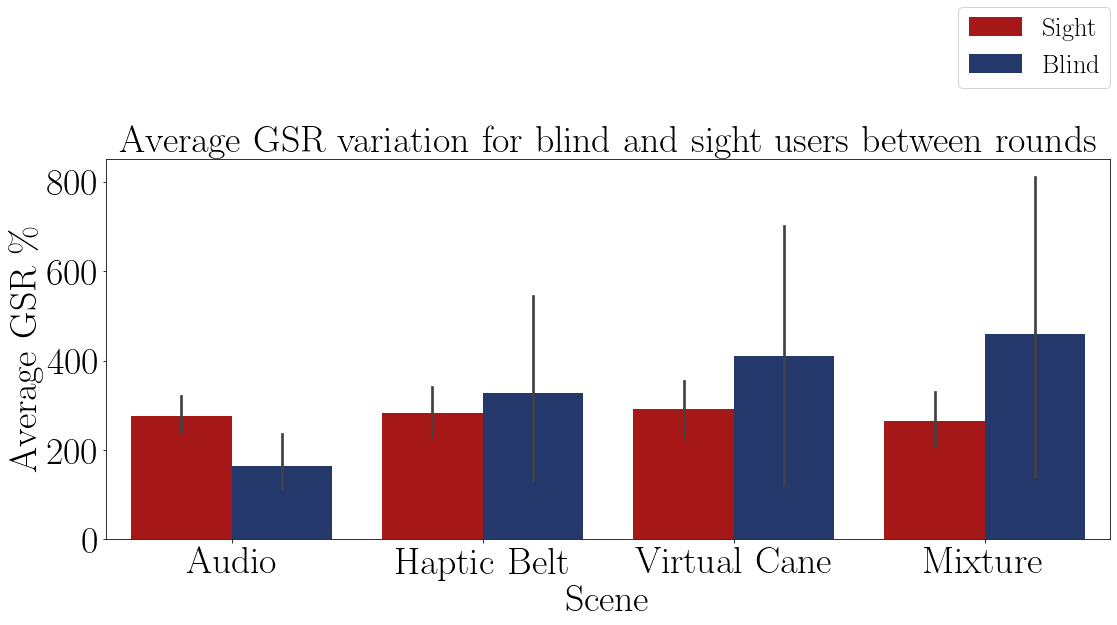


FIGURE 8.85 – Barplot of the average GSR of both participants on each method.

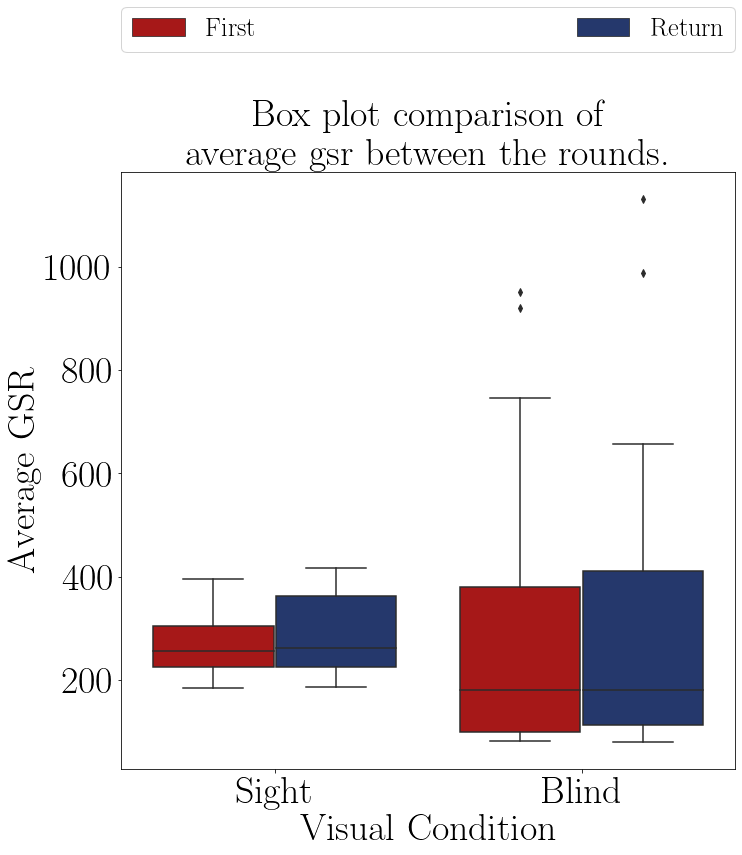
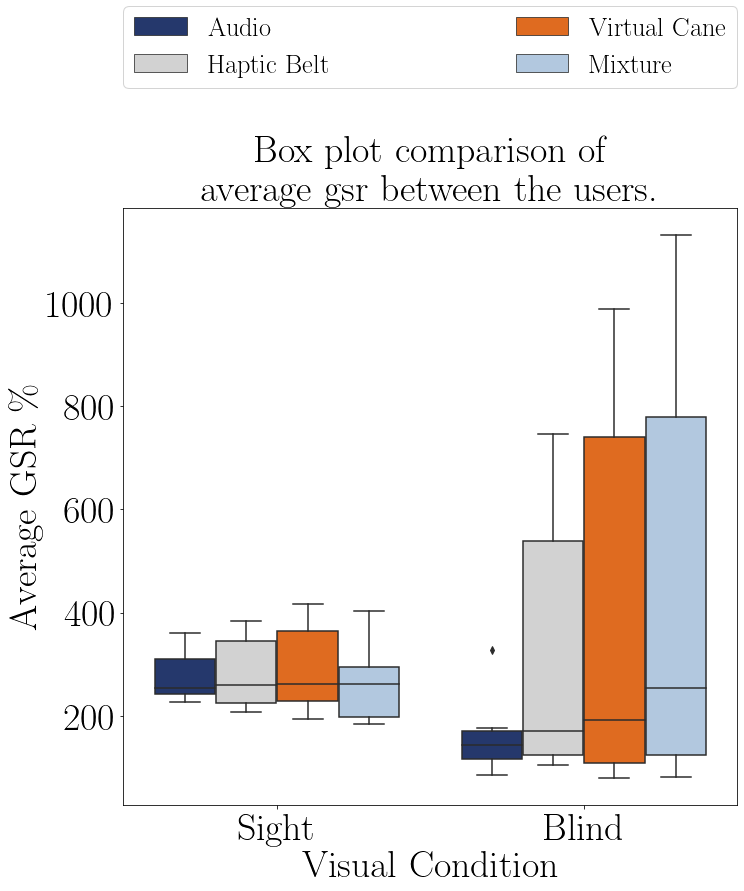


FIGURE 8.86 – Boxplot of the average GSR of the participants grouped by method.

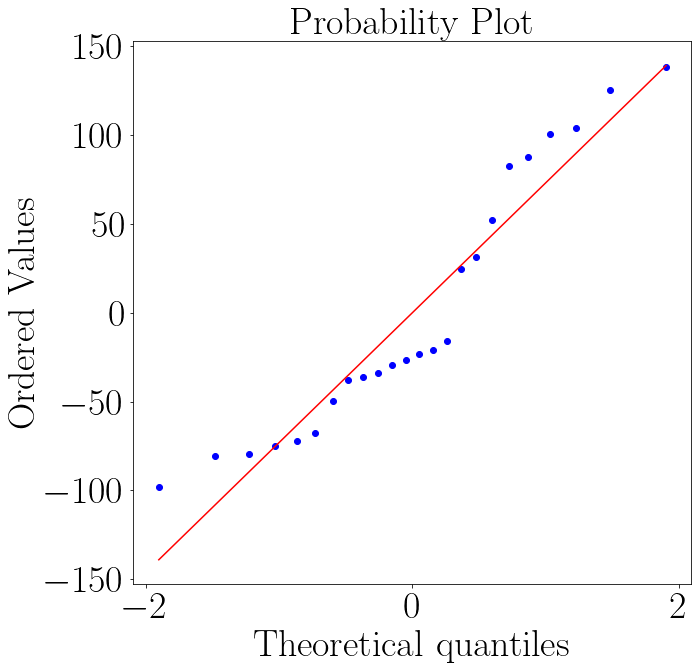


FIGURE 8.87 – Boxplot of the average GSR of the participants grouped by round.

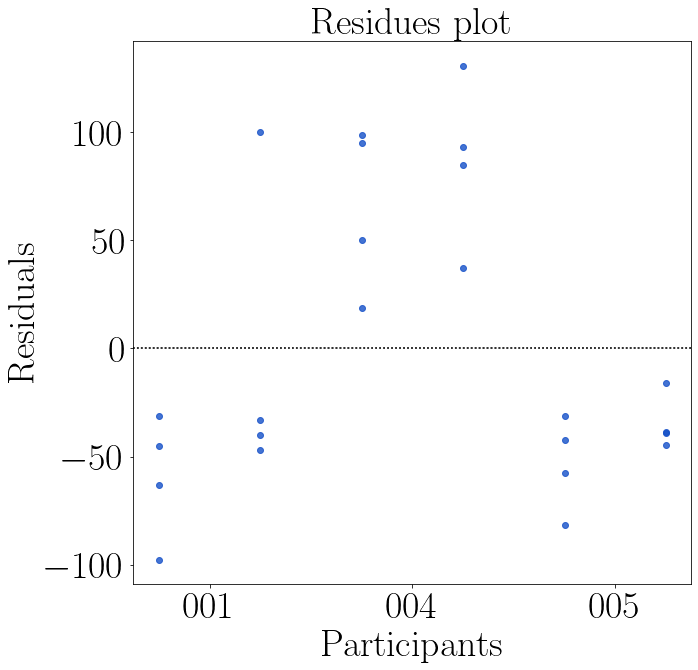


FIGURE 8.88 – QQ plot of the average skin conductance of the sight participants on each method.

FIGURE 8.89 – Residual plot of the average skin conductance score the sight participants on each method.

### 8.2.3 Final Remarks

Differently than the blind users, the results from the mental demand discipline of the NASA-TLX proved that the sight users felt a higher mental demand than the blind users.

The overall NASA-TLX score also proved a different conclusion than the one in the Section 8.1.1.1. For the sighted users, the round impacted more the overall score than the methods, whilst for the blind user were the opposite. This may be because the overall score is composed of 6 dimensions. Probably for the sighted user the mental demand score was higher and for the blind user it was not. But even so, the average score of the sight user was higher than the score of the blind user.

The Adapted SAGAT questionnaire for the sight users proved that the method impacts their situation awareness. The conclusion was different than the one proved by the blind users in the Section 8.1.1.2, who felt a bigger impact between the rounds than between the methods. The sight performance was also poorer than the blind user.

These conclusion show that the sighted users were more sensible to the methods than the blind users, although the effects were different. The blind users were more impacted by the methods than by the rounds, and when impacted by the methods, it was not possible to detect a pattern about the presence or not of a haptic device, as happened with the blind users.

The ECG sensors shown a difference in the heartrate between the methods, but the ANOVA test was not able to prove that difference, the same conclusion of the blind users in the Section 8.1.2.1. Another observation is that the heartrate frequency of the sighte user was higher than the blind users, meaning that their mental workload was probably higher.

According to the ANOVA test, The heartbeat variance also was not impact by the method or by the rounds, the same conclusion for the blind users in the Section 8.1.2.1. Graphically there was a small difference in the methods. Despite the results of the heartrate, the variance of the sight user was higher than the results from the blind user, meaning that the mental workload of the ”sight”sample was higher than the one of ”blind” sample.

The GSR ANOVA test also did not detect any impact from the methods or from the rounds, as it happened with the blind users in the Section 8.1.2.2. Graphically the sight user variations were very similar in all methods. This is a different effect than the one observed in the blind users, which graphically showed different GSR distributions on different methods. The sight GSR also show a small variation between the rounds and methods, which means that the sight user were not stressed or had a low mental workload during the experiment.

Despite the proved and not proved tests, there is a consideration to be made. The sight sample group profiling. As already explained before, the profile of the“blind”sample group was very wide and that can impact negatively in their performance. But the opposite effect may had happened with the“sight”sample group. This group was composed basically by researchers and engineer students, people that are typically involved with computers and technological devices, aging from 22 to 31 with an average of 27.5 years. This may biased the results with better performance when using the HMD and being able to feel present inside a virtual environment.

Besides these results, the “sighted” sample also commented the experiment. They all felt a lot more insecurity when walking, exploring and even when hand guided by the researcher before the start of the round. The “blind” sample group was already used to bumping their body when exploring new closed quarters. The “sighted” group did not want that to happen and approached the furniture with a lot more caution. They also noticed the lack of precision of the haptic devices, but they did rely more on then to navigate.

# 9 Conclusion

In this final chapter, the goals will be revised along with the results collected. It will be divided into four sections, one for each goal and a final one for future works and suggestions, and each section will have four more subsections, one for each data source gathered and one for a conclusion and commentaries for that goal.

Is it possible to evaluate and compare concepts of assistive device from a human factors’ perspective in a virtual environment? What are the main limitations of the use of a virtual reality environment?

As for the experiment used for to study this goal, the blind users were more affected by the rounds them by the methods, in both mental workload and situation awareness. And when impacted by the methods, the presence of a haptic device provoked negative conseguences on their perception or mental workload.

For the sighted users it were affected by both method and round in some cases, meaning that they were more sensible to the experiment than the blind users. There was no pattern in which method they performed better or not but in overall their performance was inferior than the perfomance from blind users.

Based on the gathered data, there was a variation in the mental workload and in the situation awareness during the experiment. This variation show that the users were impacted by the experiment in the virtual reality, but since no experiment outside the virtual reality was made, it is not possible to compare this data and verify that they are similar to one provided by a real scenario.

Some problems of the method was that the users walked approximately half of the experiment duration, and problably added some noise to the sensor data, leaving to unrelatable results. The heartbeat and the interbeat interval standard deviation did not show the same results as the NASA-TLX indicated.

This could also be caused because the experiment was made using a virtual reality, a technology still unvisited by most of the participants. That could have made the participant anxious and risen their heartbeat at the beginning of the experiment.

As for the limitations, the participants complained about the sound. The integrate headphone of the VIVE HMD did not provide sounds with a quality good enought for them to locate. A common commentarie was ”I feel like the sound origin is inside my head”, which was not true. But this may be solved by placing a real sound source in the real environment and use the HMD only for geolocalizing the participant inside de virtual environment.

Another limitation is the real time position of the furniture. More than once, after a ”First round”a furniture was not well aligned with the its virtual model. That caused some frustation on the participant as well in the researchers that had to stop the experiment to fix their position. A solution for this it would be to install real time locator on each piece of furniture.

Do non-BVI users, when deprived from their vision, evaluate assistive devices in a similar way as BVI users?

Comparing the results from the analyzes of the ”blind”sample and the ”sight”sample one realizes that the groups felt different reaction. Most of the blind users felt a bigger impact between the rounds than by the methods, whilst the sight users felt a bigger impact by the method.

This may be biased, since most of the conception of the devices was made by a sighted researcher, even thought there was recommendations from BVI researchers. But this may only reinterate that sighted users have a difficulty imagine how a blind users perceives the world and how to develop ways to assist them.

## 9.1 Future works and suggestions

For future works related to this one it could be suggested:

* Repeat the experiment in a real situation and compare it with this one to verify the first goal;

This experiment was made exclusivily using virtual reality, hence it is not posibly to verify the efficiency or the quality of a experiment made using Virtual Reality.

* Repeat the experiment not using the sound from the HMD;

The BVI users complained about the VIVE HMD sound system. They got confused sometimes and could figure it out if a sound source was coming from forwards or CHAPTER 9. CONCLUSION

backwards. One alternative for this problem is to add a physical sound source at each point in the real environment where it was supose to be in the virtual environment.

It still related to the virtual reality but it is more realistic.

• Repeat the experiment with bigger sample size and a more diverse sample to verify if the results of the hypothesis test do remain the same;

As commented before, most ANOVA tests showed one result and the figures showed a different conclusion. This happend because of the small sample size. If the sample size was bigger, maybe both conclusions would be the same.