# 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

In this section it will be presented the discussion between the gathered data and the first goal of this experiment, “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?”. This discussion will be divided in two different subsections, one for the data from the questionnaires and the other for the data from the physiological sensors.

### 8.1.1 Data from questionnaires

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.

* Analysis of the mental demand scale

The Table 8.7 presents the mental demand averages by each blinded participant on each scene and they are plotted in the Figures 8.5. The Figures 8.5 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 8.7 – Mental demand felled by the blinded participants.

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

The Table 8.8 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.

TABLE 8.8 – 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 |

The Table 8.9 shows the mental demand variation between the rounds. This table shows that the mental demand variation from the “Virtual Cane” and the “Haptic Belt” were bigger than the other devices, but the “Base” method was still the biggest one. Maybe this happened because the users were more used to navigate using the traditional cane than with the other devices. This same data is plotted in the Figure 8.9.

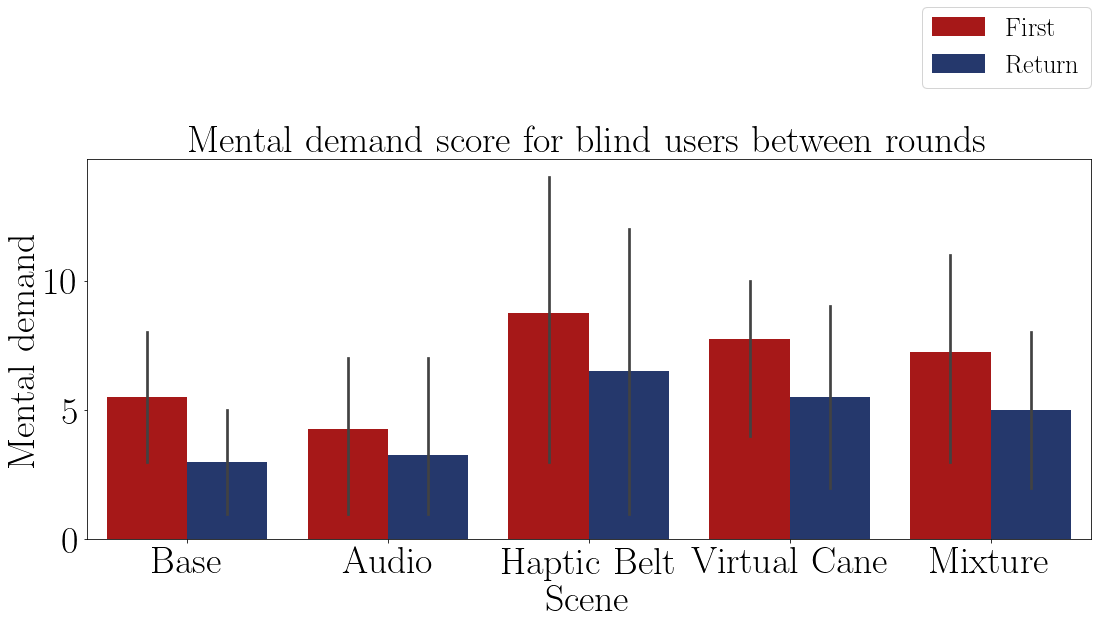


FIGURE 8.5 – Bar plot of the average mental demand of the blind participants on each method.

TABLE 8.9 – Mental demand variation grouped by participant and visual Condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | -52.2% | -20.0% | -28.8% | -32.1% | -18.8% |

The Shapiro–Wilk normality test on the Table 8.10 shows all the methods with the “blind” sample are normally distributed, that means that the following is possible to be made.

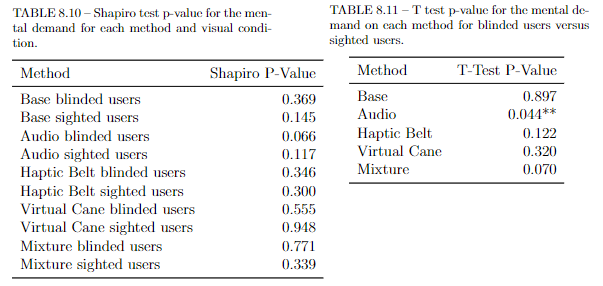
The Tables 8.14 and 8.12 shows the ANOVA tests p-value of the mental demand of the “blind” sample between the guidance methods. Both p-values indicate that there is at least one method that is statistically equal to one of the other methods.

The Table 8.15 presents the results of a pairwise Fisher LSD test of the blind mental demand average between all the guidance methods. The results show that only the “Audio” and the “Mixture” have a similar mental demand as the “Base” method.

The Table 8.13 presents the conclusion of a pairwise Fisher LSD test of the blind mental demand variation between all the guidance methods. The results show that only the “Virtual Cane” has a similar mental demand as the “Base” method.



FIGURE 8.9 – Barplot of the average mental demand variation from the blind participants of each method.



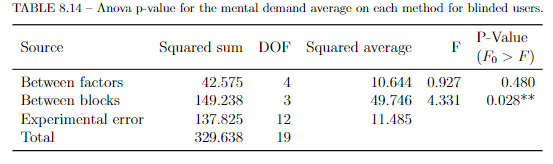


TABLE 8.12 – ANOVA p-value for the mental demand variation on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 2901.806 | 4 | 725.451 | 0.683 | 0.617 |
| Between blocks | 5263.745 | 3 | 1754.582 | 1.652 | 0.230 |
| Experimental error | 12744.201 | 12 | 1062.017 |  |  |
| Total | 20909.752 | 19 |  |  |  |

To close up, according to the LSD test at Table 8.15 and the Tables 8.8, the average mental demand of the “Audio”, the “Mixture” are not statistically different from the “Base” so the average exposed on the Table 8.8 are not true, so there were no device that caused a lesser mental demand than the “Base” method. And, according to the LSD test at Table 8.13 and the Tables 8.9, the mental demand variation of the the “Mixture” is not statistically different from the “Base”, so the device that caused the biggest mental demand variation were the “Haptic Belt” and the “Virtual Cane”.

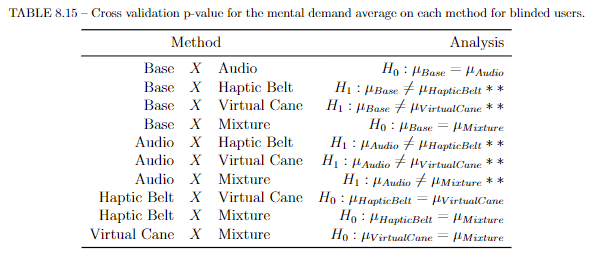


TABLE 8.13 – Cross validation p-value for the mental demand variation on each method for blinded users.

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

* Analysis of the NASA-TLX score

The Table 8.14 presents the Nasa score averages by each participant on each scenes and they are plotted in the Figures 8.10 and 8.11. It is notible that after each ”First” round the Nasa score diminishes for both ”sight” and ”blind” participants.

The Figure 8.12 shows the Nasa score between the rounds of each participant. This figure shows a noticeable difference between the two groups, meaning that probably the Nasa score from the ”sight” sample is higher than the one of the ”blind” sample. This comparison can be made also with the data in the Table 8.15, that shows the average Nasa score grouped by visual condition.

In the Figure 8.13 is plotted the average Nasa score of each group and it also presents that the sighted participants felt a higher Nasa score than the blinded participants.

The Table 8.16 shows the Nasa score variation grouped by visual condition and it also shows the difference between the mental demand of the ”sight” sample and the ”blind” sample and how this score varies between the rounds.

The Figure 8.14 shows the variation of the Nasa score of the ”blind” sample and one can notice that the variation provoked on the ”Audio” method” is a lot lesser than the other ones.

The Shapiro–Wilk normality test on the Table 8.17 shows that these data are normally

TABLE 8.14 – NASA score felled by the participants.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual  Condition | Round |  |  |  |  |  |
| 001 | Sight | First | 7.83 | 10.17 | 9.83 | 7.00 | 9.000 |
|  |  | Return | 8.00 | 11.00 | 10.83 | 6.17 | 9.333 |
| 001C | Blind | First | 4.83 | 4.00 | 8.83 | 5.17 | 6.333 |
|  |  | Return | 4.17 | 4.00 | 6.67 | 4.50 | 6.167 |
| 002C | Blind | First | 6.33 | 4.83 | 4.83 | 9.00 | 7.000 |
|  |  | Return | 4.50 | 4.83 | 4.83 | 7.00 | 5.167 |
| 003 | Sight | First | 4.83 | 9.83 | 10.17 | 9.50 | 6.500 |
|  |  | Return | 4.33 | 6.67 | 9.67 | 7.83 | 4.833 |
| 003C | Blind | First | 4.00 | 4.00 | 5.33 | 6.67 | 3.500 |
|  |  | Return | 4.00 | 3.83 | 3.67 | 3.50 | 3.500 |
| 004 | Sight | First | 6.67 | 14.83 | 13.67 | 11.50 | 15.833 |
|  |  | Return | 6.83 | 11.83 | 11.83 | 10.83 | 12.167 |
| 004C | Blind | First | 9.83 | 10.00 | 12.67 | 9.67 | 11.000 |
|  |  | Return | 8.67 | 9.17 | 11.67 | 9.33 | 10.833 |
| 005 | Sight | First | 5.00 | 7.67 | 9.00 | 8.00 | 9.667 |
|  |  | Return | 5.00 | 7.67 | 8.67 | 7.67 | 6.000 |

TABLE 8.15 – NASA-TLX score grouped by participant and visual Condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 5.79 | 5.58 | 7.31 | 6.85 | 6.688 |
| Sight | 6.06 | 9.96 | 10.46 | 8.56 | 9.167 |

TABLE 8.16 – NASA-TLX score grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | -13.7% | -3.1% | -15.9% | -21.5% | -7.6% |
| Sight | -1.4% | -11.1% | -3.0% | -9.9% | -20.8% |

distributed, with an exception of the ”Base” and ”Audio” Nasa score. This means that further analysis cannot be applied to this method.

According to the T-Test presented in the Table 8.18 the ”Audio”and the ”Haptic belt” caused a different Nasa score between the ”sight” sample and the ”blind” sample.

The Table 8.19 shows the Anova test p-value of the Nasa score, presented in the Table

8.14, of the ”blind” sample between the guidance methods. The p-value indicates that

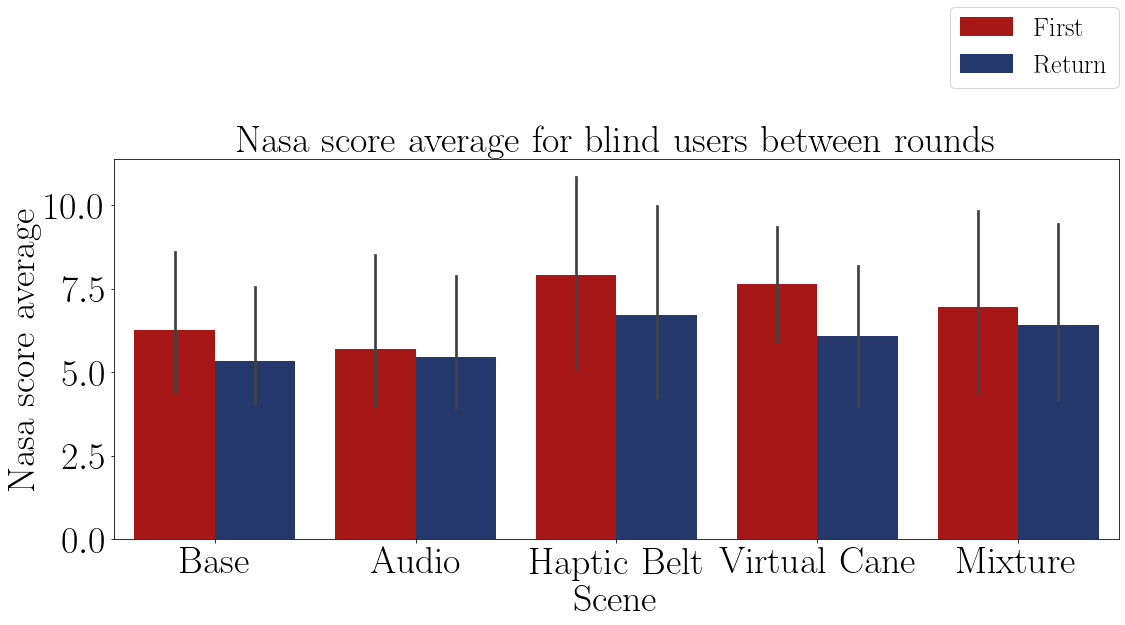


FIGURE 8.10 – Bar plot of the average Nasa-TLX score of the blind participants on each method.

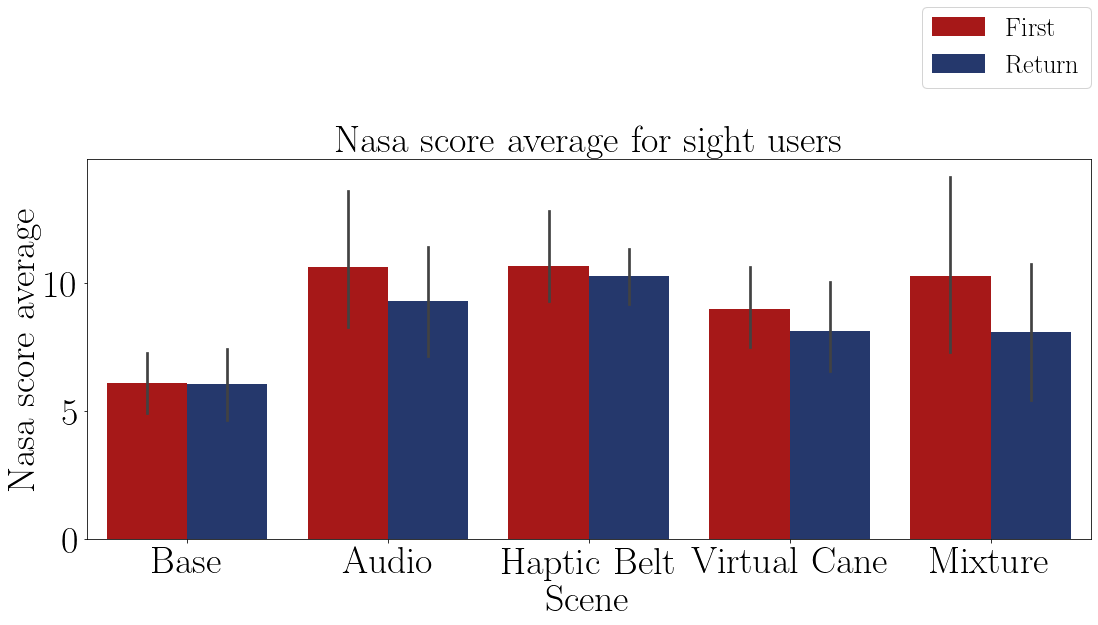


FIGURE 8.11 – Bar plot of the average Nasa-TLX score of the sighted participants on each method.

there is at least one method that is statistically equal to one of the other methods so it’s recommended to do a pairwise analysis between all the methods.

The Table 8.20 presents the results of a pairwise Fisher LSD test of the blind Nasa score average between all the guidance methods. The results show that only ”Audio” proved different from the ”Base” method.

According to T-Test on Table 8.18 the ”Audio” and ”Haptic belt” caused a different Nasa score when comparing both groups and analyzing the Figure 8.12 is noticiceable that they are different. The rest also seems to be different, but since the sample size was to small, it could be possible that the test would result in a different result if the sample size was bigger.

According to Anova test at Table 8.19 and the 8.20 and analyzing the data in the

Table 8.15 and in the Figure 8.12 the ”Audio”method provoked a lower Nasa Score in the

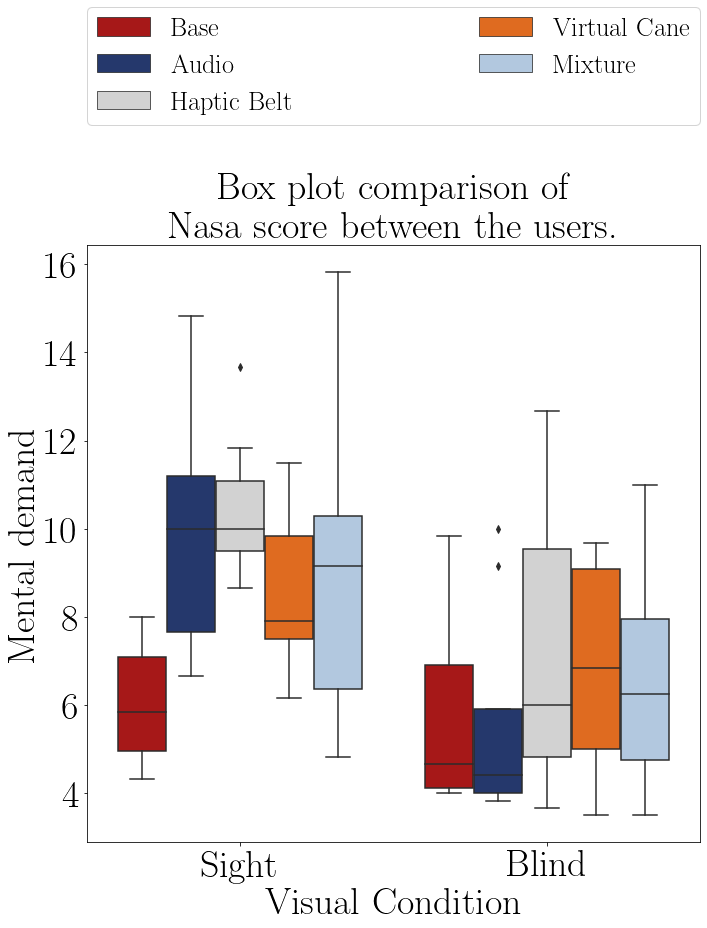


FIGURE 8.12 – Boxplot of the average NasaTLX score of the participants.

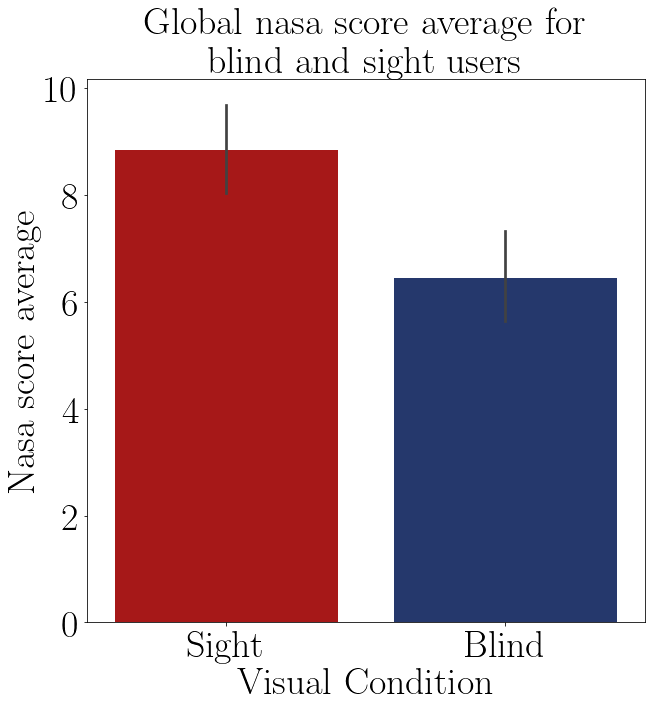


FIGURE 8.13 – Barplot of the average nasa score of each group.



FIGURE 8.14 – Barplot of the Nasa score variation from the blind participants of each method. blind participant.

TABLE 8.17 – Shapiro test p-value for the TABLE 8.18 – T test p-value for the NASA NASA score for each method and visual con- score on each method for blinded users versus dition. sighted users.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  | | --- | --- | | Method | Shapiro P-Value | | Base blinded users | 0.176 | | Base sighted users | 0.550 | | Audio blinded users | 0.034 | | Audio sighted users | 0.533 | | Haptic Belt blinded users | 0.321 | | Haptic Belt sighted users | 0.592 | | Virtual Cane blinded users | 0.329 | | Virtual Cane sighted users | 0.792 | | Mixture blinded users | 0.527 | | Mixture sighted users | 0.695 | | |  |  | | --- | --- | | Method | T-Test P-Value | | Base | 0.855 | | Audio | 0.058 | | Haptic Belt | 0.159 | | Virtual Cane | 0.296 | | Mixture | 0.331 | |

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 825.191 | 4 | 206.298 | 1.065 | 0.415 |
| Between blocks | 315.471 | 3 | 105.157 | 0.543 | 0.662 |
| Experimental error | 2324.141 | 12 | 193.678 |  |  |
| Total | 3464.803 | 19 |  |  |  |

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

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

### 8.2.2 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 participant is presented on the Table 8.21 and they are plotted in the Figures 8.15 and 8.16. It is visually noticeable that both of the groups perform better the second time they visit the room.

TABLE 8.21 – Adapted Sagat global score by participant and guidance method.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual  Condition | Round |  |  |  |  |  |
| 001 | Sight | First | 1.00 | 0.45 | 0.43 | 0.27 | 0.650 |
|  |  | Return | 1.00 | 0.60 | 0.50 | 0.50 | 0.450 |
| 001C | Blind | First | 0.62 | 0.55 | 0.53 | 0.58 | 0.350 |
|  |  | Return | 0.62 | 0.65 | 0.85 | 0.55 | 0.550 |
| 002C | Blind | First | 0.68 | 0.45 | 0.40 | 0.45 | 0.625 |
|  |  | Return | 0.53 | 0.50 | 0.40 | 0.65 | 0.850 |
| 003 | Sight | First | 1.00 | 0.68 | 0.60 | 0.40 | 0.675 |
|  |  | Return | 1.00 | 0.60 | 0.72 | 0.62 | 0.750 |
| 003C | Blind | First | 0.72 | 0.75 | 0.75 | 0.47 | 0.900 |
|  |  | Return | 1.00 | 1.00 | 0.85 | 0.90 | 0.900 |
| 004 | Sight | First | 1.00 | 0.72 | 0.80 | 0.60 | 0.825 |
|  |  | Return | 1.00 | 0.78 | 0.95 | 0.82 | 0.700 |
| 004C | Blind | First | 0.75 | 0.60 | 0.77 | 0.50 | 0.650 |
|  |  | Return | 0.90 | 0.60 | 0.93 | 0.72 | 0.900 |
| 005 | Sight | First | 1.00 | 0.30 | 0.32 | 0.40 | 0.400 |
|  |  | Return | 1.00 | 0.38 | 0.30 | 0.20 | 0.600 |

The Figure 8.17 shows the Sagat score between the rounds of each participant. It is possible to assume only that some methods cause different Sagat scores than others, and in the global average the ”blind”samnple had a better Sagat score than the ”sight”sample, as also shown in the Figure 8.18, which has the above data plotted, without considering the ”Base” method.

The Tables 8.22 and 8.23 shows the average and the variation between the rounds of the Sagat score grouped by visual condition, both of then present that the ”blind”sample had a better performance than the ”sight” sample.

TABLE 8.22 – Adapted Sagat average global score grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 0.73 | 0.64 | 0.68 | 0.60 | 0.716 |
| Sight | 1.00 | 0.56 | 0.58 | 0.48 | 0.631 |

The Shapiro–Wilk normality test on the Table 8.24 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform a T-Test to guarantee that the ”blind” sample is different than the ”sight” sample.

According to the T-Test presented in the Table 8.25, the only method that showed

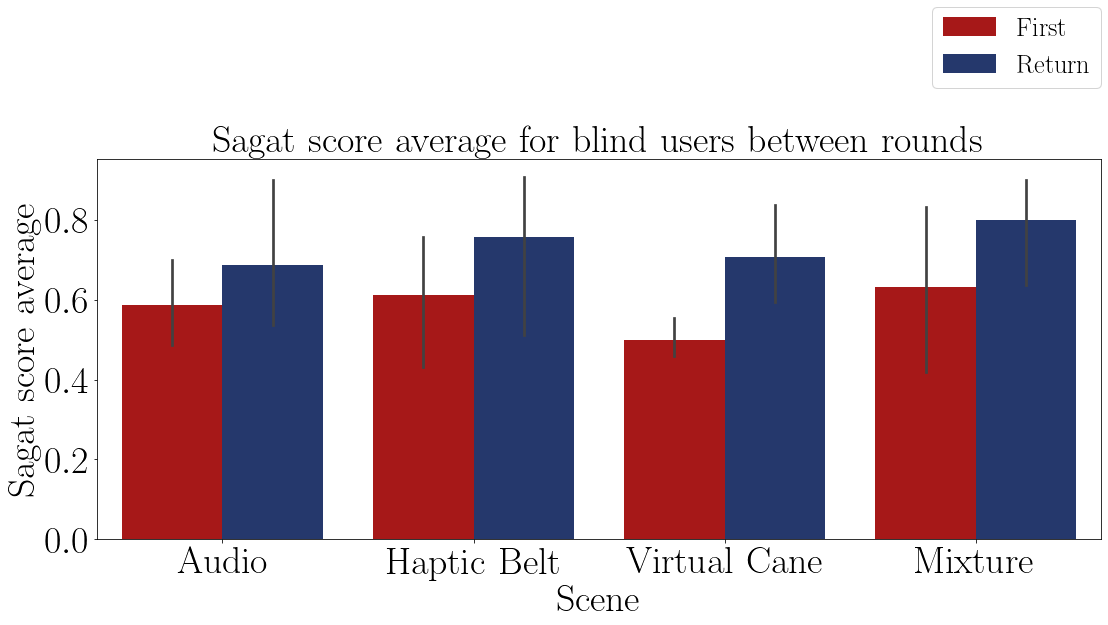


FIGURE 8.15 – Bar plot of the average Sagat score of the blind participants on each method.

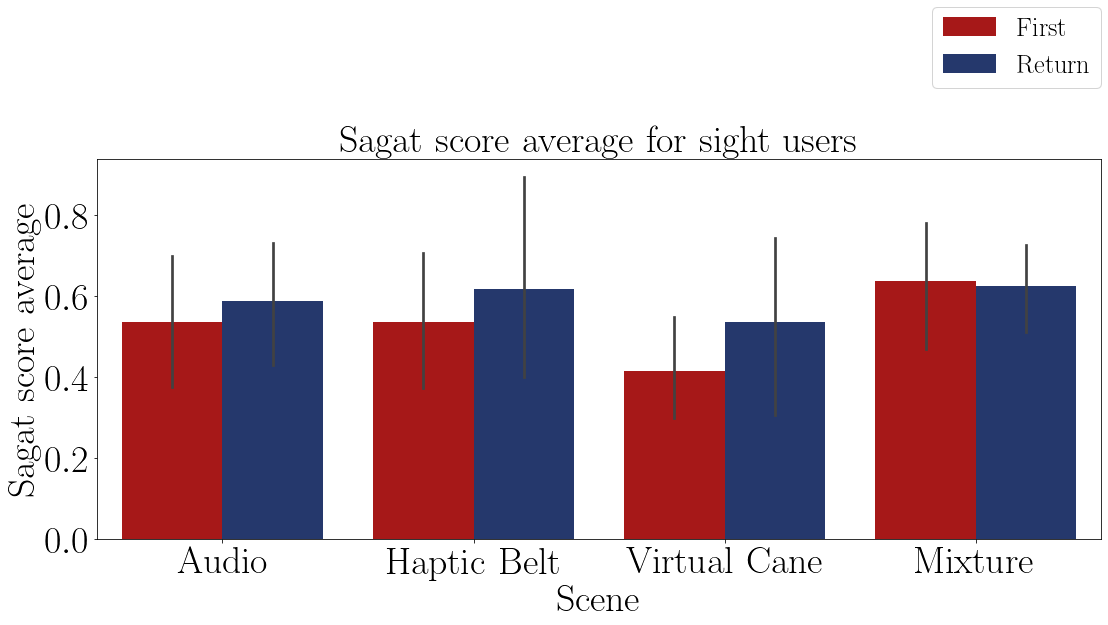


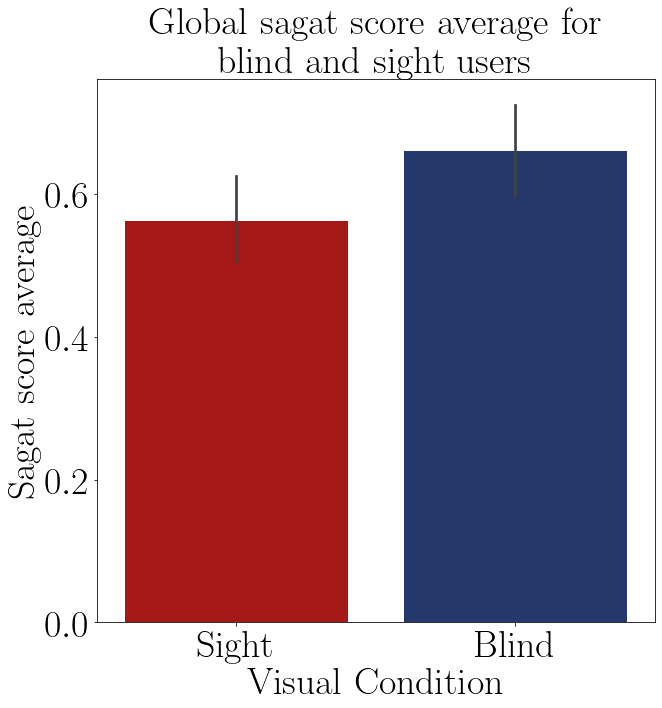
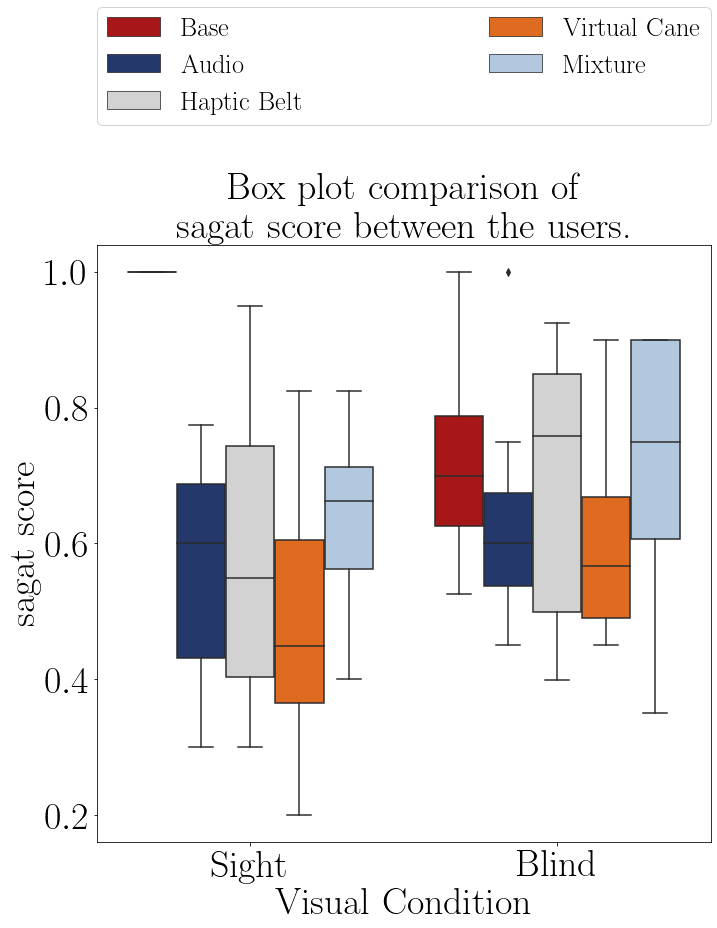
FIGURE 8.16 – Bar plot of the average Sagat score of the sighted participants on each method.

TABLE 8.23 – Adapted Sagat global score variation grouped by participant and visual Condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 8.9% | 15.7% | 23.5% | 44.3% | 32.9% |
| Sight | 0.0% | 13.5% | 12.6% | 33.1% | 3.8% |

a difference in the Sagat score between the ”sight” sample and the ”blind” sample is the ”Base”method, which is expected. In the other methods both samples had a similar Sagat score.

The Table 8.26 shows the Anova test p-value of the Sagat score of the ”blind” sample between the guidance methods presented in the Table 8.21. The p-value indicates that



|  |  |  |
| --- | --- | --- |
| FIGURE 8.17 – Boxplot of the average Sagat score of participant. | FIGURE 8.18 – Barplot of the average Sagat score of each group. | |
| TABLE 8.24 – Shapiro test p-value for the Sagat score for each method and visual condition | TABLE 8.25 – T test p-value for the Sagat score on each method for blinded users versus sighted users. | |
| |  |  | | --- | --- | | Method | Shapiro P-Value | | Base blinded users | 0.189 | | Base sighted users | 1.000 | | Audio blinded users | 0.350 | | Audio sighted users | 0.925 | | Haptic Belt blinded users | 0.315 | | Haptic Belt sighted users | 0.942 | | Virtual Cane blinded users | 0.549 | | Virtual Cane sighted users | 0.784 | | Mixture blinded users | 0.520 | | Mixture sighted users | 0.446 | | | |  |  | | --- | --- | | Method | T-Test P-Value | | Base | 0.007\*\* | | Audio | 0.561 | | Haptic Belt | 0.527 | | Virtual Cane | 0.230 | | Mixture | 0.488 | |

there is at least one method that is statistically equal to one of the other methods.

The Table 8.27 presents the analysis of a pairwise Fisher LSD test of the blind average Sagat score between all the guidance methods. The results show that the ”Audio” and ”Virtual Cane”caused a different Sagat score than the one noticed on the ”Base”Method. The rest of the methods did not significantly change it.

According to T-Test on Table 8.25, there is no difference in Sagat score between the ”sight” and the ”blind” sample except the ”Base” method, which is expected.

TABLE 8.26 – 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*) |
| Between factors | 0.045 | 4 | 0.011 | 0.966 | 0.461 |
| Between blocks | 0.241 | 3 | 0.080 | 6.962 | 0.006\*\* |
| Experimental error | 0.139 | 12 | 0.012 |  |  |
| Total | 0.424 | 19 |  |  |  |

TABLE 8.27 – Cross validation p-value for the Sagat score on each method for blinded users.

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

According to both Anova test at Table 8.26 and LSD test at Table 8.27 only the ”Audio” and the ”Virtual Cane” provoked a similar situation awareness when compared to the ”Base” method.

8.2.3 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 satisfactied with that method. The Table 8.28 shows the average score of each method and they are plotted in the Figures 8.5 and 8.6

The Table 8.29 show the the average questionnaire score of each participant and the Figure 8.21 these data is plotted. It is possible only to assume that some methods cause different Sagat scores than others, but both groups performed rather similarly.

The Shapiro–Wilk normality test on the Table 8.30 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform the following test to check if there is a significant difference between the methods

The Table 8.31 shows the Anova test p-value of the Sagat score average of the ”blind”

TABLE 8.28 – Guidance method questionnaire average score grouped by participant.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Participant | Audio | Haptic  Belt | Virtual  Cane | Mixture | Visual Condition |
| 001 | 0.75 | 0.49 | 0.57 | 0.69 | Sight |
| 001C | 0.77 | 0.54 | 0.63 | 0.87 | Blind |
| 002C | 0.86 | 0.74 | 0.54 | 0.93 | Blind |
| 003 | 0.76 | 0.54 | 0.54 | 0.78 | Sight |
| 003C | 0.93 | 0.57 | 0.54 | 0.74 | Blind |
| 004 | 0.86 | 0.60 | 0.79 | 0.76 | Sight |
| 004C | 0.88 | 0.49 | 0.40 | 0.73 | Blind |
| 005 | 0.61 | 0.57 | 0.75 | 0.84 | Sight |

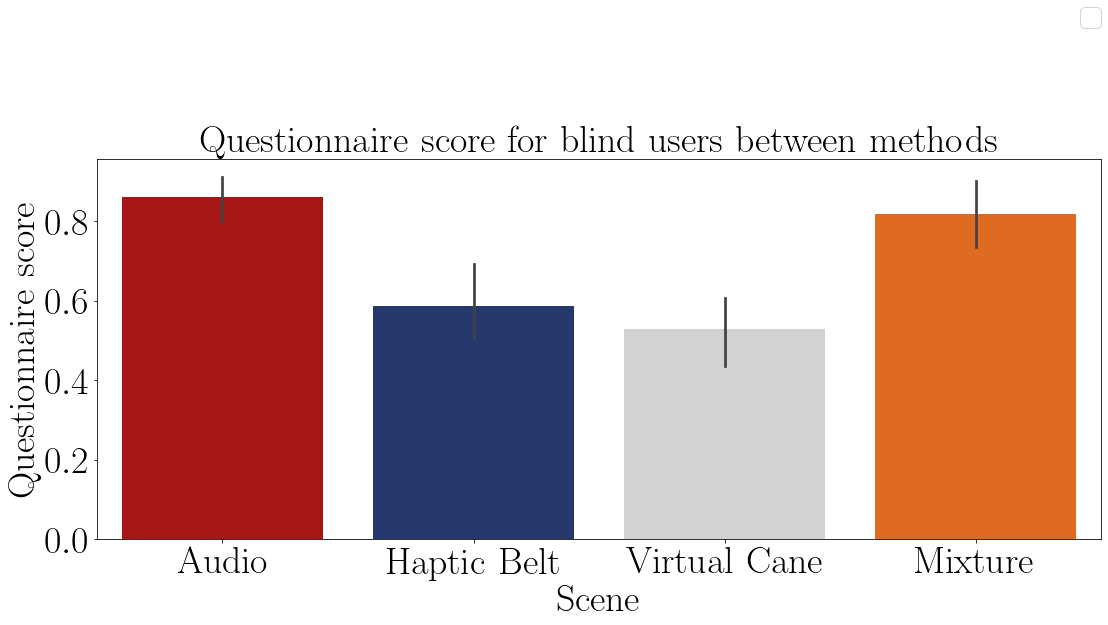


FIGURE 8.19 – Bar plot of the average mental demand of the blind participants on each method.

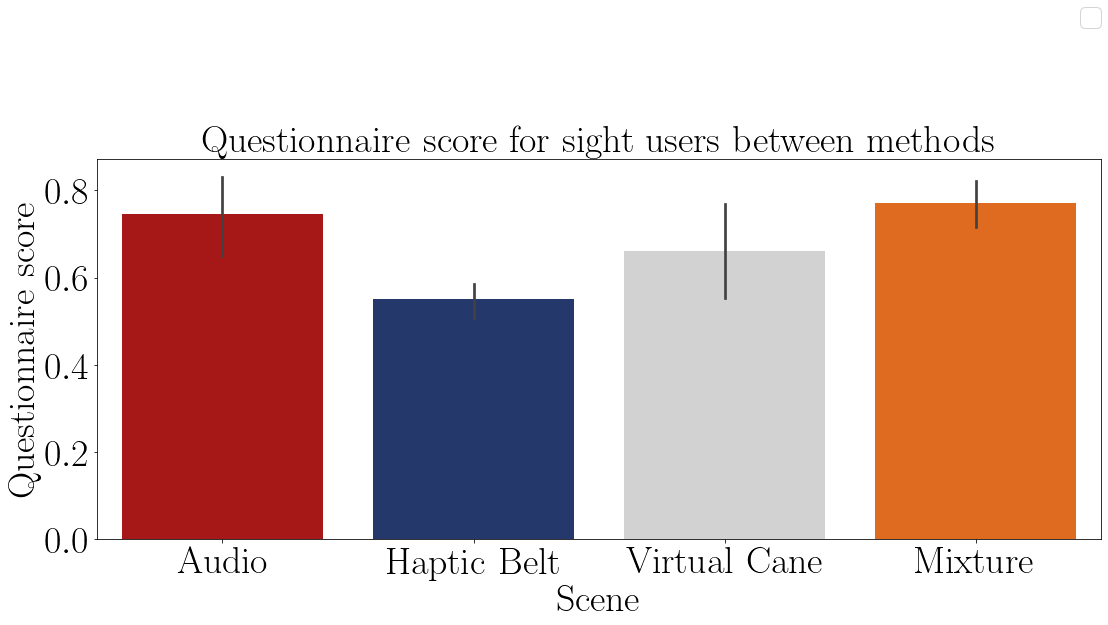


FIGURE 8.20 – Bar plot of the average mental demand of the sighted participants on each method.

TABLE 8.29 – 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 |
| Sight | 0.75 | 0.55 | 0.66 | 0.77 |

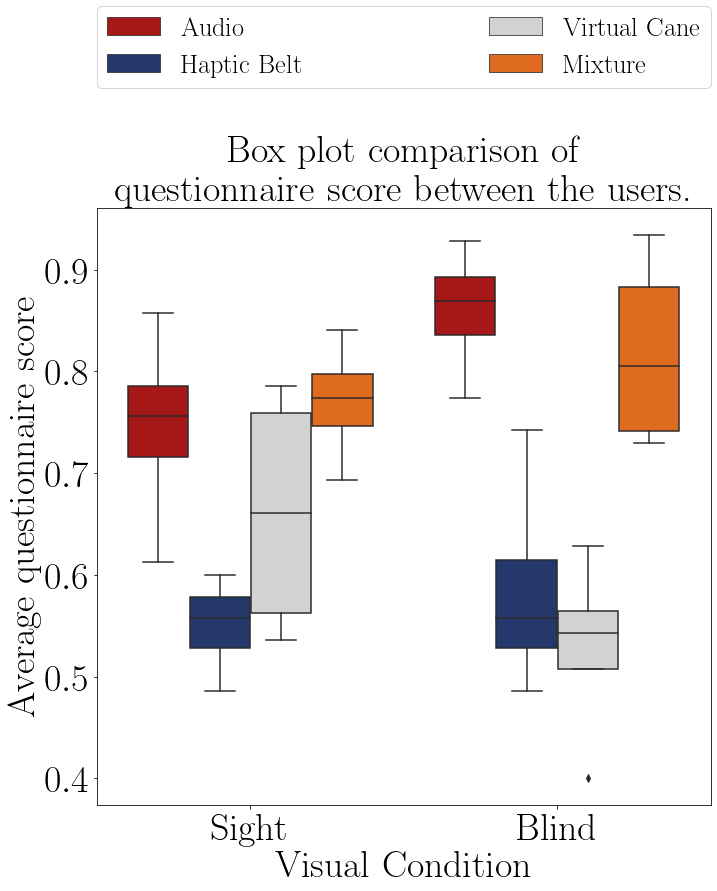


FIGURE 8.21 – Boxplot of the average questionnaire score of each group.

TABLE 8.30 – Shapiro test p-value for the questionnaires score for each method and visual condition.

|  |  |
| --- | --- |
| Method | Shapiro P-Value |
| Audio blinded users | 0.827 |
| Audio sighted users | 0.722 |
| Haptic Belt blinded users | 0.414 |
| Haptic Belt sighted users | 0.850 |
| Virtual Cane blinded users | 0.515 |
| Virtual Cane sighted users | 0.262 |
| Mixture blinded users | 0.392 |
| Mixture sighted users | 0.916 |

sample between the guidance methods presented in the Table 8.28. The p-value indicates that all scores are significantly different from each other. That means that the highest scores shown in Table 8.29, which are the ”Haptic Belt” and the ”Mixture” methods were the most favorite by the participant.

TABLE 8.31 – 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*) |
| Between factors | 0.329 | 3 | 0.110 | 15.677 | 0.001\*\* |
| Between blocks | 0.042 | 3 | 0.014 | 2.014 | 0.183 |
| Experimental error | 0.063 | 9 | 0.007 |  |  |
| Total | 0.434 | 15 |  |  |  |

## 8.3 Data from physiological sensors

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

* Electrocardiogram (ECG) data;

Is expected that the ECG frequency to increase at every ”First” round and then a slight decrease in the next round. Also, the variation 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.

### 8.3.1 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 state induced state by the scene.

After the data gathering, an algorithm in python was used to read the data and separate it accordingly to each participant, method and round. Since the participants moved during the whole experience a lot of noise was collected by the sensors, so these outliers were removed. The following steps were to normalize the data between -1 and 1 and then a peak detection method was used then, if the results were appropriate, the interval between each peak was calculated and saved to be used in the next software. This judgment was made by analyzing the plotted ECG signal and the detected peaks. If the detected peaks are not aligned with the peaks of the signal, then the method’s parameters were tuned to fit the detected peaks with the signals’ peaks.

The next used software was Kubios HRV Standard. Kubios is a heart rate variability (HRV) analysis software for personal non-commercial 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 saved intervals was analyzed and the results were saved in a report file to be read in python again. 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.

8.3.1.1 Analysis of the heartbeat frequency

The Table 8.32 presents the average heart rate by each participant on each scenes and they are plotted in the Figures 8.22 and 8.23. It is possible to see that there was no heart rate increase by any participant with the exception only of the ”sight”sample in the ”First” round of the ”Base” method.

The Table 8.33 show the average heartbeat frequency variation between the rounds of each group and the Figure 8.24 these data is plotted. Despite all the variations being negative, which was not as expected, it possible to see that the ”Audio” and the ”Virtual cane” provoked the highest variation in heartrate.

The Figures 8.24 and 8.25 show a comparison between both groups and both of them show that the blind group felt a bigger variation. That means that the ”blind”sample felt a bigger mental workload variation.

The Shapiro–Wilk normality test on the Table 8.34 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform a T-Test to guarantee that the ”blind” sample is different than the ”sight” sample.

According to the T-Test presented in the Table 8.35 there is no difference in the heart rate frequency variation between the sample groups.

The Table 8.36 shows the Anova test p-value of the heart rate frequency of the ”blind” sample between the guidance methods presented in the Table 8.32. The p-value indicates

TABLE 8.32 – ECG average BPM felled by the participants.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Baseline | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Part. | Visual  Condition | Round |  |  |  |  |  |  |
| 001 | Sight | First | 81.29 | 76.86 | 71.23 | 63.02 | 64.85 | 58.77 |
|  |  | Return |  | 72.88 | 73.18 | 61.18 | 66.78 | 66.26 |
| 001C | Blind | First | 78.33 | 75.75 | 60.71 | 71.17 | 59.07 | 68.24 |
|  |  | Return |  | 71.05 | 58.61 | 66.22 | 64.20 | 70.76 |
| 002C | Blind | First | 67.78 | 48.69 | 38.67 | 48.74 | 46.89 | 52.23 |
|  |  | Return |  | 52.46 | 47.58 | 58.97 | 56.75 | 58.25 |
| 003 | Sight | First | 77.38 | 74.98 | 63.47 | 71.80 | 70.90 | 72.76 |
|  |  | Return |  | 69.29 | 72.75 | 71.23 | 67.49 | 73.01 |
| 003C | Blind | First | 63.45 | 68.37 | 69.89 | 70.95 | 69.41 | 66.94 |
|  |  | Return |  | 67.34 | 67.44 | 69.68 | 68.82 | 67.37 |
| 004 | Sight | First | 65.32 | 72.97 | 66.85 | 62.45 | 65.94 | 67.86 |
|  |  | Return |  | 76.85 | 69.48 | 65.65 | 64.58 | 71.86 |
| 004C | Blind | First | 78.30 | 75.09 | 73.55 | 73.70 | 71.94 | 74.03 |
|  |  | Return |  | 74.74 | 74.79 | 74.02 | 72.69 | 67.34 |
| 005 | Sight | First | 71.25 | 70.18 | 71.34 | 66.93 | 66.46 | 67.06 |
|  |  | Return |  | 67.69 | 69.57 | 65.97 | 67.00 | 65.47 |

TABLE 8.33 – ECG average BPM average in relation to the baseline grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | -7.3% | -14.3% | -6.9% | -10.9% | -8.4% |
| Sight | -0.8% | -5.0% | -10.0% | -9.0% | -7.2% |

TABLE 8.34 – Shapiro test p-value for the ecg average BPM for each method and visual con-

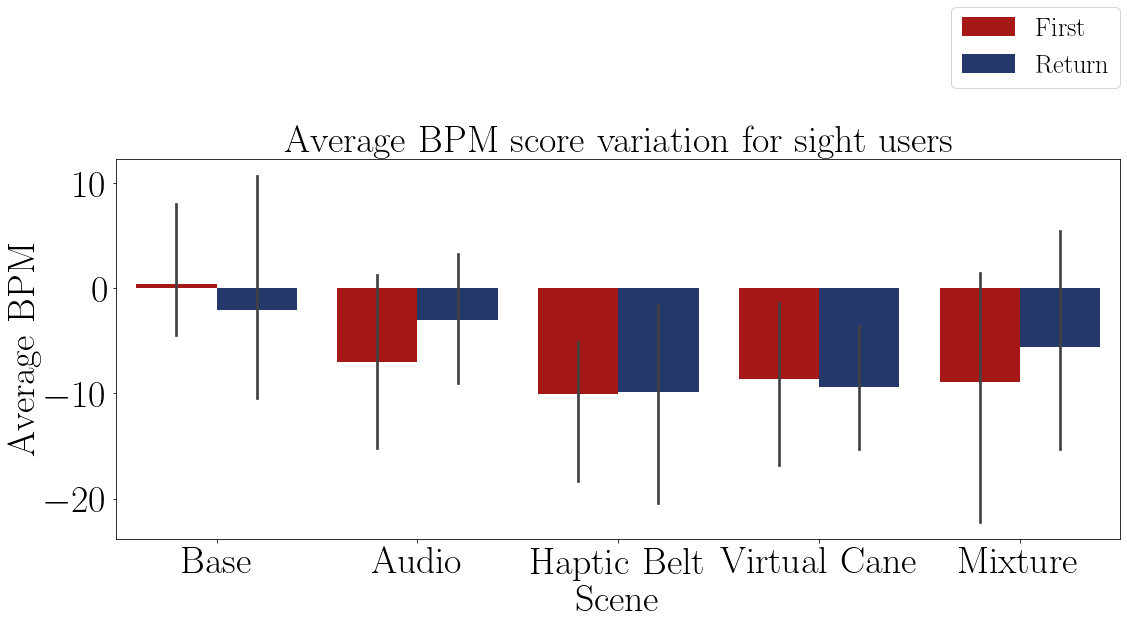
dition

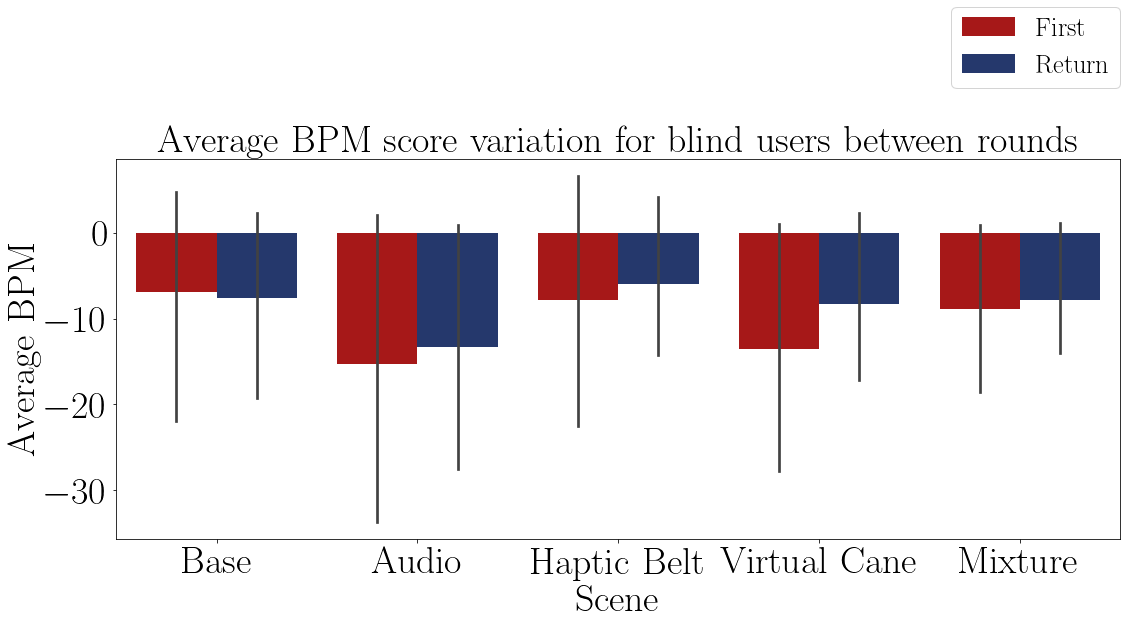
|  |  |
| --- | --- |
| Method | Shapiro P-Value |
| Base blind | 0.377 |
| Base sight | 0.086 |
| Audio blind | 0.721 |
| Audio sight | 0.969 |
| Haptic Belt blind | 0.665 |
| Haptic Belt sight | 0.059 |
| Virtual Cane blind | 0.584 |
| Virtual Cane sight | 0.743 |
| Mixture blind | 0.379 |
| Mixture sight | 0.663 |

TABLE 8.35 – T test p-value for the ecg average BPM each method for blinded users versus sighted users.

|  |  |
| --- | --- |
| Method | T-Test P-Value |
| Base | 0.279 |
| Audio | 0.215 |
| Haptic Belt | 0.594 |
| Virtual Cane | 0.750 |
| Mixture | 0.834 |

FIGURE 8.22 – Bar plot of the average heart rate of the blind participants on each method.



FIGURE 8.23 – Bar plot of the average heart rate of the sighted participants on each method.

that there is at least one method that is statistically equal to one of the other methods, and the LSD Fischer test in the Table 8.37 shows that the ”Audio”and the ”Virtual Cane” are differente than the ”Base” method.

TABLE 8.36 – Anova p-value for the BPM on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 151.789 | 4 | 37.947 | 1.570 | 0.245 |
| Between blocks | 2934.674 | 3 | 978.225 | 40.471 | 0.000\*\* |
| Experimental error | 290.050 | 12 | 24.171 |  |  |
| Total | 3376.513 | 19 |  |  |  |

According to the Anova test at Table 8.36 and the LSD test at 8.37 the ”Audio” and the ”Virtual Cane” method provoked a different reaction than the ”Base” method and

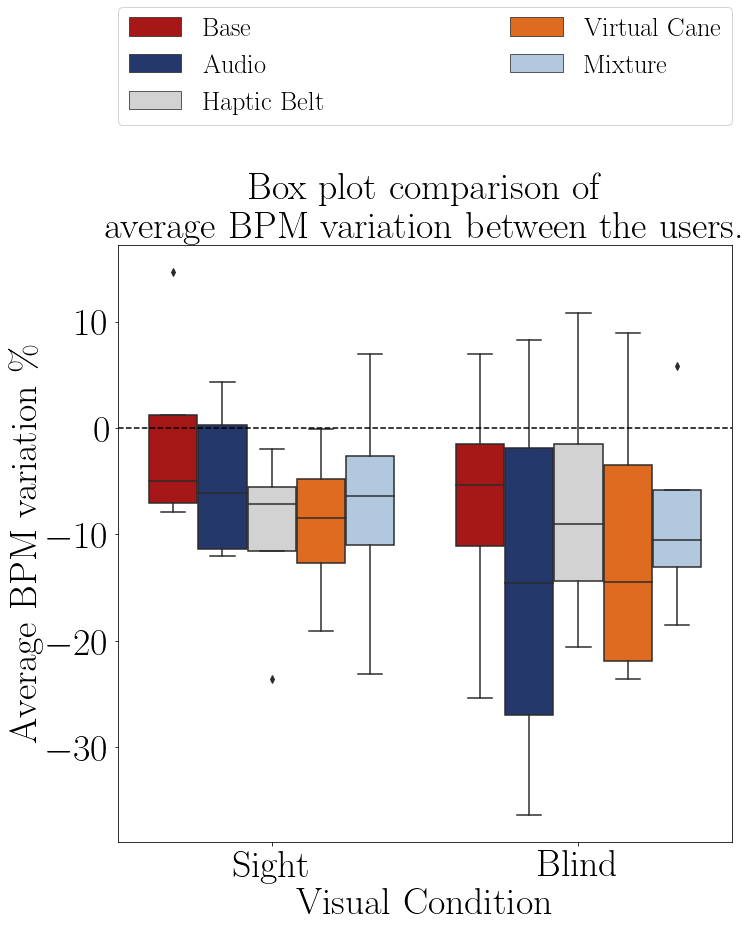


FIGURE 8.24 – Boxplot of the average heart rate of participants on each method.

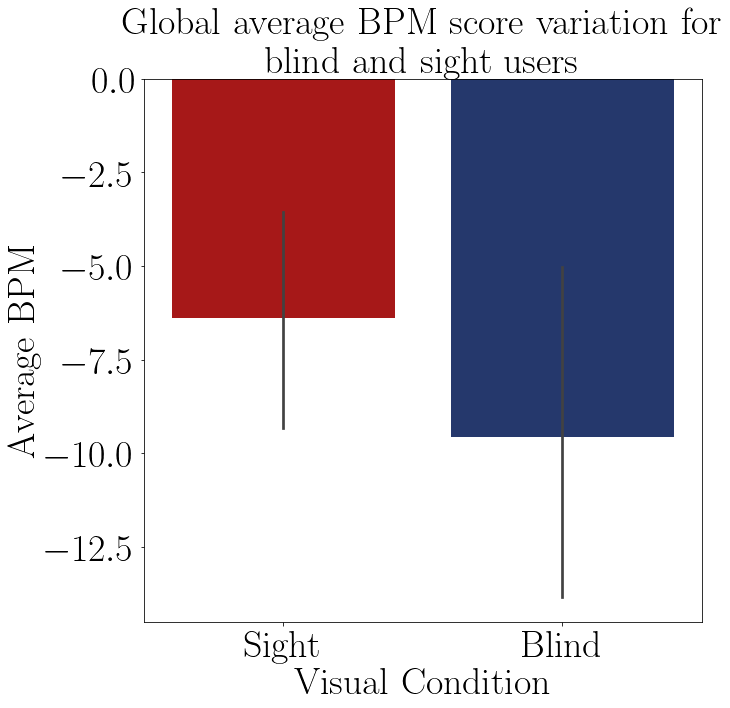


FIGURE 8.25 – Barplot of the average BPM score of each group.

TABLE 8.37 – Cross validation p-value for the average BPM on each method for blinded users.

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

analysing the Table 8.33 and the Figure 8.24 both of them provoked the highest heartrate variation.

8.3.1.2 Analysis of the heartbeat variancy

The Table 8.38 presents the standard deviation of the interbeat interval by each participant on each scenes and they are plotted in the Figures 8.26 and 8.27. It is possible to see that there were all of the users felt an increase in the heartbeat variance.

The Figures 8.28 and 8.29 show a comparison between both groups. They show that both groups had a similar standard deviation of the heartbeat and that means a similar

TABLE 8.38 – ECG Average SDNN felled by the participants.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Baseline | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Part. | Visual  Condition | Round |  |  |  |  |  |  |
| 001 | Sight | First | 37.52 | 82.73 | 82.19 | 134.53 | 134.77 | 225.41 |
|  |  | Return |  | 84.96 | 69.48 | 318.75 | 116.00 | 136.51 |
| 001C | Blind | First | 78.55 | 81.29 | 107.06 | 124.74 | 163.97 | 129.05 |
|  |  | Return |  | 120.72 | 130.88 | 131.59 | 157.59 | 124.79 |
| 002C | Blind | First | 93.77 | 73.76 | 98.86 | 81.14 | 33.98 | 79.29 |
|  |  | Return |  | 108.94 | 49.63 | 42.81 | 114.06 | 107.55 |
| 003 | Sight | First | 45.40 | 58.07 | 79.60 | 51.78 | 68.68 | 60.84 |
|  |  | Return |  | 21.30 | 45.71 | 40.93 | 66.32 | 47.82 |
| 003C | Blind | First | 26.14 | 36.87 | 38.32 | 35.10 | 42.39 | 43.69 |
|  |  | Return |  | 52.75 | 41.20 | 44.26 | 42.60 | 46.14 |
| 004 | Sight | First | 91.79 | 120.51 | 121.13 | 154.72 | 128.48 | 125.95 |
|  |  | Return |  | 139.86 | 100.37 | 122.56 | 140.12 | 119.26 |
| 004C | Blind | First | 20.98 | 70.73 | 86.83 | 62.56 | 85.90 | 70.47 |
|  |  | Return |  | 71.95 | 74.89 | 70.02 | 66.09 | 104.04 |
| 005 | Sight | First | 80.61 | 44.50 | 87.69 | 120.52 | 88.59 | 102.80 |
|  |  | Return |  | 59.77 | 93.21 | 122.84 | 141.31 | 96.03 |

mental workload in both groups.

The Table 8.39 shows the variation of the heartbeat in each round of each group. In general, all the standard deviations increased, meaning that the mental workload decreased between the ”Baseline” and the method.

TABLE 8.39 – ECG Average SDNN average in relation to the baseline grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 84.4% | 92.1% | 74.3% | 102.1% | 112.2% |
| Sight | 29.3% | 43.2% | 152.0% | 92.9% | 114.7% |

The Shapiro–Wilk normality test on the Table 8.40 shows that all of the ”blind”sample data are normally distributed, except the ”Mixture”method. In the ”sight”sample only the ”Base” and the ”Audio” method are normally distributed. That means that the following analyses cannot be made with those exceptions.

According to the T-Test presented in the Table 8.35 there is no difference in the heart rate frequency variation between the sample groups.

The Table 8.42 shows the Anova test p-value of the heart rate frequency of the ”blind” sample between the guidance methods presented in the Table 8.38. The p-value indicates

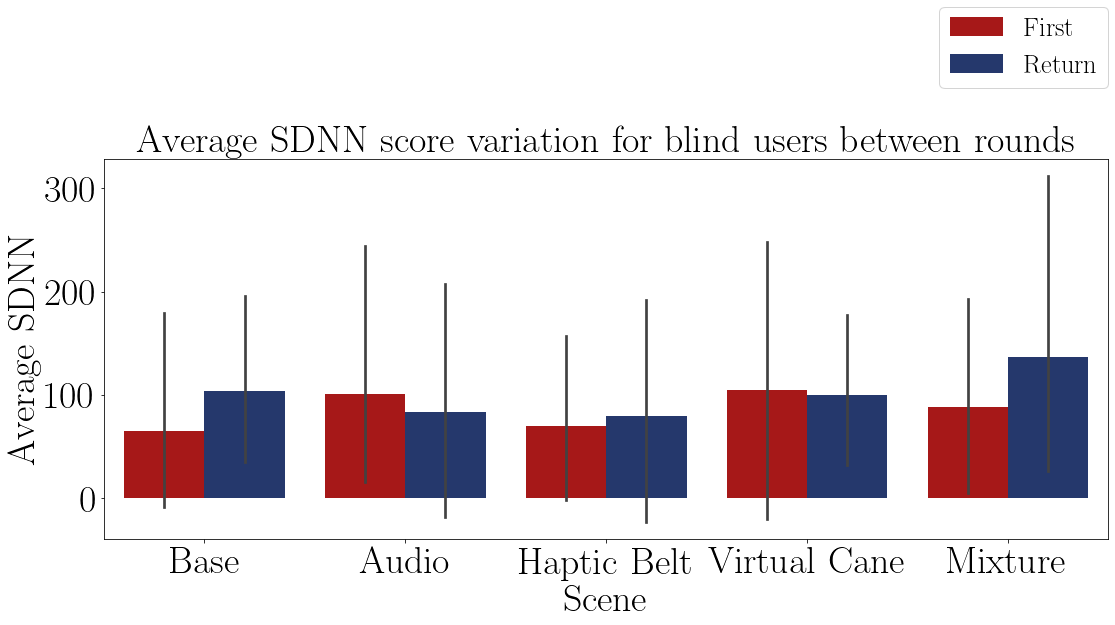


FIGURE 8.26 – Bar plot of the standard deviation of the heart of the blind participants on each method.

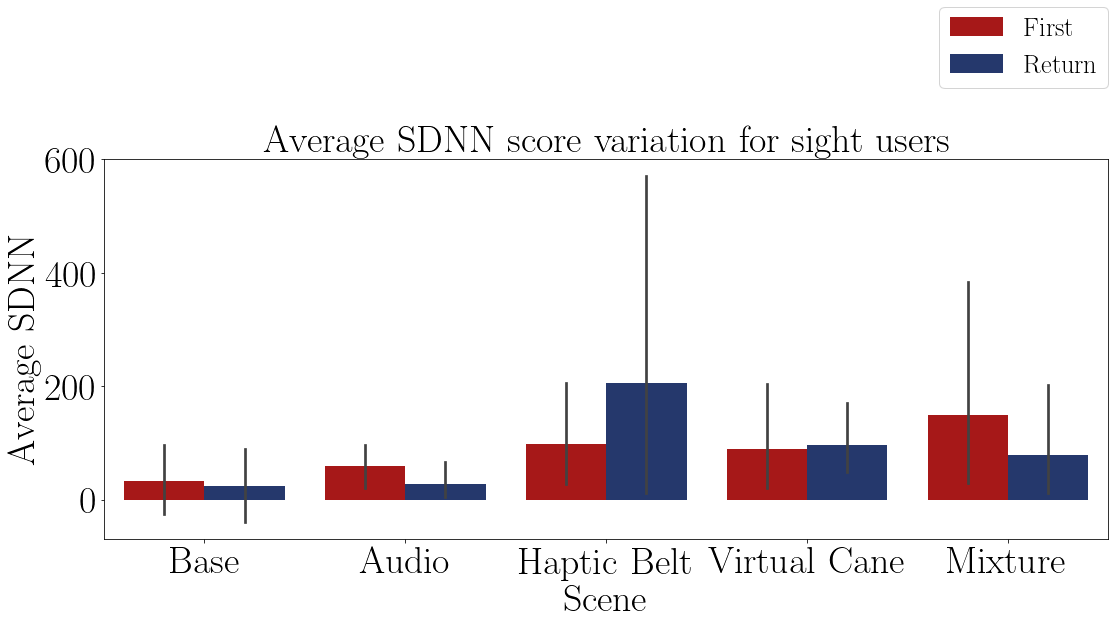


FIGURE 8.27 – Bar plot of the standard deviation of the heart of the sighted participants on each method.

that there is at least one method that is statistically equal to one of the other methods.

The Table 8.43 presents the conclusion of a pairwise Fisher LSD test of the blind heart rate frequency variation between all the guidance methods. The results show that the ”Virtual cane” and the ”Mixture” method differs from the ”Base” method.

According to the Anova test at Table 8.42 and the LSD test at 8.43 and the Table 8.39 the ”Virtual cane”and the ”Mixture”method did provoke an increase in the heartrate variancy.

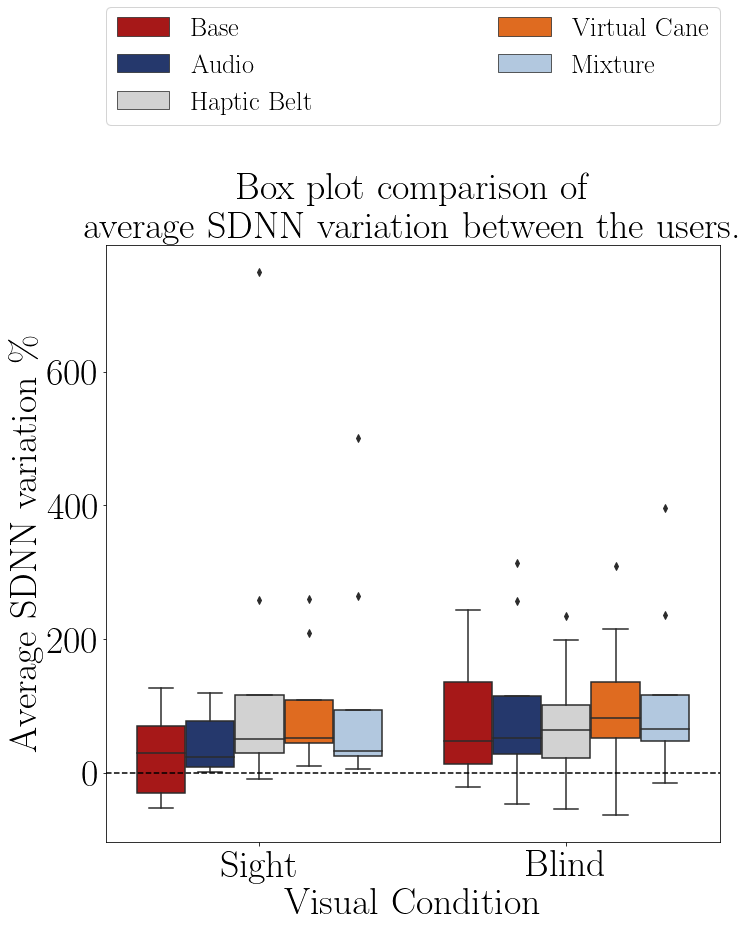


FIGURE 8.28 – Boxplot of the average heart rate of the participants on each method.

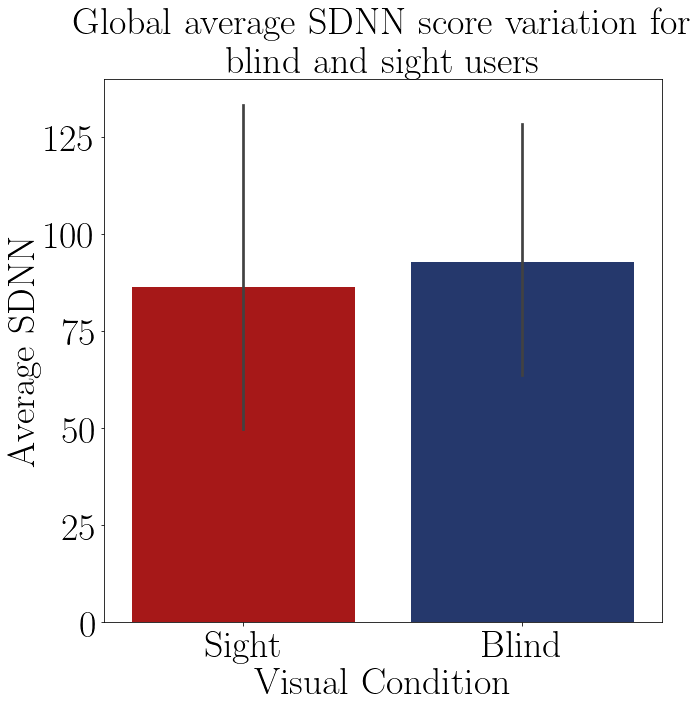


FIGURE 8.29 – Barplot of the average SDNN score of each group.

TABLE 8.40 – Shapiro test p-value for the ecg average SDNN for each method and visual con-

dition

|  |  |
| --- | --- |
| Method | Shapiro P-Value |
| Base blind | 0.078 |
| Base sight | 0.347 |
| Audio blind | 0.071 |
| Audio sight | 0.130 |
| Haptic Belt blind | 0.414 |
| Haptic Belt sight | 0.001 |
| Virtual Cane blind | 0.723 |
| Virtual Cane sight | 0.015 |
| Mixture blind | 0.027 |
| Mixture sight | 0.001 |

TABLE 8.41 – T test p-value for the ecg average SDNN each method for blinded users versus sighted users.

|  |  |
| --- | --- |
| Method | T-Test P-Value |
| Base | 0.230 |
| Audio | 0.317 |
| Haptic Belt | 0.434 |
| Virtual Cane | 0.862 |
| Mixture | 0.976 |

TABLE 8.42 – Anova p-value for the SDNN on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 3519.680 | 4 | 879.920 | 1.564 | 0.247 |
| Between blocks | 214885.879 | 3 | 71628.626 | 127.314 | 0.000\*\* |
| Experimental error | 6751.365 | 12 | 562.614 |  |  |
| Total | 225156.923 | 19 |  |  |  |

TABLE 8.43 – Cross validation p-value for the average SDNN on each method for blinded users.

|  |  |  |  |
| --- | --- | --- | --- |
| Method | | | Analysis |
| Base | *X* | Audio | *H*0 : *µBase* = *µAudio* |
| Base | *X* | Haptic Belt | *H*0 : *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*0 : *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* |

### 8.3.2 Galvanic skin reaction and temperature data;

The GSR analysis is made by analyzing the average in each round and comparing it with the ”Baseline” average. The temperature was analyzed with the GSR to see if there is some influence and by a graphical analysis there was none.

The Table 8.44 presents the average skin conductance by each participant on each scenes and they are plotted in the Figures 8.30 and 8.31. It is possible to see that in all of the methods there was an increase in the average skin conductance, meaning that the user was aroused and maybe an increase in the mental workload.

The Figure 8.24 shows a comparison between both groups

The Table 8.45 shows the variation of the heartbeat in each round of each group. It is also possible to notice the same increase noticed before.

The Shapiro–Wilk normality test on the Table 8.46 shows that only the ”Audio” method is normally distributed for the ”blind” sample while for the ”sight” sample only the ”Virtual Cane” is not normally distributed

According to the T-Test presented in the Table 8.47 there is no difference in the skin conductace frequency variation between the sample groups.

The Table 8.48 shows the Anova test p-value of the skin conductance frequency of the ”blind” sample between the guidance methods presented in the Table 8.44. The p-value indicates that there is at least one method that is statistically equal to one of the other methods.

The Table 8.49 presents the conclusion of a pairwise Fisher LSD test of the blind skin conductance frequency variation between all the guidance methods. The results show that the ”Virtual Cane” and the ”Mixture” have different variations, but since they are not normally distributed this conclusion can not statistically be made.

TABLE 8.44 – Average GSR felled by the participants.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Baseline | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Part. | Visual  Condition | Round |  |  |  |  |  |  |
| 001 | Sight | First | 4.27 | 8.80 | 15.19 | 15.67 | 15.19 | 14.15 |
|  |  | Return |  | 11.48 | 14.95 | 15.09 | 15.72 | 21.52 |
| 001C | Blind | First | 0.37 | 0.48 | 1.03 | 3.14 | 3.79 | 3.90 |
|  |  | Return |  | 0.83 | 1.58 | 2.81 | 4.04 | 4.57 |
| 002C | Blind | First | 0.17 | 0.91 | 0.23 | 0.17 | 0.17 | 0.17 |
|  |  | Return |  | 0.43 | 0.17 | 0.16 | 0.17 | 0.17 |
| 003 | Sight | First | 0.19 | 0.19 | 0.17 | 0.17 | 0.17 | 0.17 |
|  |  | Return |  | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| 003C | Blind | First | 0.30 | 0.56 | 0.56 | 0.62 | 0.85 | 1.09 |
|  |  | Return |  | 0.62 | 0.63 | 0.65 | 0.92 | 1.06 |
| 004 | Sight | First | 2.60 | 9.71 | 11.18 | 12.60 | 12.92 | 10.34 |
|  |  | Return |  | 10.89 | 11.97 | 12.25 | 13.47 | 10.16 |
| 004C | Blind | First | 1.24 | 2.34 | 3.07 | 3.49 | 2.28 | 2.23 |
|  |  | Return |  | 2.57 | 2.95 | 3.20 | 2.21 | 2.24 |
| 005 | Sight | First | 0.47 | 1.88 | 1.58 | 1.44 | 1.37 | 1.33 |
|  |  | Return |  | 1.66 | 1.53 | 1.47 | 1.49 | 1.33 |

TABLE 8.45 – Average GSR variation in relation to the baseline grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 72.2% | 3.4% | -4.1% | 2.9% | 4.2% |
| Sight | 89.9% | 0.5% | -1.3% | 5.9% | 18.3% |

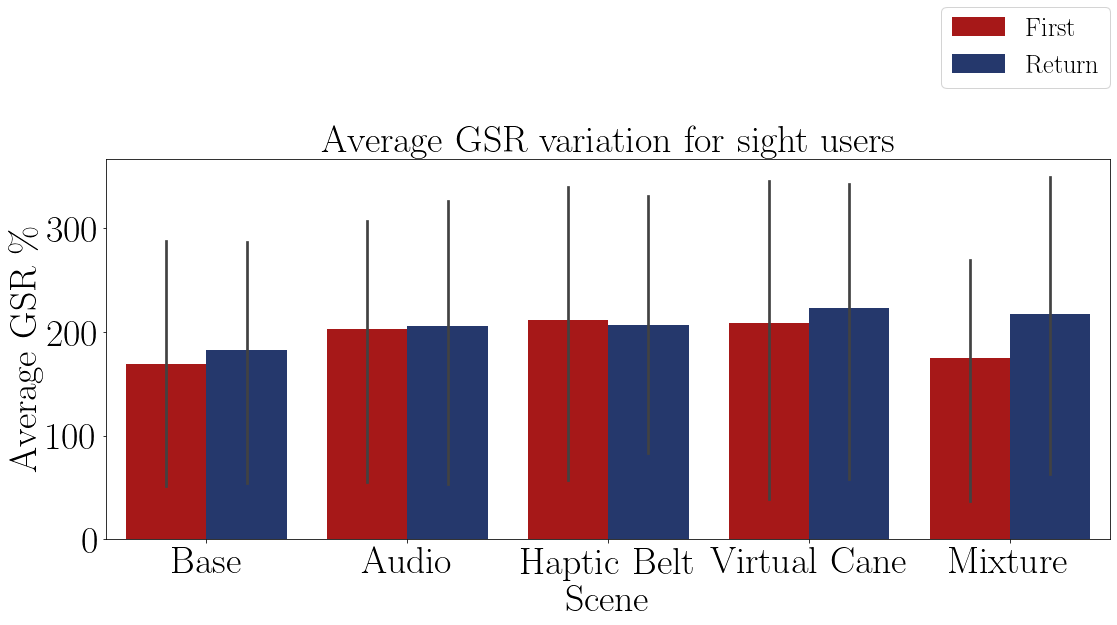
TABLE 8.46 – Shapiro test p-value for the gsr average for each method and visual condition

|  |  |
| --- | --- |
| Method | Shapiro P-Value |
| Base blind | 0.002 |
| Base sight | 0.187 |
| Audio blind | 0.544 |
| Audio sight | 0.046 |
| Haptic Belt blind | 0.017 |
| Haptic Belt sight | 0.155 |
| Virtual Cane blind | 0.004 |
| Virtual Cane sight | 0.275 |
| Mixture blind | 0.011 |
| Mixture sight | 0.376 |

TABLE 8.47 – T test p-value for the average GSR on each method for blinded users versus sighted users.

|  |  |
| --- | --- |
| Method | T-Test P-Value |
| Base | 0.876 |
| Audio | 0.942 |
| Haptic Belt | 0.627 |
| Virtual Cane | 0.557 |
| Mixture | 0.493 |

FIGURE 8.30 – Bar plot of the average skin conductance of the blind participants on each method.



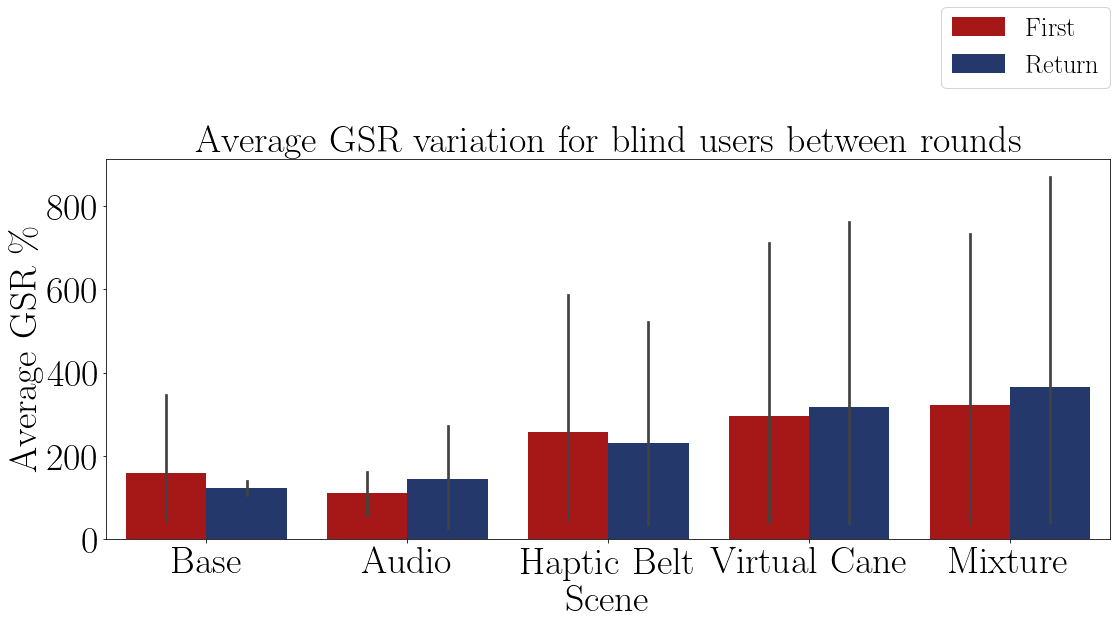
FIGURE 8.31 – Bar plot of the average skin conductance of the sighted participants on each method.

TABLE 8.48 – Anova p-value for the GSR score on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 886616.269 | 4 | 221654.067 | 3.310 | 0.048\*\* |
| Between blocks | 1918983.649 | 3 | 639661.216 | 9.552 | 0.002\*\* |
| Experimental error | 803557.557 | 12 | 66963.130 |  |  |
| Total | 3609157.475 | 39 |  |  |  |

According to the Anova test at Table 8.48 and the LSD test at 8.49 only the ”Virtual Cane” and the ”Mixture” method provoked a different reaction than the ”Base” method, but since the Shapiro test at the Table 8.46 showed that they are not normally distributed, than this conclusion has no foundation.

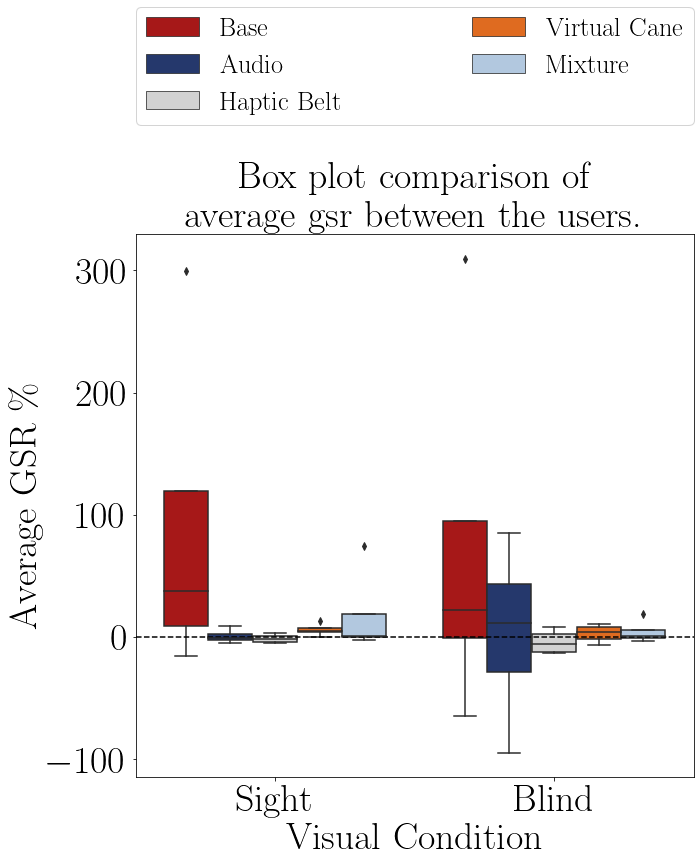


FIGURE 8.32 – Boxplot of the average skin conductace of the participants on each method.

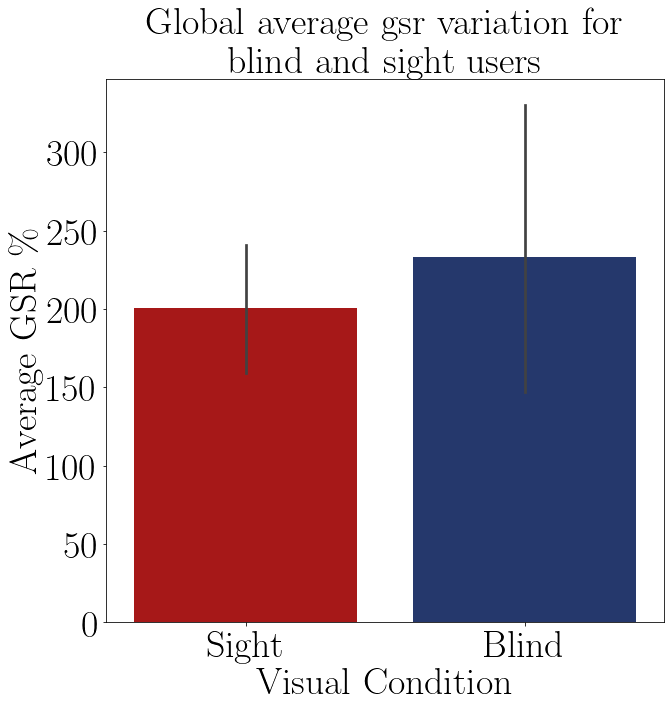


FIGURE 8.33 – Bar plot of the average GSR of of each group.

TABLE 8.49 – Cross validation p-value for the GSR on each method for blinded users.

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

8.2 Comparison between BVI users and sighted users.

In this section, the relationship between 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. As was the last section, this section will also be divided in the same subsections.

### 8.2.1 Data from questionnaires

Only the two questionnaires will be analyzed 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.

8.1.1.1 NASA-TLX

* Analysis of the mental demand scale

The Table 8.8 presents the mental demand average on each scene grouped by visual condition. This tables shows a clear difference between the mental demand from the users in the different conditions. Something similar is also presented in the Table 8.9, where it shows the mental demand variation and that this variation is higher in the “blind” sample than in the “sighted” sample

TABLE 8.8 – 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 |
| Sight | 4.00 | 11.75 | 14.25 | 9.38 | 12.125 |

TABLE 8.9 – Mental demand variation grouped by participant and visual Condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | -52.2% | -20.0% | -28.8% | -32.1% | -18.8% |
| Sight | -21.9% | -1.1% | -10.0% | -22.0% | -10.4% |

The Figure 8.7 presents a box plot of the mental demand scores of both groups plotted. A similar graphic is plotted in the Figure 8.8, where the average mental demand of both groups are plotted. In both figures it is noticeable that there is a difference between those two groups, but this difference is only statically meaningful a hypothesis confirms it.

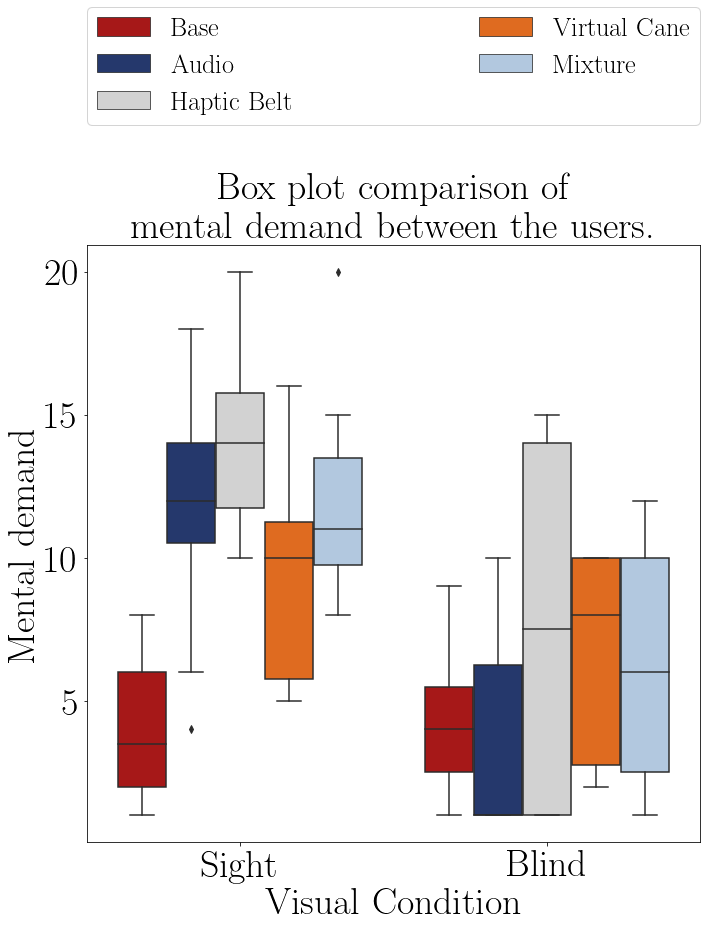


FIGURE 8.7 – Boxplot of the average mental demand of participant.

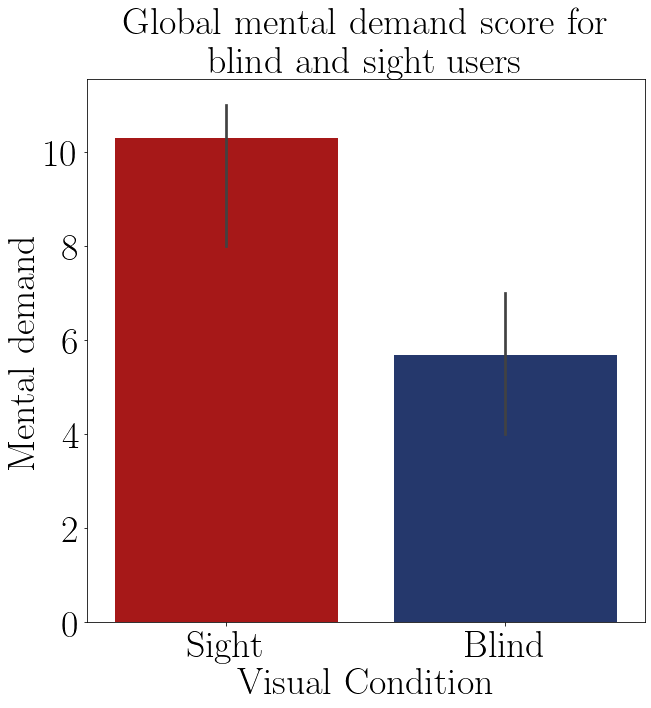
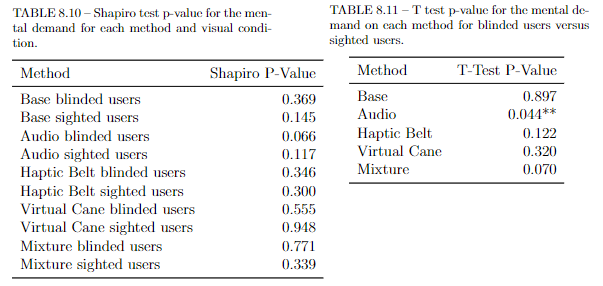


FIGURE 8.8 – Barplot of the average mental demand of each group.

According to the T-Test presented in the Table 8.11, all the methods showed a difference in the mental demand between the “sight” sample, with the exception of the “Audio”.



That means that only the “Audio” method proved to be different between the two groups, even though the Figure 8.7 shows that the other scenes are clearly different as well. This is probably a consequence of the result of a hypothesis test from a small sample group.

8.2.1.2 Analysis of the NASA-TLX score

The Table 8.14 presents the Nasa score averages by each participant on each scenes and they are plotted in the Figures 8.10 and 8.11. It is notible that after each ”First” round the Nasa score diminishes for both ”sight” and ”blind” participants.

The Figure 8.12 shows the Nasa score between the rounds of each participant. This figure shows a noticeable difference between the two groups, meaning that probably the Nasa score from the ”sight” sample is higher than the one of the ”blind” sample. This comparison can be made also with the data in the Table 8.15, that shows the average Nasa score grouped by visual condition.

In the Figure 8.13 is plotted the average Nasa score of each group and it also presents that the sighted participants felt a higher Nasa score than the blinded participants.

The Table 8.16 shows the Nasa score variation grouped by visual condition and it also shows the difference between the mental demand of the ”sight” sample and the ”blind” sample and how this score varies between the rounds.

The Figure 8.14 shows the variation of the Nasa score of the ”blind” sample and one can notice that the variation provoked on the ”Audio” method” is a lot lesser than the other ones.

The Shapiro–Wilk normality test on the Table 8.17 shows that these data are normally

TABLE 8.14 – NASA score felled by the participants.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual  Condition | Round |  |  |  |  |  |
| 001 | Sight | First | 7.83 | 10.17 | 9.83 | 7.00 | 9.000 |
|  |  | Return | 8.00 | 11.00 | 10.83 | 6.17 | 9.333 |
| 001C | Blind | First | 4.83 | 4.00 | 8.83 | 5.17 | 6.333 |
|  |  | Return | 4.17 | 4.00 | 6.67 | 4.50 | 6.167 |
| 002C | Blind | First | 6.33 | 4.83 | 4.83 | 9.00 | 7.000 |
|  |  | Return | 4.50 | 4.83 | 4.83 | 7.00 | 5.167 |
| 003 | Sight | First | 4.83 | 9.83 | 10.17 | 9.50 | 6.500 |
|  |  | Return | 4.33 | 6.67 | 9.67 | 7.83 | 4.833 |
| 003C | Blind | First | 4.00 | 4.00 | 5.33 | 6.67 | 3.500 |
|  |  | Return | 4.00 | 3.83 | 3.67 | 3.50 | 3.500 |
| 004 | Sight | First | 6.67 | 14.83 | 13.67 | 11.50 | 15.833 |
|  |  | Return | 6.83 | 11.83 | 11.83 | 10.83 | 12.167 |
| 004C | Blind | First | 9.83 | 10.00 | 12.67 | 9.67 | 11.000 |
|  |  | Return | 8.67 | 9.17 | 11.67 | 9.33 | 10.833 |
| 005 | Sight | First | 5.00 | 7.67 | 9.00 | 8.00 | 9.667 |
|  |  | Return | 5.00 | 7.67 | 8.67 | 7.67 | 6.000 |

TABLE 8.15 – NASA-TLX score grouped by participant and visual Condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 5.79 | 5.58 | 7.31 | 6.85 | 6.688 |
| Sight | 6.06 | 9.96 | 10.46 | 8.56 | 9.167 |

TABLE 8.16 – NASA-TLX score grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | -13.7% | -3.1% | -15.9% | -21.5% | -7.6% |
| Sight | -1.4% | -11.1% | -3.0% | -9.9% | -20.8% |

distributed, with an exception of the ”Base” and ”Audio” Nasa score. This means that further analysis cannot be applied to this method.

According to the T-Test presented in the Table 8.18 the ”Audio”and the ”Haptic belt” caused a different Nasa score between the ”sight” sample and the ”blind” sample.

The Table 8.19 shows the Anova test p-value of the Nasa score, presented in the Table

8.14, of the ”blind” sample between the guidance methods. The p-value indicates that

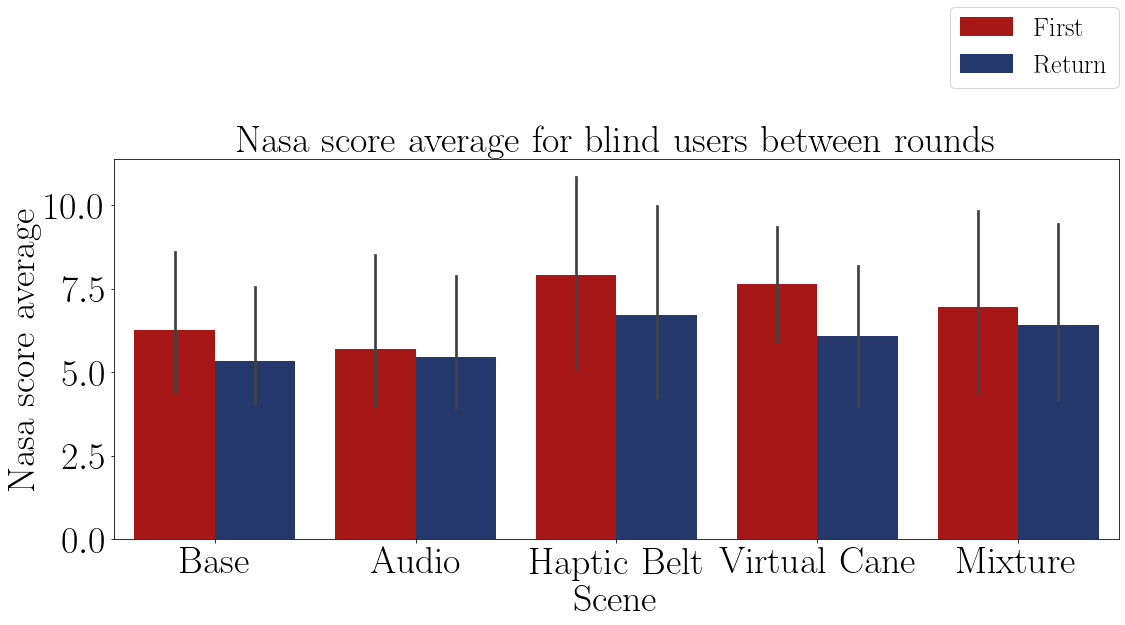


FIGURE 8.10 – Bar plot of the average Nasa-TLX score of the blind participants on each method.

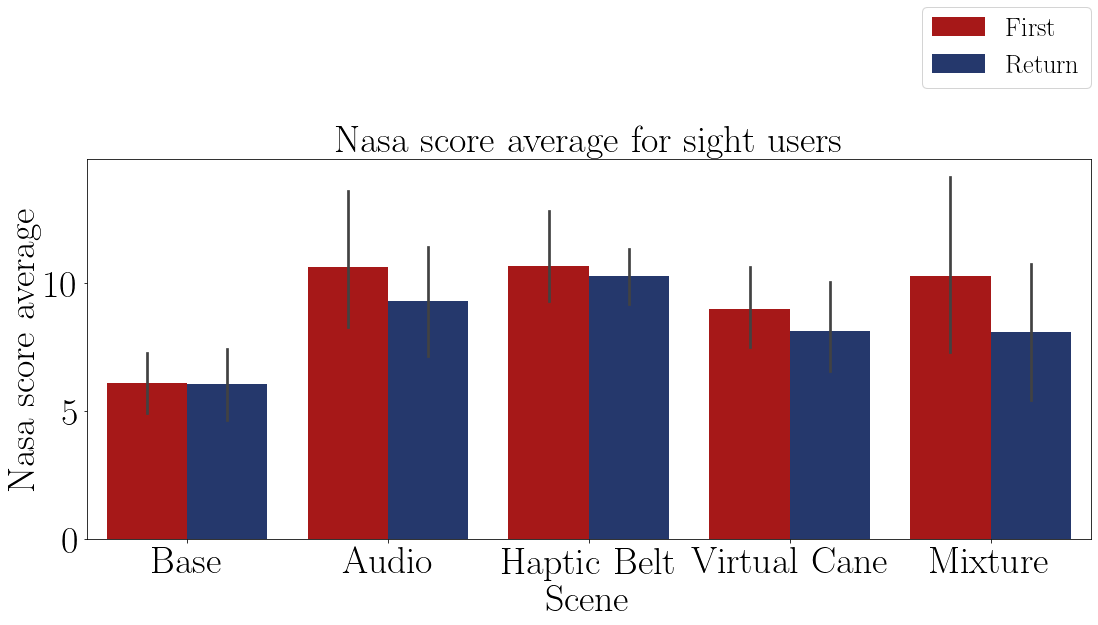


FIGURE 8.11 – Bar plot of the average Nasa-TLX score of the sighted participants on each method.

there is at least one method that is statistically equal to one of the other methods so it’s recommended to do a pairwise analysis between all the methods.

The Table 8.20 presents the results of a pairwise Fisher LSD test of the blind Nasa score average between all the guidance methods. The results show that only ”Audio” proved different from the ”Base” method.

According to T-Test on Table 8.18 the ”Audio” and ”Haptic belt” caused a different Nasa score when comparing both groups and analyzing the Figure 8.12 is noticiceable that they are different. The rest also seems to be different, but since the sample size was to small, it could be possible that the test would result in a different result if the sample size was bigger.

According to Anova test at Table 8.19 and the 8.20 and analyzing the data in the

Table 8.15 and in the Figure 8.12 the ”Audio”method provoked a lower Nasa Score in the

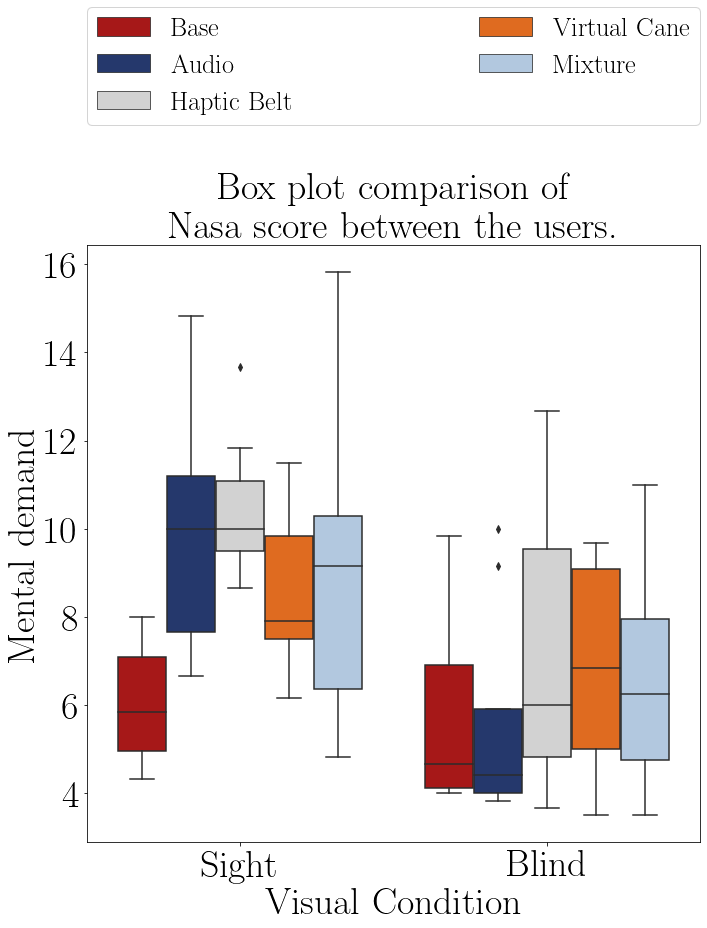


FIGURE 8.12 – Boxplot of the average NasaTLX score of the participants.

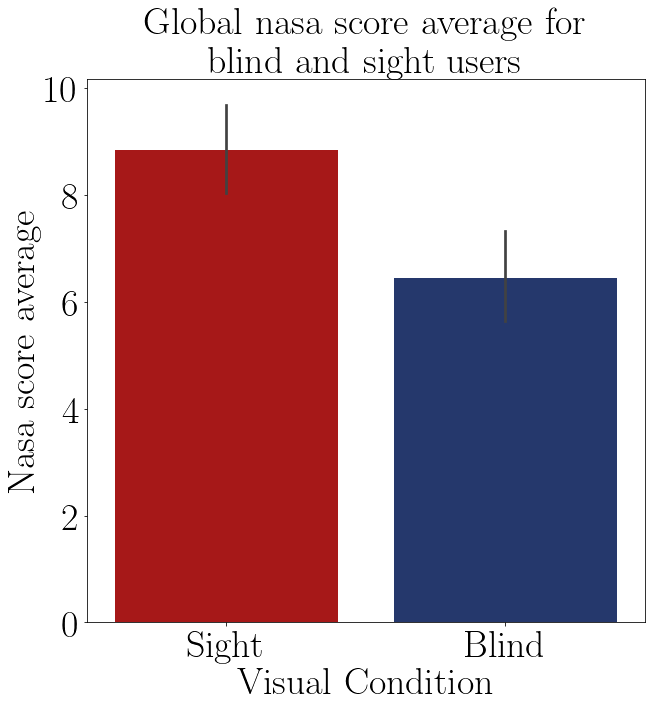


FIGURE 8.13 – Barplot of the average nasa score of each group.



FIGURE 8.14 – Barplot of the Nasa score variation from the blind participants of each method. blind participant.

TABLE 8.17 – Shapiro test p-value for the TABLE 8.18 – T test p-value for the NASA NASA score for each method and visual con- score on each method for blinded users versus dition. sighted users.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  | | --- | --- | | Method | Shapiro P-Value | | Base blinded users | 0.176 | | Base sighted users | 0.550 | | Audio blinded users | 0.034 | | Audio sighted users | 0.533 | | Haptic Belt blinded users | 0.321 | | Haptic Belt sighted users | 0.592 | | Virtual Cane blinded users | 0.329 | | Virtual Cane sighted users | 0.792 | | Mixture blinded users | 0.527 | | Mixture sighted users | 0.695 | | |  |  | | --- | --- | | Method | T-Test P-Value | | Base | 0.855 | | Audio | 0.058 | | Haptic Belt | 0.159 | | Virtual Cane | 0.296 | | Mixture | 0.331 | |

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 825.191 | 4 | 206.298 | 1.065 | 0.415 |
| Between blocks | 315.471 | 3 | 105.157 | 0.543 | 0.662 |
| Experimental error | 2324.141 | 12 | 193.678 |  |  |
| Total | 3464.803 | 19 |  |  |  |

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

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

### 8.2.2 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 participant is presented on the Table 8.21 and they are plotted in the Figures 8.15 and 8.16. It is visually noticeable that both of the groups perform better the second time they visit the room.

TABLE 8.21 – Adapted Sagat global score by participant and guidance method.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Participant | Visual  Condition | Round |  |  |  |  |  |
| 001 | Sight | First | 1.00 | 0.45 | 0.43 | 0.27 | 0.650 |
|  |  | Return | 1.00 | 0.60 | 0.50 | 0.50 | 0.450 |
| 001C | Blind | First | 0.62 | 0.55 | 0.53 | 0.58 | 0.350 |
|  |  | Return | 0.62 | 0.65 | 0.85 | 0.55 | 0.550 |
| 002C | Blind | First | 0.68 | 0.45 | 0.40 | 0.45 | 0.625 |
|  |  | Return | 0.53 | 0.50 | 0.40 | 0.65 | 0.850 |
| 003 | Sight | First | 1.00 | 0.68 | 0.60 | 0.40 | 0.675 |
|  |  | Return | 1.00 | 0.60 | 0.72 | 0.62 | 0.750 |
| 003C | Blind | First | 0.72 | 0.75 | 0.75 | 0.47 | 0.900 |
|  |  | Return | 1.00 | 1.00 | 0.85 | 0.90 | 0.900 |
| 004 | Sight | First | 1.00 | 0.72 | 0.80 | 0.60 | 0.825 |
|  |  | Return | 1.00 | 0.78 | 0.95 | 0.82 | 0.700 |
| 004C | Blind | First | 0.75 | 0.60 | 0.77 | 0.50 | 0.650 |
|  |  | Return | 0.90 | 0.60 | 0.93 | 0.72 | 0.900 |
| 005 | Sight | First | 1.00 | 0.30 | 0.32 | 0.40 | 0.400 |
|  |  | Return | 1.00 | 0.38 | 0.30 | 0.20 | 0.600 |

The Figure 8.17 shows the Sagat score between the rounds of each participant. It is possible to assume only that some methods cause different Sagat scores than others, and in the global average the ”blind”samnple had a better Sagat score than the ”sight”sample, as also shown in the Figure 8.18, which has the above data plotted, without considering the ”Base” method.

The Tables 8.22 and 8.23 shows the average and the variation between the rounds of the Sagat score grouped by visual condition, both of then present that the ”blind”sample had a better performance than the ”sight” sample.

TABLE 8.22 – Adapted Sagat average global score grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 0.73 | 0.64 | 0.68 | 0.60 | 0.716 |
| Sight | 1.00 | 0.56 | 0.58 | 0.48 | 0.631 |

The Shapiro–Wilk normality test on the Table 8.24 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform a T-Test to guarantee that the ”blind” sample is different than the ”sight” sample.

According to the T-Test presented in the Table 8.25, the only method that showed

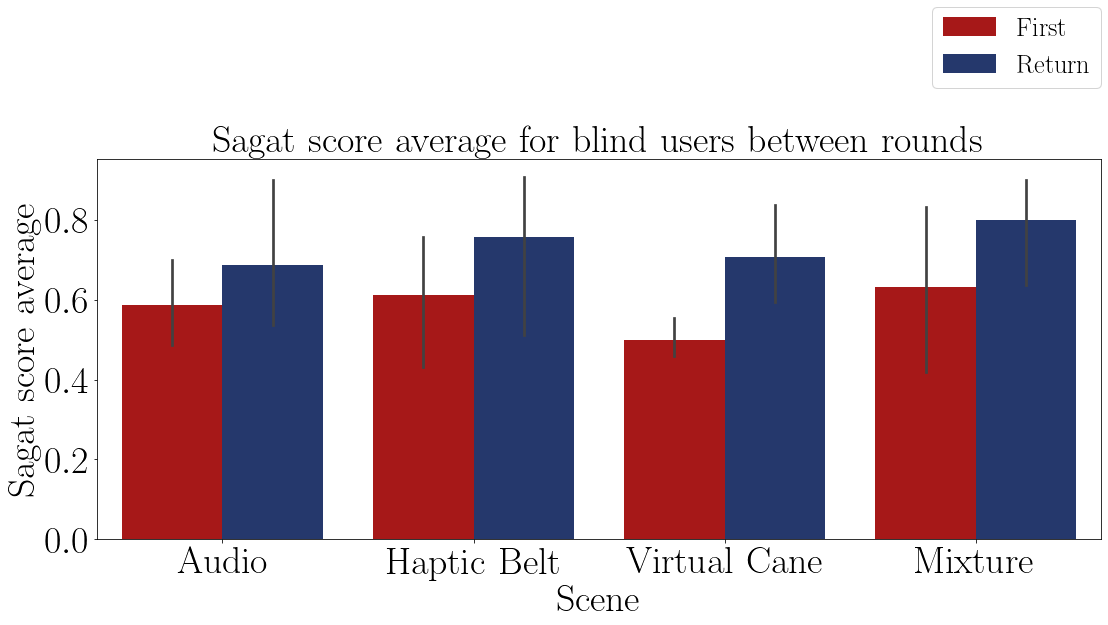


FIGURE 8.15 – Bar plot of the average Sagat score of the blind participants on each method.

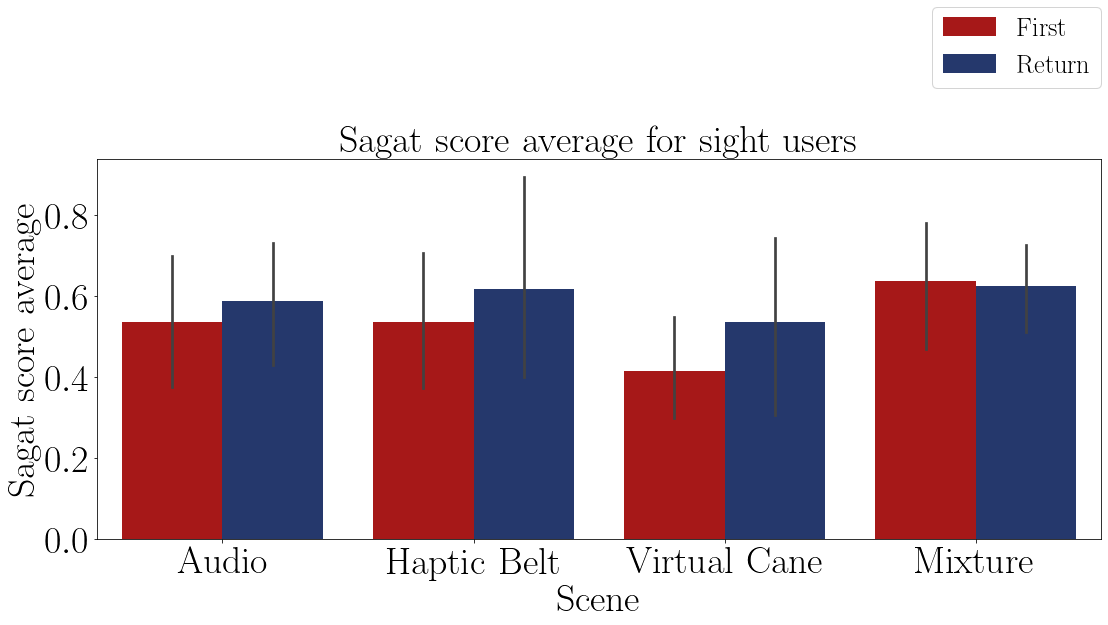


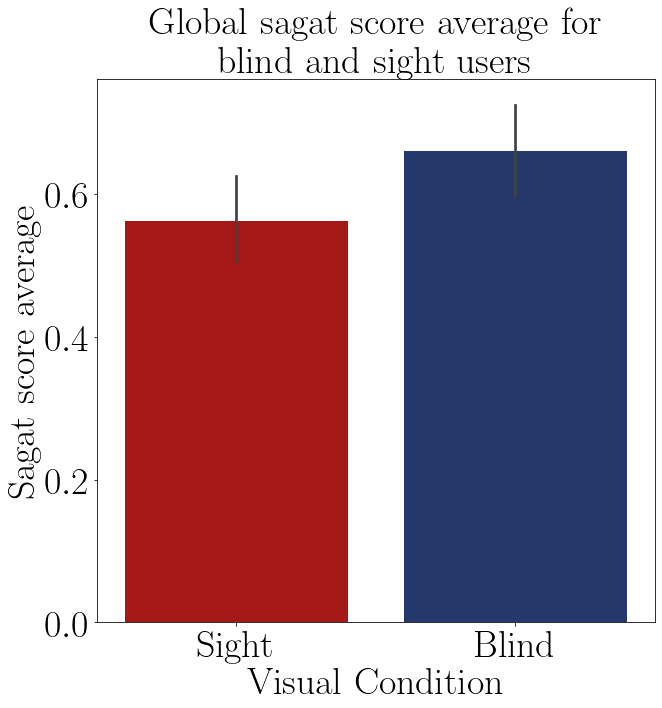
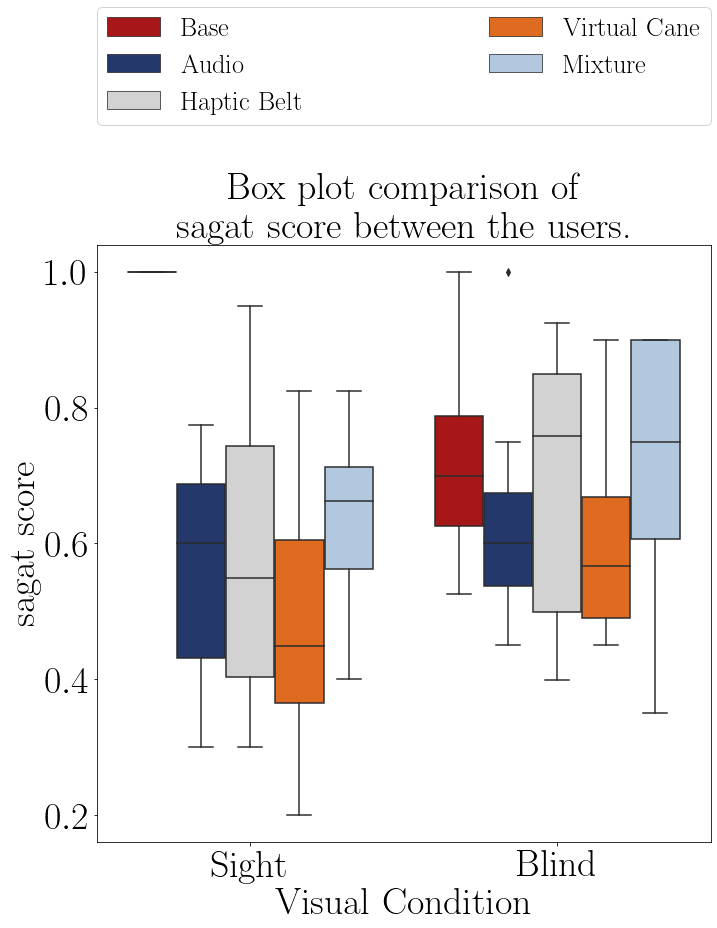
FIGURE 8.16 – Bar plot of the average Sagat score of the sighted participants on each method.

TABLE 8.23 – Adapted Sagat global score variation grouped by participant and visual Condition

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Blind | 8.9% | 15.7% | 23.5% | 44.3% | 32.9% |
| Sight | 0.0% | 13.5% | 12.6% | 33.1% | 3.8% |

a difference in the Sagat score between the ”sight” sample and the ”blind” sample is the ”Base”method, which is expected. In the other methods both samples had a similar Sagat score.

The Table 8.26 shows the Anova test p-value of the Sagat score of the ”blind” sample between the guidance methods presented in the Table 8.21. The p-value indicates that



|  |  |  |
| --- | --- | --- |
| FIGURE 8.17 – Boxplot of the average Sagat score of participant. | FIGURE 8.18 – Barplot of the average Sagat score of each group. | |
| TABLE 8.24 – Shapiro test p-value for the Sagat score for each method and visual condition | TABLE 8.25 – T test p-value for the Sagat score on each method for blinded users versus sighted users. | |
| |  |  | | --- | --- | | Method | Shapiro P-Value | | Base blinded users | 0.189 | | Base sighted users | 1.000 | | Audio blinded users | 0.350 | | Audio sighted users | 0.925 | | Haptic Belt blinded users | 0.315 | | Haptic Belt sighted users | 0.942 | | Virtual Cane blinded users | 0.549 | | Virtual Cane sighted users | 0.784 | | Mixture blinded users | 0.520 | | Mixture sighted users | 0.446 | | | |  |  | | --- | --- | | Method | T-Test P-Value | | Base | 0.007\*\* | | Audio | 0.561 | | Haptic Belt | 0.527 | | Virtual Cane | 0.230 | | Mixture | 0.488 | |

there is at least one method that is statistically equal to one of the other methods.

The Table 8.27 presents the analysis of a pairwise Fisher LSD test of the blind average Sagat score between all the guidance methods. The results show that the ”Audio” and ”Virtual Cane”caused a different Sagat score than the one noticed on the ”Base”Method. The rest of the methods did not significantly change it.

According to T-Test on Table 8.25, there is no difference in Sagat score between the ”sight” and the ”blind” sample except the ”Base” method, which is expected.

TABLE 8.26 – 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*) |
| Between factors | 0.045 | 4 | 0.011 | 0.966 | 0.461 |
| Between blocks | 0.241 | 3 | 0.080 | 6.962 | 0.006\*\* |
| Experimental error | 0.139 | 12 | 0.012 |  |  |
| Total | 0.424 | 19 |  |  |  |

TABLE 8.27 – Cross validation p-value for the Sagat score on each method for blinded users.

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

According to both Anova test at Table 8.26 and LSD test at Table 8.27 only the ”Audio” and the ”Virtual Cane” provoked a similar situation awareness when compared to the ”Base” method.

8.2.3 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 satisfactied with that method. The Table 8.28 shows the average score of each method and they are plotted in the Figures 8.5 and 8.6

The Table 8.29 show the the average questionnaire score of each participant and the Figure 8.21 these data is plotted. It is possible only to assume that some methods cause different Sagat scores than others, but both groups performed rather similarly.

The Shapiro–Wilk normality test on the Table 8.30 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform the following test to check if there is a significant difference between the methods

The Table 8.31 shows the Anova test p-value of the Sagat score average of the ”blind”

TABLE 8.28 – Guidance method questionnaire average score grouped by participant.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Participant | Audio | Haptic  Belt | Virtual  Cane | Mixture | Visual Condition |
| 001 | 0.75 | 0.49 | 0.57 | 0.69 | Sight |
| 001C | 0.77 | 0.54 | 0.63 | 0.87 | Blind |
| 002C | 0.86 | 0.74 | 0.54 | 0.93 | Blind |
| 003 | 0.76 | 0.54 | 0.54 | 0.78 | Sight |
| 003C | 0.93 | 0.57 | 0.54 | 0.74 | Blind |
| 004 | 0.86 | 0.60 | 0.79 | 0.76 | Sight |
| 004C | 0.88 | 0.49 | 0.40 | 0.73 | Blind |
| 005 | 0.61 | 0.57 | 0.75 | 0.84 | Sight |

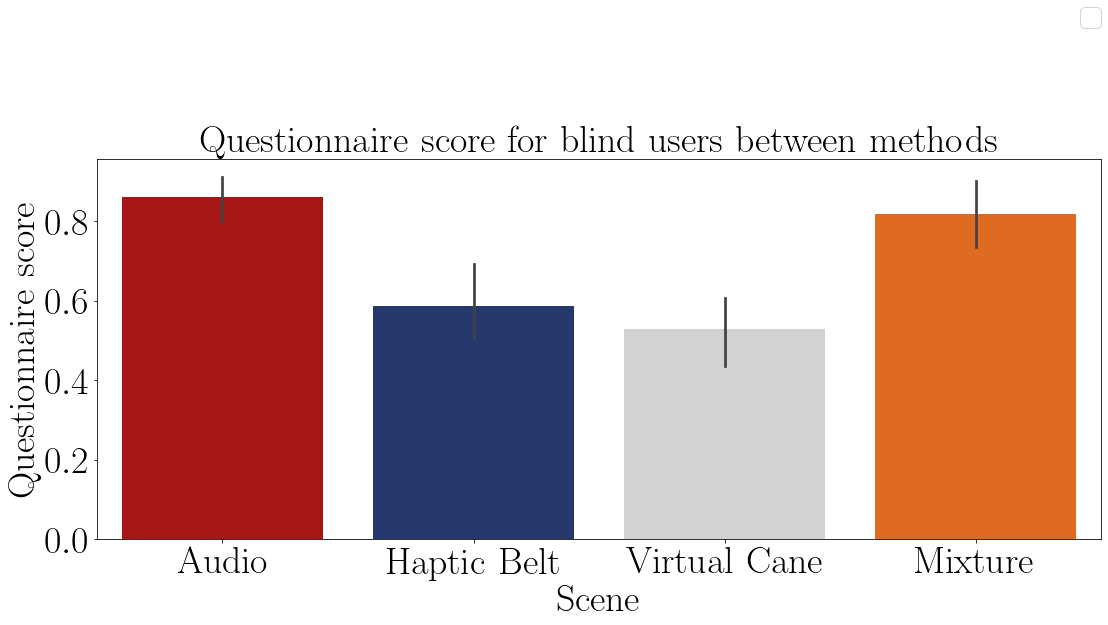


FIGURE 8.19 – Bar plot of the average mental demand of the blind participants on each method.

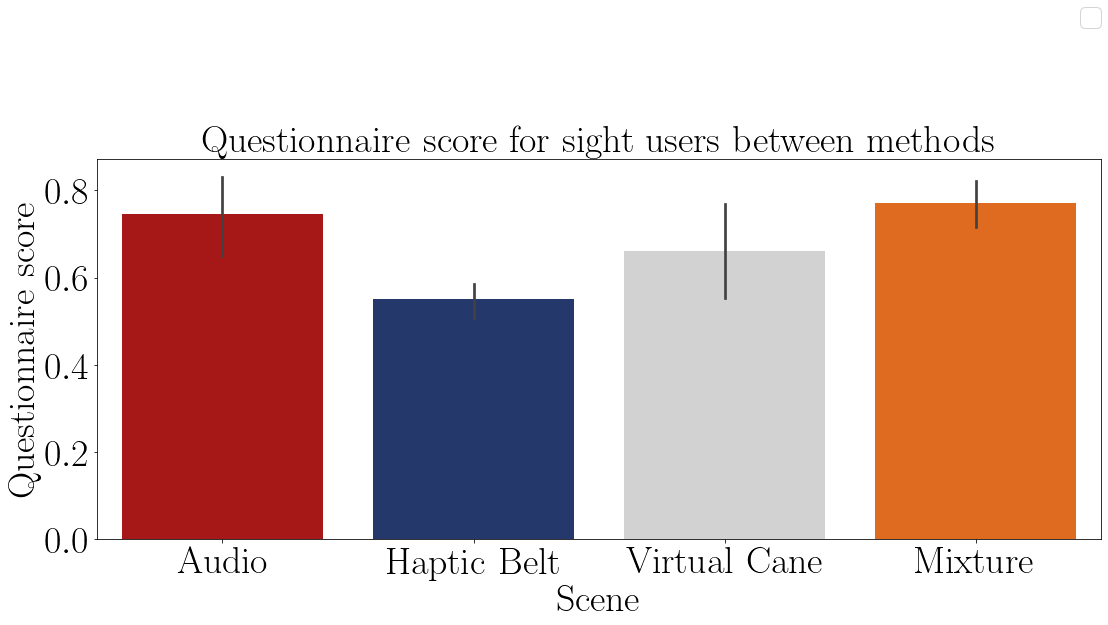


FIGURE 8.20 – Bar plot of the average mental demand of the sighted participants on each method.

TABLE 8.29 – 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 |
| Sight | 0.75 | 0.55 | 0.66 | 0.77 |

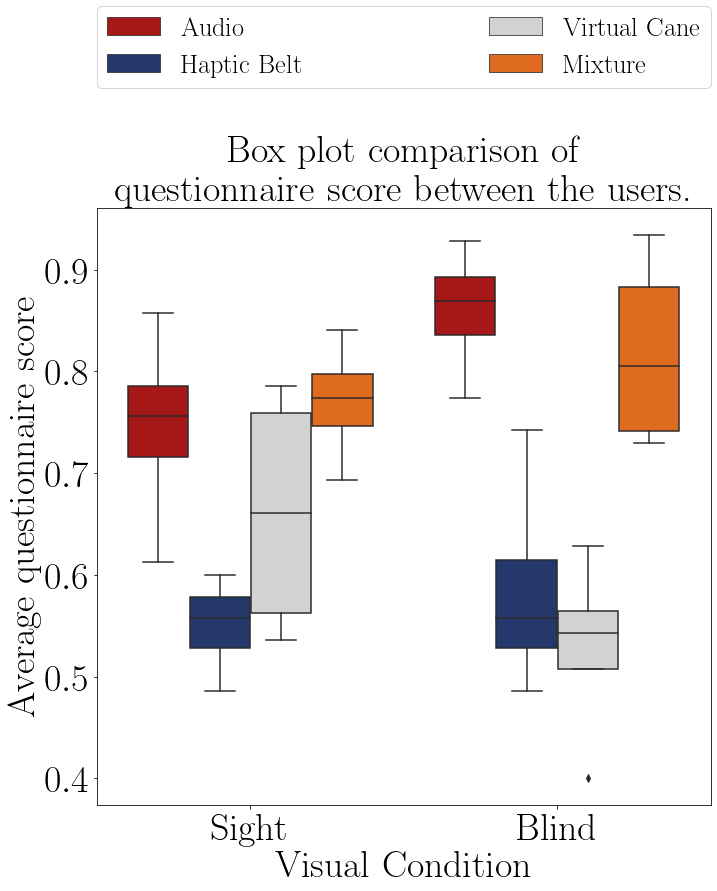


FIGURE 8.21 – Boxplot of the average questionnaire score of each group.

TABLE 8.30 – Shapiro test p-value for the questionnaires score for each method and visual condition.

|  |  |
| --- | --- |
| Method | Shapiro P-Value |
| Audio blinded users | 0.827 |
| Audio sighted users | 0.722 |
| Haptic Belt blinded users | 0.414 |
| Haptic Belt sighted users | 0.850 |
| Virtual Cane blinded users | 0.515 |
| Virtual Cane sighted users | 0.262 |
| Mixture blinded users | 0.392 |
| Mixture sighted users | 0.916 |

sample between the guidance methods presented in the Table 8.28. The p-value indicates that all scores are significantly different from each other. That means that the highest scores shown in Table 8.29, which are the ”Haptic Belt” and the ”Mixture” methods were the most favorite by the participant.

TABLE 8.31 – 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*) |
| Between factors | 0.329 | 3 | 0.110 | 15.677 | 0.001\*\* |
| Between blocks | 0.042 | 3 | 0.014 | 2.014 | 0.183 |
| Experimental error | 0.063 | 9 | 0.007 |  |  |
| Total | 0.434 | 15 |  |  |  |

## 8.3 Data from physiological sensors

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

* Electrocardiogram (ECG) data;

Is expected that the ECG frequency to increase at every ”First” round and then a slight decrease in the next round. Also, the variation 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.

### 8.3.1 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 state induced state by the scene.

After the data gathering, an algorithm in python was used to read the data and separate it accordingly to each participant, method and round. Since the participants moved during the whole experience a lot of noise was collected by the sensors, so these outliers were removed. The following steps were to normalize the data between -1 and 1 and then a peak detection method was used then, if the results were appropriate, the interval between each peak was calculated and saved to be used in the next software. This judgment was made by analyzing the plotted ECG signal and the detected peaks. If the detected peaks are not aligned with the peaks of the signal, then the method’s parameters were tuned to fit the detected peaks with the signals’ peaks.

The next used software was Kubios HRV Standard. Kubios is a heart rate variability (HRV) analysis software for personal non-commercial 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 saved intervals was analyzed and the results were saved in a report file to be read in python again. 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.

8.3.1.1 Analysis of the heartbeat frequency

The Table 8.32 presents the average heart rate by each participant on each scenes and they are plotted in the Figures 8.22 and 8.23. It is possible to see that there was no heart rate increase by any participant with the exception only of the ”sight”sample in the ”First” round of the ”Base” method.

The Table 8.33 show the average heartbeat frequency variation between the rounds of each group and the Figure 8.24 these data is plotted. Despite all the variations being negative, which was not as expected, it possible to see that the ”Audio” and the ”Virtual cane” provoked the highest variation in heartrate.

The Figures 8.24 and 8.25 show a comparison between both groups and both of them show that the blind group felt a bigger variation. That means that the ”blind”sample felt a bigger mental workload variation.

The Shapiro–Wilk normality test on the Table 8.34 shows that these data are normally distributed, with a p-value higher than 0.05, then it is possible to perform a T-Test to guarantee that the ”blind” sample is different than the ”sight” sample.

According to the T-Test presented in the Table 8.35 there is no difference in the heart rate frequency variation between the sample groups.

The Table 8.36 shows the Anova test p-value of the heart rate frequency of the ”blind” sample between the guidance methods presented in the Table 8.32. The p-value indicates

TABLE 8.32 – ECG average BPM felled by the participants.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Baseline | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Part. | Visual  Condition | Round |  |  |  |  |  |  |
| 001 | Sight | First | 81.29 | 76.86 | 71.23 | 63.02 | 64.85 | 58.77 |
|  |  | Return |  | 72.88 | 73.18 | 61.18 | 66.78 | 66.26 |
| 001C | Blind | First | 78.33 | 75.75 | 60.71 | 71.17 | 59.07 | 68.24 |
|  |  | Return |  | 71.05 | 58.61 | 66.22 | 64.20 | 70.76 |
| 002C | Blind | First | 67.78 | 48.69 | 38.67 | 48.74 | 46.89 | 52.23 |
|  |  | Return |  | 52.46 | 47.58 | 58.97 | 56.75 | 58.25 |
| 003 | Sight | First | 77.38 | 74.98 | 63.47 | 71.80 | 70.90 | 72.76 |
|  |  | Return |  | 69.29 | 72.75 | 71.23 | 67.49 | 73.01 |
| 003C | Blind | First | 63.45 | 68.37 | 69.89 | 70.95 | 69.41 | 66.94 |
|  |  | Return |  | 67.34 | 67.44 | 69.68 | 68.82 | 67.37 |
| 004 | Sight | First | 65.32 | 72.97 | 66.85 | 62.45 | 65.94 | 67.86 |
|  |  | Return |  | 76.85 | 69.48 | 65.65 | 64.58 | 71.86 |
| 004C | Blind | First | 78.30 | 75.09 | 73.55 | 73.70 | 71.94 | 74.03 |
|  |  | Return |  | 74.74 | 74.79 | 74.02 | 72.69 | 67.34 |
| 005 | Sight | First | 71.25 | 70.18 | 71.34 | 66.93 | 66.46 | 67.06 |
|  |  | Return |  | 67.69 | 69.57 | 65.97 | 67.00 | 65.47 |

TABLE 8.33 – ECG average BPM average in relation to the baseline grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | -7.3% | -14.3% | -6.9% | -10.9% | -8.4% |
| Sight | -0.8% | -5.0% | -10.0% | -9.0% | -7.2% |

TABLE 8.34 – Shapiro test p-value for the ecg average BPM for each method and visual con-

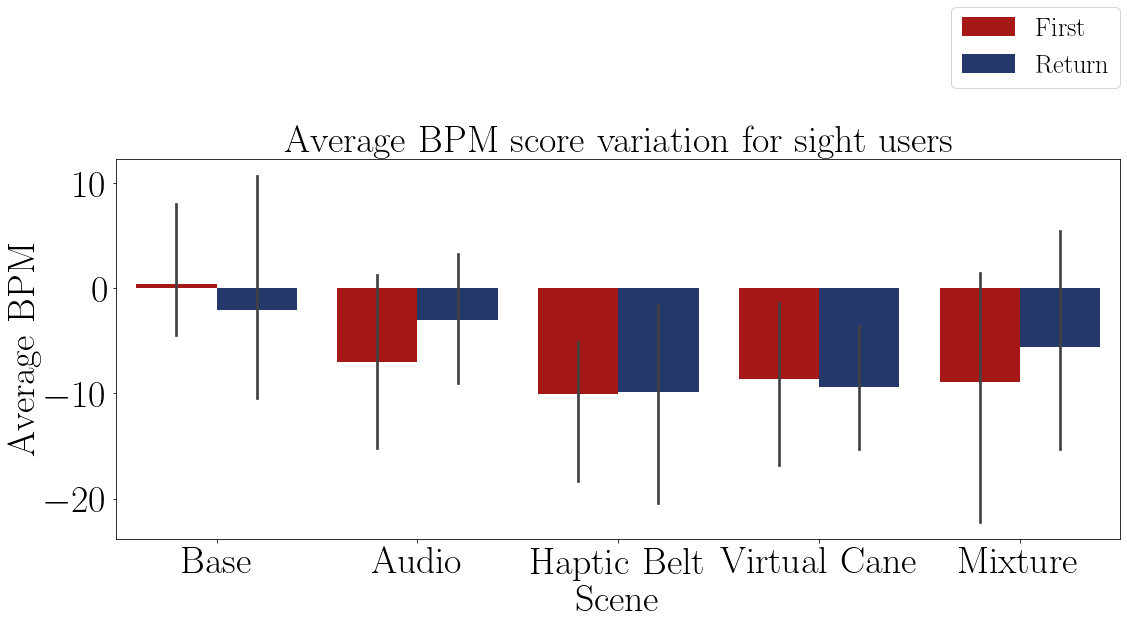
dition

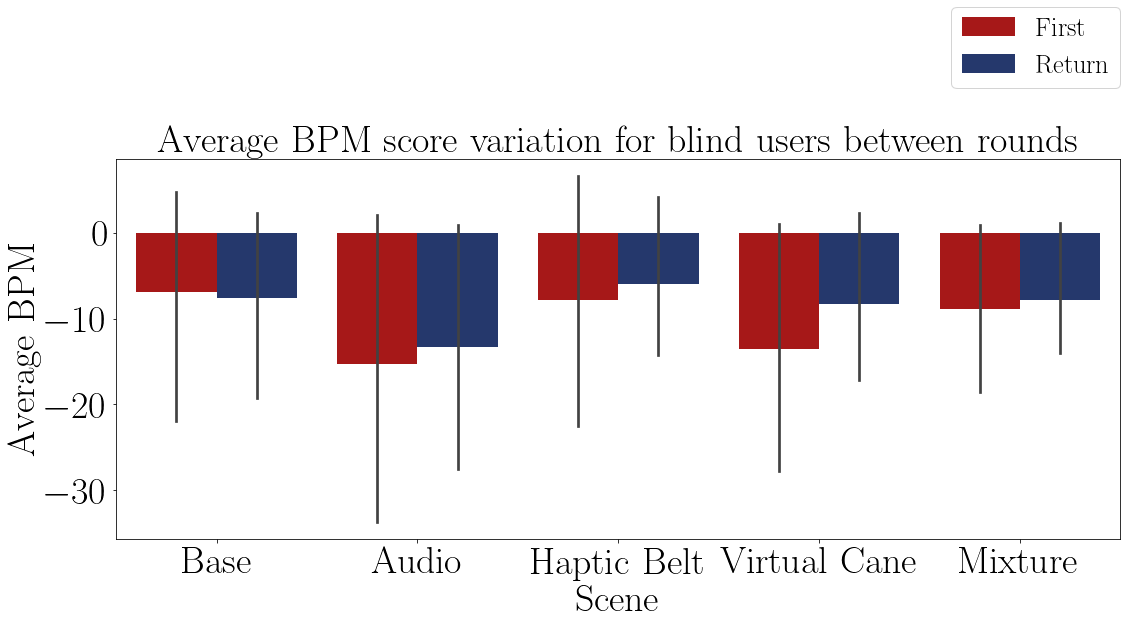
|  |  |
| --- | --- |
| Method | Shapiro P-Value |
| Base blind | 0.377 |
| Base sight | 0.086 |
| Audio blind | 0.721 |
| Audio sight | 0.969 |
| Haptic Belt blind | 0.665 |
| Haptic Belt sight | 0.059 |
| Virtual Cane blind | 0.584 |
| Virtual Cane sight | 0.743 |
| Mixture blind | 0.379 |
| Mixture sight | 0.663 |

TABLE 8.35 – T test p-value for the ecg average BPM each method for blinded users versus sighted users.

|  |  |
| --- | --- |
| Method | T-Test P-Value |
| Base | 0.279 |
| Audio | 0.215 |
| Haptic Belt | 0.594 |
| Virtual Cane | 0.750 |
| Mixture | 0.834 |

FIGURE 8.22 – Bar plot of the average heart rate of the blind participants on each method.



FIGURE 8.23 – Bar plot of the average heart rate of the sighted participants on each method.

that there is at least one method that is statistically equal to one of the other methods, and the LSD Fischer test in the Table 8.37 shows that the ”Audio”and the ”Virtual Cane” are differente than the ”Base” method.

TABLE 8.36 – Anova p-value for the BPM on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 151.789 | 4 | 37.947 | 1.570 | 0.245 |
| Between blocks | 2934.674 | 3 | 978.225 | 40.471 | 0.000\*\* |
| Experimental error | 290.050 | 12 | 24.171 |  |  |
| Total | 3376.513 | 19 |  |  |  |

According to the Anova test at Table 8.36 and the LSD test at 8.37 the ”Audio” and the ”Virtual Cane” method provoked a different reaction than the ”Base” method and

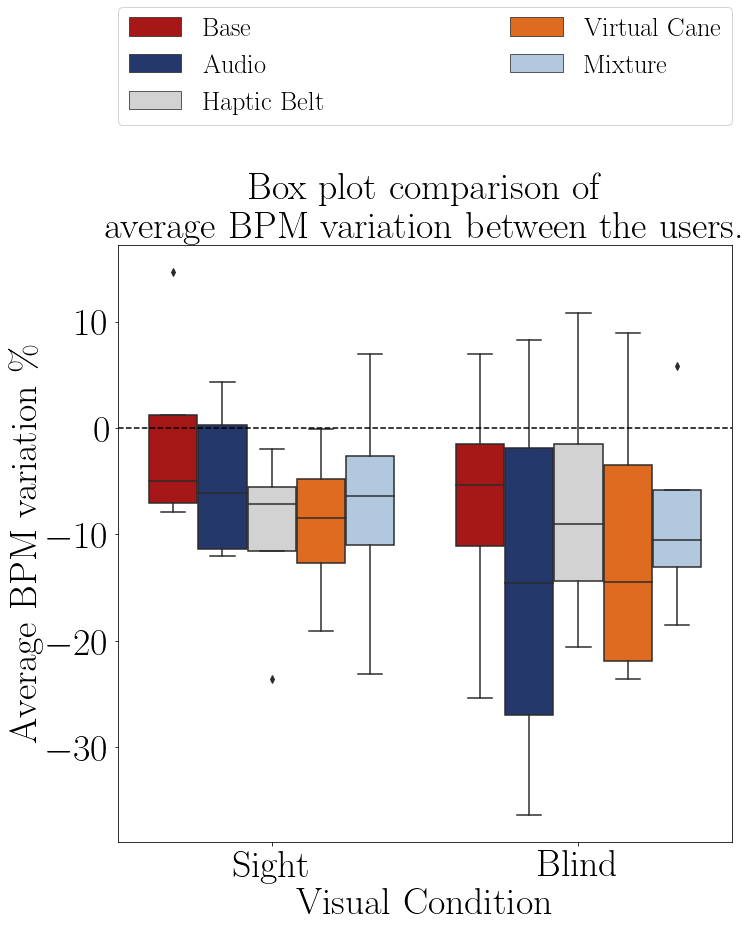


FIGURE 8.24 – Boxplot of the average heart rate of participants on each method.

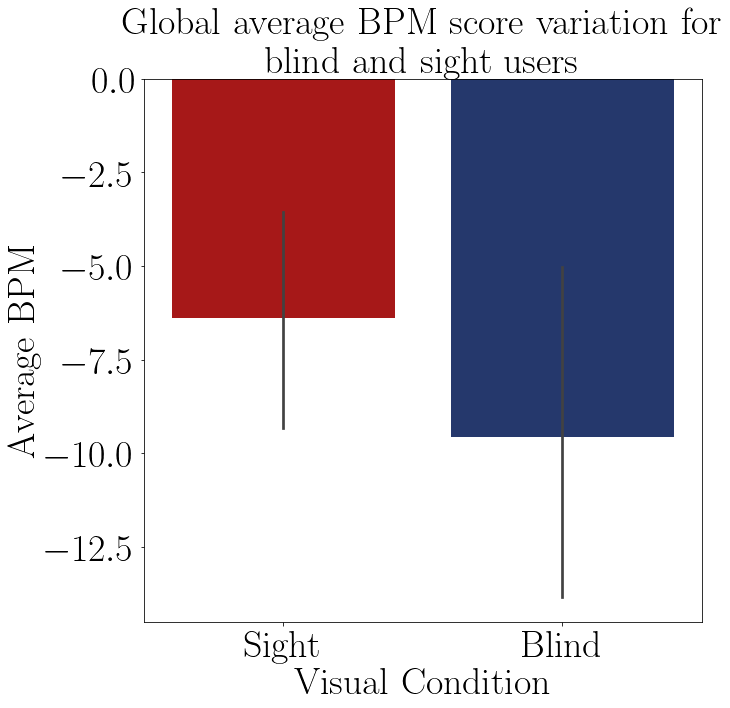


FIGURE 8.25 – Barplot of the average BPM score of each group.

TABLE 8.37 – Cross validation p-value for the average BPM on each method for blinded users.

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

analysing the Table 8.33 and the Figure 8.24 both of them provoked the highest heartrate variation.

8.3.1.2 Analysis of the heartbeat variancy

The Table 8.38 presents the standard deviation of the interbeat interval by each participant on each scenes and they are plotted in the Figures 8.26 and 8.27. It is possible to see that there were all of the users felt an increase in the heartbeat variance.

The Figures 8.28 and 8.29 show a comparison between both groups. They show that both groups had a similar standard deviation of the heartbeat and that means a similar

TABLE 8.38 – ECG Average SDNN felled by the participants.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Baseline | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Part. | Visual  Condition | Round |  |  |  |  |  |  |
| 001 | Sight | First | 37.52 | 82.73 | 82.19 | 134.53 | 134.77 | 225.41 |
|  |  | Return |  | 84.96 | 69.48 | 318.75 | 116.00 | 136.51 |
| 001C | Blind | First | 78.55 | 81.29 | 107.06 | 124.74 | 163.97 | 129.05 |
|  |  | Return |  | 120.72 | 130.88 | 131.59 | 157.59 | 124.79 |
| 002C | Blind | First | 93.77 | 73.76 | 98.86 | 81.14 | 33.98 | 79.29 |
|  |  | Return |  | 108.94 | 49.63 | 42.81 | 114.06 | 107.55 |
| 003 | Sight | First | 45.40 | 58.07 | 79.60 | 51.78 | 68.68 | 60.84 |
|  |  | Return |  | 21.30 | 45.71 | 40.93 | 66.32 | 47.82 |
| 003C | Blind | First | 26.14 | 36.87 | 38.32 | 35.10 | 42.39 | 43.69 |
|  |  | Return |  | 52.75 | 41.20 | 44.26 | 42.60 | 46.14 |
| 004 | Sight | First | 91.79 | 120.51 | 121.13 | 154.72 | 128.48 | 125.95 |
|  |  | Return |  | 139.86 | 100.37 | 122.56 | 140.12 | 119.26 |
| 004C | Blind | First | 20.98 | 70.73 | 86.83 | 62.56 | 85.90 | 70.47 |
|  |  | Return |  | 71.95 | 74.89 | 70.02 | 66.09 | 104.04 |
| 005 | Sight | First | 80.61 | 44.50 | 87.69 | 120.52 | 88.59 | 102.80 |
|  |  | Return |  | 59.77 | 93.21 | 122.84 | 141.31 | 96.03 |

mental workload in both groups.

The Table 8.39 shows the variation of the heartbeat in each round of each group. In general, all the standard deviations increased, meaning that the mental workload decreased between the ”Baseline” and the method.

TABLE 8.39 – ECG Average SDNN average in relation to the baseline grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 84.4% | 92.1% | 74.3% | 102.1% | 112.2% |
| Sight | 29.3% | 43.2% | 152.0% | 92.9% | 114.7% |

The Shapiro–Wilk normality test on the Table 8.40 shows that all of the ”blind”sample data are normally distributed, except the ”Mixture”method. In the ”sight”sample only the ”Base” and the ”Audio” method are normally distributed. That means that the following analyses cannot be made with those exceptions.

According to the T-Test presented in the Table 8.35 there is no difference in the heart rate frequency variation between the sample groups.

The Table 8.42 shows the Anova test p-value of the heart rate frequency of the ”blind” sample between the guidance methods presented in the Table 8.38. The p-value indicates

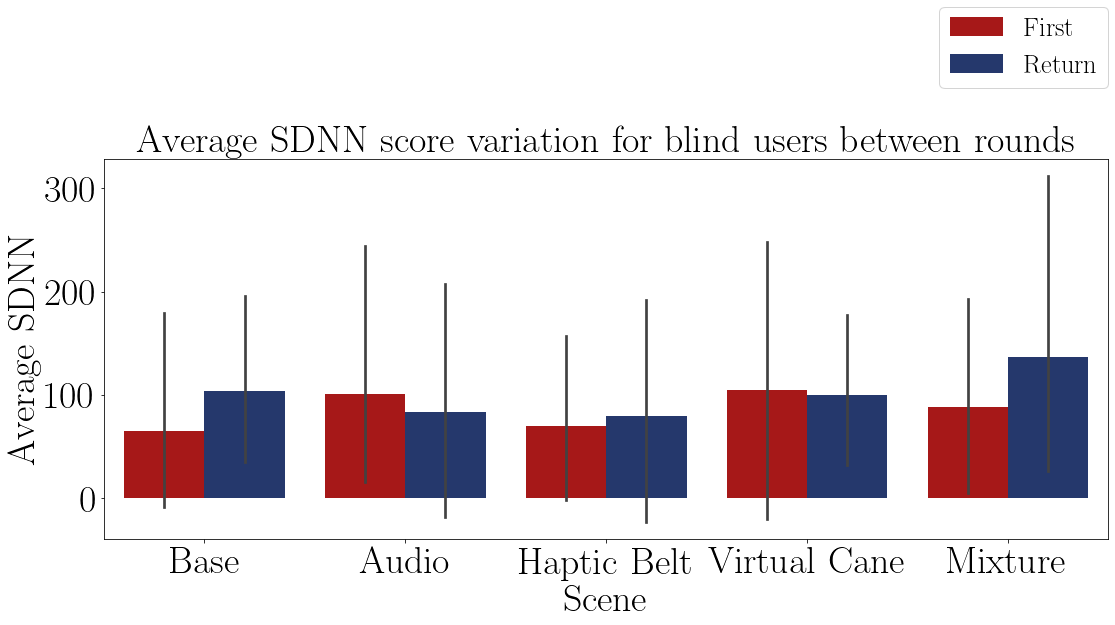


FIGURE 8.26 – Bar plot of the standard deviation of the heart of the blind participants on each method.

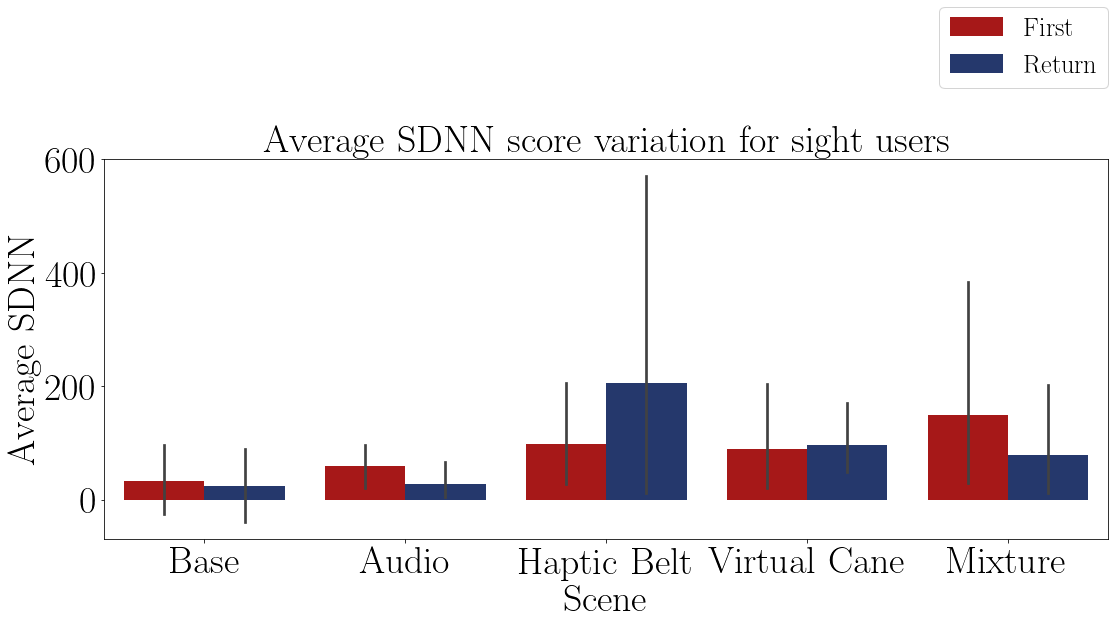


FIGURE 8.27 – Bar plot of the standard deviation of the heart of the sighted participants on each method.

that there is at least one method that is statistically equal to one of the other methods.

The Table 8.43 presents the conclusion of a pairwise Fisher LSD test of the blind heart rate frequency variation between all the guidance methods. The results show that the ”Virtual cane” and the ”Mixture” method differs from the ”Base” method.

According to the Anova test at Table 8.42 and the LSD test at 8.43 and the Table 8.39 the ”Virtual cane”and the ”Mixture”method did provoke an increase in the heartrate variancy.

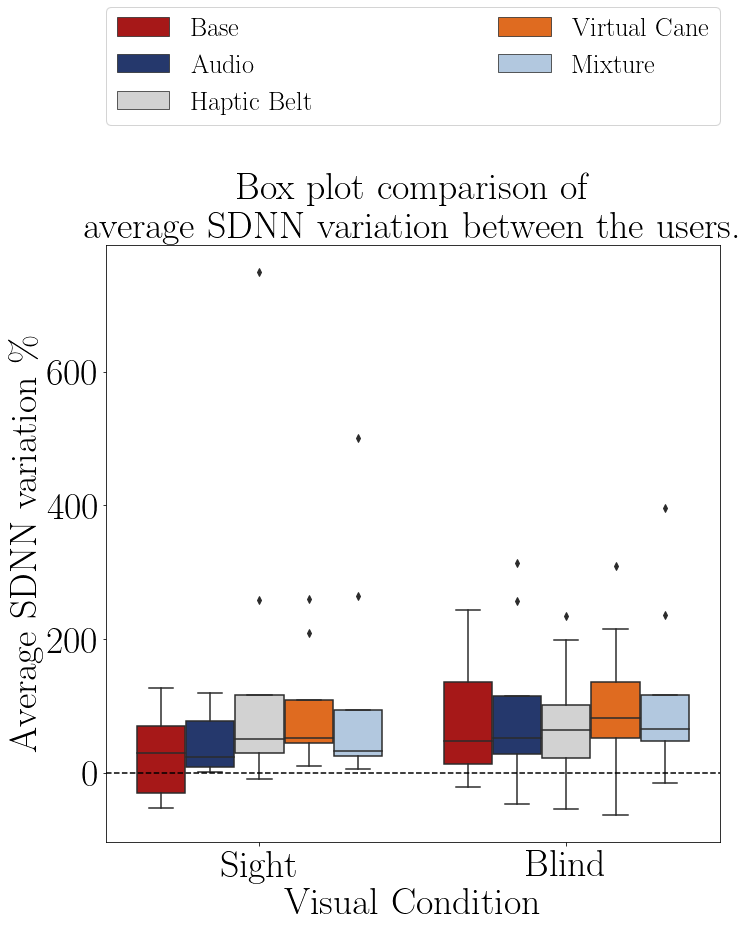


FIGURE 8.28 – Boxplot of the average heart rate of the participants on each method.

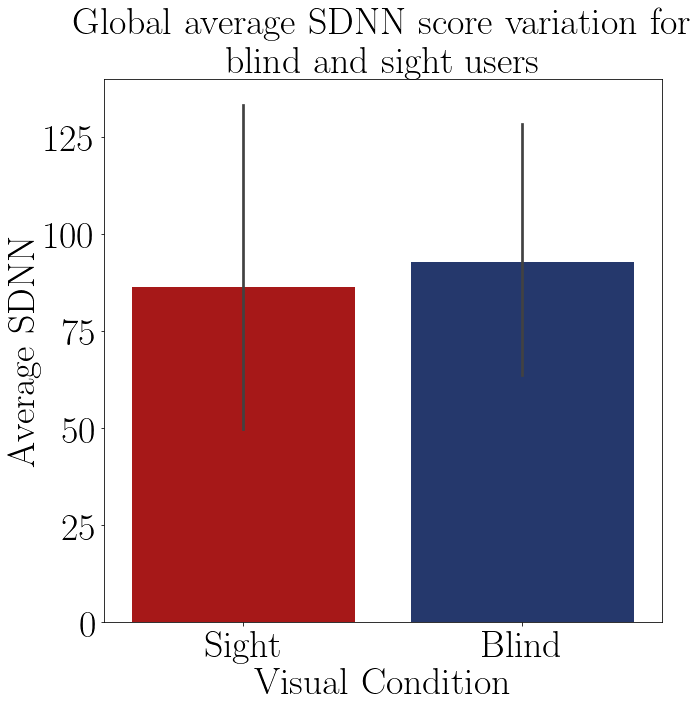


FIGURE 8.29 – Barplot of the average SDNN score of each group.

TABLE 8.40 – Shapiro test p-value for the ecg average SDNN for each method and visual con-

dition

|  |  |
| --- | --- |
| Method | Shapiro P-Value |
| Base blind | 0.078 |
| Base sight | 0.347 |
| Audio blind | 0.071 |
| Audio sight | 0.130 |
| Haptic Belt blind | 0.414 |
| Haptic Belt sight | 0.001 |
| Virtual Cane blind | 0.723 |
| Virtual Cane sight | 0.015 |
| Mixture blind | 0.027 |
| Mixture sight | 0.001 |

TABLE 8.41 – T test p-value for the ecg average SDNN each method for blinded users versus sighted users.

|  |  |
| --- | --- |
| Method | T-Test P-Value |
| Base | 0.230 |
| Audio | 0.317 |
| Haptic Belt | 0.434 |
| Virtual Cane | 0.862 |
| Mixture | 0.976 |

TABLE 8.42 – Anova p-value for the SDNN on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 3519.680 | 4 | 879.920 | 1.564 | 0.247 |
| Between blocks | 214885.879 | 3 | 71628.626 | 127.314 | 0.000\*\* |
| Experimental error | 6751.365 | 12 | 562.614 |  |  |
| Total | 225156.923 | 19 |  |  |  |

TABLE 8.43 – Cross validation p-value for the average SDNN on each method for blinded users.

|  |  |  |  |
| --- | --- | --- | --- |
| Method | | | Analysis |
| Base | *X* | Audio | *H*0 : *µBase* = *µAudio* |
| Base | *X* | Haptic Belt | *H*0 : *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*0 : *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* |

### 8.3.2 Galvanic skin reaction and temperature data;

The GSR analysis is made by analyzing the average in each round and comparing it with the ”Baseline” average. The temperature was analyzed with the GSR to see if there is some influence and by a graphical analysis there was none.

The Table 8.44 presents the average skin conductance by each participant on each scenes and they are plotted in the Figures 8.30 and 8.31. It is possible to see that in all of the methods there was an increase in the average skin conductance, meaning that the user was aroused and maybe an increase in the mental workload.

The Figure 8.24 shows a comparison between both groups

The Table 8.45 shows the variation of the heartbeat in each round of each group. It is also possible to notice the same increase noticed before.

The Shapiro–Wilk normality test on the Table 8.46 shows that only the ”Audio” method is normally distributed for the ”blind” sample while for the ”sight” sample only the ”Virtual Cane” is not normally distributed

According to the T-Test presented in the Table 8.47 there is no difference in the skin conductace frequency variation between the sample groups.

The Table 8.48 shows the Anova test p-value of the skin conductance frequency of the ”blind” sample between the guidance methods presented in the Table 8.44. The p-value indicates that there is at least one method that is statistically equal to one of the other methods.

The Table 8.49 presents the conclusion of a pairwise Fisher LSD test of the blind skin conductance frequency variation between all the guidance methods. The results show that the ”Virtual Cane” and the ”Mixture” have different variations, but since they are not normally distributed this conclusion can not statistically be made.

TABLE 8.44 – Average GSR felled by the participants.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Baseline | Base | Audio | Haptic  Belt | Virtual  Cane | Mixture |
| Part. | Visual  Condition | Round |  |  |  |  |  |  |
| 001 | Sight | First | 4.27 | 8.80 | 15.19 | 15.67 | 15.19 | 14.15 |
|  |  | Return |  | 11.48 | 14.95 | 15.09 | 15.72 | 21.52 |
| 001C | Blind | First | 0.37 | 0.48 | 1.03 | 3.14 | 3.79 | 3.90 |
|  |  | Return |  | 0.83 | 1.58 | 2.81 | 4.04 | 4.57 |
| 002C | Blind | First | 0.17 | 0.91 | 0.23 | 0.17 | 0.17 | 0.17 |
|  |  | Return |  | 0.43 | 0.17 | 0.16 | 0.17 | 0.17 |
| 003 | Sight | First | 0.19 | 0.19 | 0.17 | 0.17 | 0.17 | 0.17 |
|  |  | Return |  | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| 003C | Blind | First | 0.30 | 0.56 | 0.56 | 0.62 | 0.85 | 1.09 |
|  |  | Return |  | 0.62 | 0.63 | 0.65 | 0.92 | 1.06 |
| 004 | Sight | First | 2.60 | 9.71 | 11.18 | 12.60 | 12.92 | 10.34 |
|  |  | Return |  | 10.89 | 11.97 | 12.25 | 13.47 | 10.16 |
| 004C | Blind | First | 1.24 | 2.34 | 3.07 | 3.49 | 2.28 | 2.23 |
|  |  | Return |  | 2.57 | 2.95 | 3.20 | 2.21 | 2.24 |
| 005 | Sight | First | 0.47 | 1.88 | 1.58 | 1.44 | 1.37 | 1.33 |
|  |  | Return |  | 1.66 | 1.53 | 1.47 | 1.49 | 1.33 |

TABLE 8.45 – Average GSR variation in relation to the baseline grouped by participant and visual Condition.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Visual Condition | Base | Audio | Haptic Belt | Virtual Cane | Mixture |
| Blind | 72.2% | 3.4% | -4.1% | 2.9% | 4.2% |
| Sight | 89.9% | 0.5% | -1.3% | 5.9% | 18.3% |

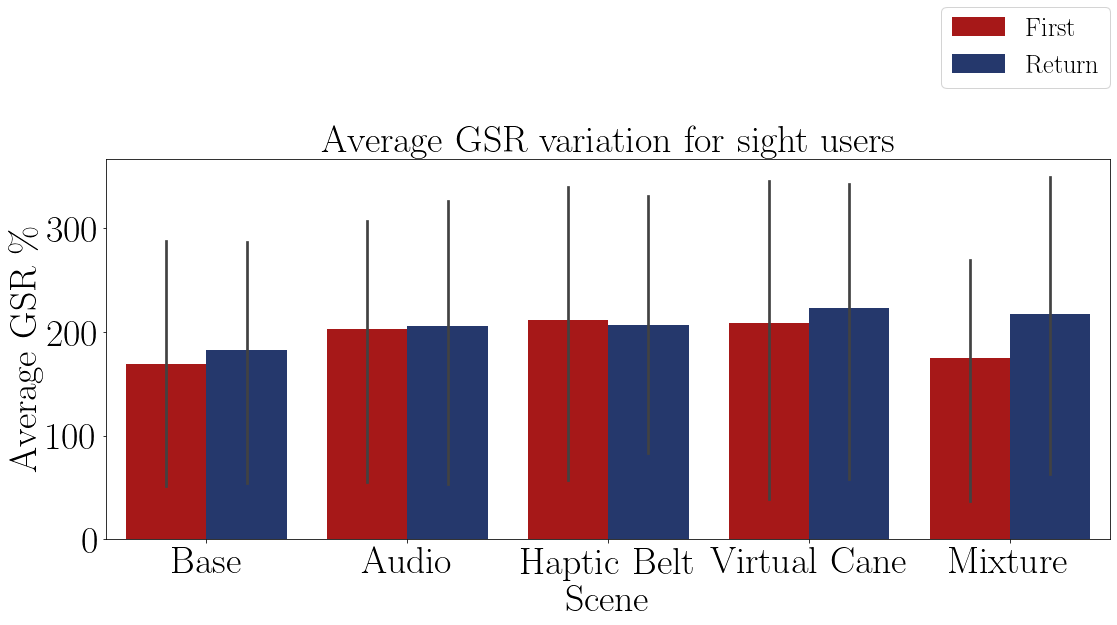
TABLE 8.46 – Shapiro test p-value for the gsr average for each method and visual condition

|  |  |
| --- | --- |
| Method | Shapiro P-Value |
| Base blind | 0.002 |
| Base sight | 0.187 |
| Audio blind | 0.544 |
| Audio sight | 0.046 |
| Haptic Belt blind | 0.017 |
| Haptic Belt sight | 0.155 |
| Virtual Cane blind | 0.004 |
| Virtual Cane sight | 0.275 |
| Mixture blind | 0.011 |
| Mixture sight | 0.376 |

TABLE 8.47 – T test p-value for the average GSR on each method for blinded users versus sighted users.

|  |  |
| --- | --- |
| Method | T-Test P-Value |
| Base | 0.876 |
| Audio | 0.942 |
| Haptic Belt | 0.627 |
| Virtual Cane | 0.557 |
| Mixture | 0.493 |

FIGURE 8.30 – Bar plot of the average skin conductance of the blind participants on each method.



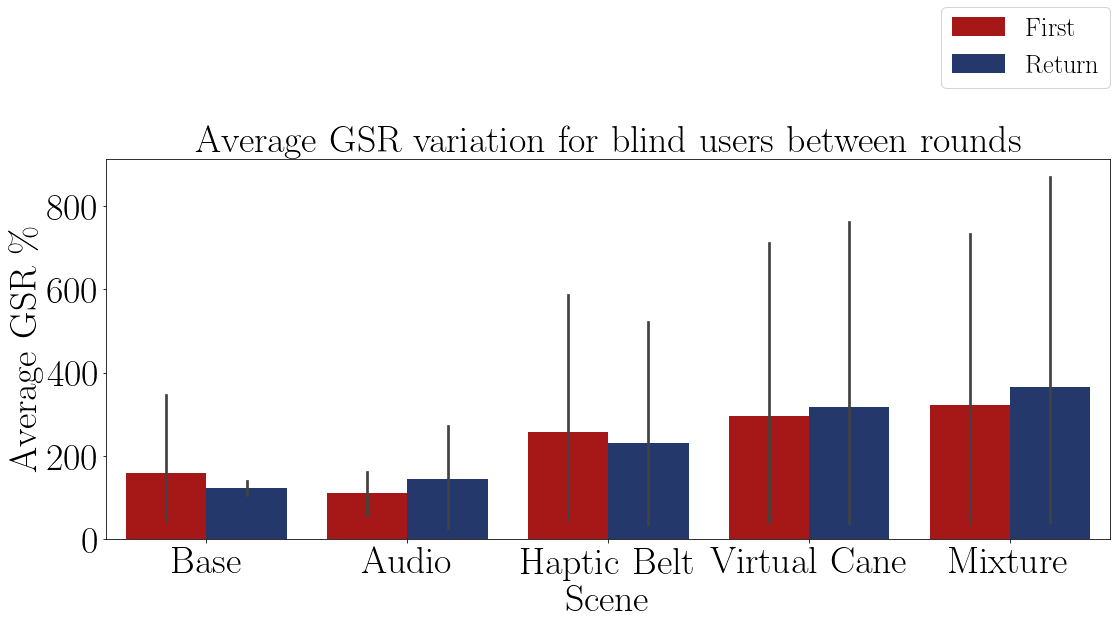
FIGURE 8.31 – Bar plot of the average skin conductance of the sighted participants on each method.

TABLE 8.48 – Anova p-value for the GSR score on each method for blinded users.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Squared sum | DOF | Squared average | F | P-Value  (*F*0 *> F*) |
| Between factors | 886616.269 | 4 | 221654.067 | 3.310 | 0.048\*\* |
| Between blocks | 1918983.649 | 3 | 639661.216 | 9.552 | 0.002\*\* |
| Experimental error | 803557.557 | 12 | 66963.130 |  |  |
| Total | 3609157.475 | 39 |  |  |  |

According to the Anova test at Table 8.48 and the LSD test at 8.49 only the ”Virtual Cane” and the ”Mixture” method provoked a different reaction than the ”Base” method, but since the Shapiro test at the Table 8.46 showed that they are not normally distributed, than this conclusion has no foundation.

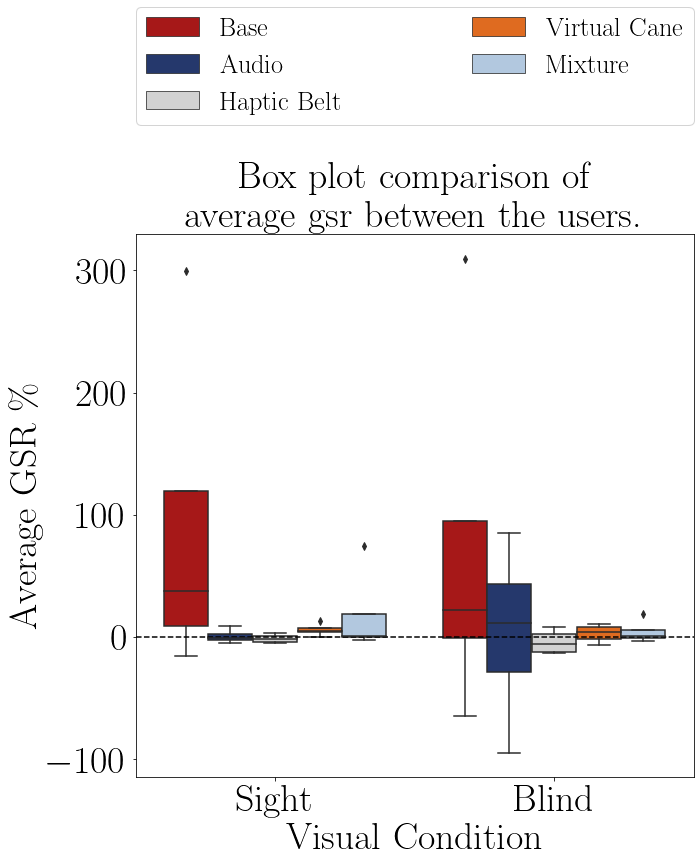


FIGURE 8.32 – Boxplot of the average skin conductace of the participants on each method.

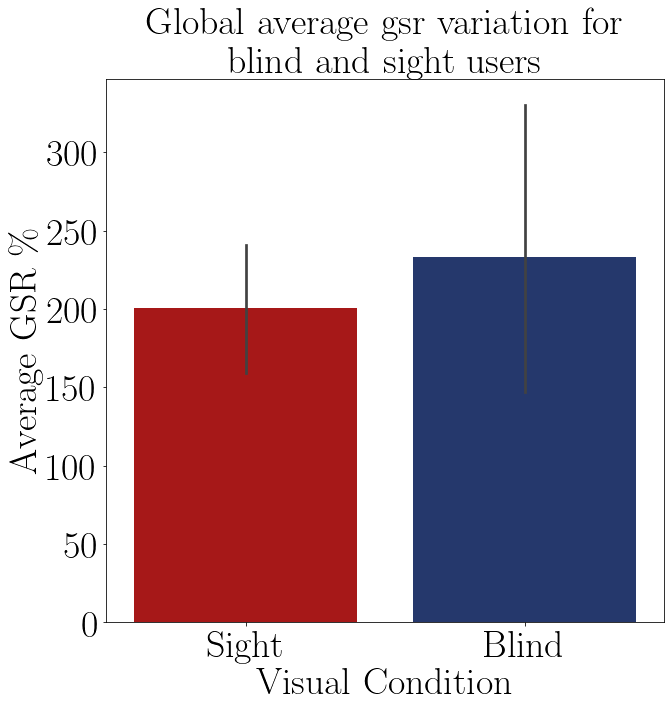


FIGURE 8.33 – Bar plot of the average GSR of of each group.

TABLE 8.49 – Cross validation p-value for the GSR on each method for blinded users.

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