Quality of Experience of 360-degree Videos Played in Google Cardboard Devices

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Abstract: Google Cardboard boxes provide a cost-efficient way to introduce users to Virtual Reality (VR) applications. These devices are suitable to be utilized for entertainment, gaming, and online studies. The 360-degree videos also known as immersive videos, play panoramic view in a video. The videos are played with a mobile phone mounted on a cardboard box and are viewed by wearing or holding the cardboard box. This paper studies the QoE of users (N=60) with QoE features user comfort, presence, and interactivity with panoramic video, based on QoE factors such as lens quality, weight and handling properties of the device. The experimental data is analysed in terms of statistical properties such as Mean Opinion Scores (MOS) including confidence intervals, as well as Percents of Good or Better (%GoB) and Poor or Worse (%PoW). Furthermore, the correlations between user ratings with respect to different groups of QoE features are investigated. Overall, the paper shows cardboard boxes to yield good-to-fair QoE for viewing panoramic videos.

1 INTRODUCTION

Virtual Reality (VR) devices are increasingly being used in many industries for entertainment, educational, and training purposes. Cardboard boxes are low cost, simple devices to view videos and experience VR with mobile phones. Gaming and educational content are important use cases for Google Cardboard (Schlögl et al., 2017). There are benefits of using VR (Choi et al., 2017) and Google Cardboard (2019) as content delivery systems, with sufficiently high user immersion (Lee et al., 2017; Di Stefano and Battisti, 2017), but even risks for vertigo, nausea, and headaches (Klein, 2017). Highly immersive experiences using 360° videos provide positive educational experiences while minimizing simulator sickness (Rupp et al., 2019). Google Cardboard and 360-degree videos have been used to study bullying at school and ambiguous social situations (Berg et al., 2016).

Given this background and potential, our study aims at quantifying to which extent low cost cardboard box devices can provide adequate Quality of Experience (QoE), defined as "the degree of delight or annoyance to the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and/or enjoyment of the application or service in the light of the user's personality and current state" (Le Callet et al., 2013). Thus, we have analyzed QoE features such as comfort, presence and interactivity of user, and correlations between these factors. User experiments have been conducted for 360-degree videos in mobile phone virtual reality (VR) environments with three cardboard box devices as shown in Figure 1, namely Irusu (2019), Music Joy (2019) and Getcardboard (AuRAVR, 2019), along with the Coral Reef ocean view, which is available inside the official Google Cardboard video app (Google Cardboard, 2019). Our work complements (Di Stefano and Battisti, 2017), which reports on average QoE ratings of N=10 users who evaluated Google Cardboard in a virtual museum setting, without any further statistical analysis.

The remainder of the paper is structured as follows. Section 2 discusses QoE features and Section 3 shortly reviews QoE factors that are of relevance to our experiments. Section 4 presents and discussed the user experiments and the questionnaire

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used. Section 5 presents the results of the user study in terms of Mean Opinion Scores (MOS) with confidence intervals, Percent of Good or Bad (%GoB) and Poor or Worse (%PoW), as well as correlations between different groups of QoE features. Section 6 concludes the paper.

Figure 1: Google Cardboard boxes used in this study (from left to right: Irusu, Music Joy and Getcardboard).

2 QoE FEATURES

A QoE feature is defined as "a perceivable, recognized and namable characteristic of the individual's experience of a service which contributes to its quality" (Le Callet et al., 2013). In the following, we provide an overview of the features of relevance for our use case and our specific study.

- *User comfort* in terms of agreeability and convenience is a basic and natural feature; being uncomfortable may contribute to cybersickness (Huyen et al., 2017).
- *User presence* refers to a user's subjective psychological response to a VR system (Slater and Wilbur, 1997). Presence is a subjective parameter and only quantifiable by a user (Slater, 1999).
- *User interactivity* depends on objective parameters of devices and videos played. The user is able to interact with the video playout by opening information popups, zoom in or zoom out the viewport of cardboard. Interactivity is present in only one of the devices (Irusu), with a button on the top at the right-hand side of the device.

Furthermore, *user immersion* refers to the objective level of sensory fidelity a VR system provides (Slater and Wilbur, 1997), which we chose to leave for future work. In their virtual museum case, Stefano and Battisti (2017) have asked users about *immersiveness*, *usability*, and *utility*.

3 QoE FACTORS

A QoE factor is "any characteristic of a user, system, services, application, or context whose actual state or setting may have an influence on the Quality of Experience for the user" (Le Callet et al., 2013). (Narciso et al., 2019) reported that both video and audio formats did not produce a significant effect on the sense of presence or cybersickness. The major factor as to why this occurred is related to the nature of the content used in the experiments. The authors "found a statistically significant effect on Video and Gender on both presence and cybersickness." (Narciso et al., 2019). In our study, we noted the following features of particular importance:

- *Lenses:* The capability of adjusting the lenses is only present in Music Joy. The quality of the lenses cannot be directly measured. However, the impact of those factors is expected to be visible through user ratings with respect to comfort and presence.
- *Weight:* Another factor of particular importance is related to how heavy the box is, which is expected to be seen in comfort-related ratings.
- *Handling:* Whether the device has to be held while watching or whether it can be worn is also expected to contribute to comfort-related ratings.
- *Controls:* The means of control available to the user, as well as the way they are to be handled are expected to primarily affect the interactivity-related (and secondarily the presence- and comfort-related) ratings.

4 USER EXPERIMENTS

The setup of the user experiments is summarised in Table 1, followed by an overview of the experimental procedure and the questionnaire, respectively.

Table 1: Details of the user experiments.

Users studied	N=60, age 22–39 y (average: 28 y) 40 males, 20 females 29 novice cardboard box users
Duration	1 video, each of 1 minute, watched by every user
Environmental conditions	Closed room with controlled sound and temperature
Mobile device	Apple Iphone 6S
Cardboard devices	1. Irusu 2. Music Joy 3. GetCardboard
Video used	Coral Reef Ocean View inside the Google Cardboard (2019) app

The recruited participants are working in the IT industry, and are well versed in handling mobile phones and videos. They quickly grasped the methodology of viewing and answering the questionnaires, which allowed them to focus on the videos and answer the questions in an efficient manner.

The three cardboardbox devices that we used offer different levels of interactivity and possibilities to adjust the image. Unfortunately, the original cardboardbox by Google was not available to be included in the study.

4.1 Procedure

In a first step, the users were informed about the three devices and their features, as well as the features of 360-degree video to be viewed by rotating the head in all directions. The 360-degree video content is neutral with natural environment settings, and viewing the same video with three devices brings consistency in comparison. Interactivity with the video happens by clicking on information popups over different objects appearing in the video and choosing options to view different paths.

The users have a demo session to understand the environment. During the experiment, the users watch the video for one minute on each device. This is followed by a questionnaire (cf. Section 4.2) to be answered by each user based on their experience. The questions appear in the same order to all the users for each experiment. Before starting the questionnaire, the rating scales are explained, while any confusion regarding the questions is clarified while answering them. The users conclude their questionnaire with verbal feedback on their experience. This process is repeated for all three devices for each user.

4.2 Questionnaire

Table 2 shows the questionnaire used in this study. The ACR scale (ITU-T P.910, 2008) stretches from 1 (= bad) to 5 (= excellent). Proprietary scales were used for questions Q4, Q9 and Q11, also ranging from 1 (= minimal level) to 5 (= maximal level).

Table 3 groups the questions and matches them to the QoE features of interest, cf. Section 2. This grouping will be of particular importance when correlating the user ratings to each other, cf. Section 5.

Table 2: Questionnaire used.

Q#	Question	Scale
1	How comfortable you were in moving your head to view the 360-degree video?	ACR
2	How do you rate the comfort of watching video with Cardboardbox device?	ACR
3	How pleasant was your overall 360-degree video viewing experience?	ACR
4	During the time of your experience in virtual environment, how would you rate your sense of somewhere else from the virtual environment?	1–5
5	To which extent did your experiences in the virtual environment seem consistent with your real-world experiences?	ACR
6	When you think back of the experience, how closely you think of the virtual environment as a place that you visited?	ACR
7	Please rate your sense of being in the virtual environment.	ACR
8	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.	ACR
9	How often did you want to use control buttons when u saw them on screen while watching the 360-degree video?	1–5
10	To which extent did the presence of the control button on headset device help you in a more pleasant experience?	ACR
11	How often did you adjust your device to focus on the videos?	1–5
12	What is your age (years)?	
13	What is your gender (M/F)?	
14	How experienced are you in using VR headsets (in months)?	
15	Which device have you used in this session? (Irusu/ Music Joy/ Getcardboard)	
16	Please share your feedback for the session.	

Table 3: Grouping of questions.

Group	Factor (if applicable)	Number of questions	Range (Q#)
Overall QoE		1	3
Factors	Comfort	2	1 – 2
	Presence	5	4 – 8
	Interactivity	3	9 – 11
User profile and device used		1	12 – 15
Subjective feedback		1	16

5 RESULTS

For each of the three devices and questions Q1 to Q11, we obtain a set of opinion scores set of N opinion scores $\{OS_1, OS_2 \dots OS_N\}$. In the next subsections, we analyse a set of statistics.

5.1 Mean Opinion Score (MOS)

The *Mean Opinion Score* (MOS) is defined as the average of the user ratings,

$$MOS = \sum_{i=1}^{N} \frac{OS_i}{N} \quad (1)$$

and the *Standard deviation of Opinion Scores* (SOS) as a measure of the deviation of said ratings from the average,

$$SOS = \sqrt{\sum_{i=1}^{N} \frac{(OS_i - MOS)^2}{N-1}} \quad (2)$$

The combination of both are used for outlier removal (opinion scores outside the interval $MOS \pm 2\ SOS$ are not taken into account for the statistics) as well for constructing 90% confidence intervals (CI)

$$\left[MOS - t_{N-1,0.95}\frac{SOS}{\sqrt{N}}, MOS + t_{N-1,0.95}\frac{SOS}{\sqrt{N}}\right] \quad (3)$$

with $t_{N-1,0.95} \approx 1.67$ for $N = 60$. Figure 2 illustrates the obtained results for the overall viewing experience.

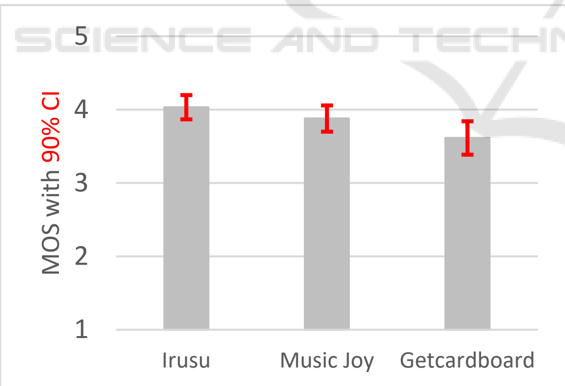

Figure 2: Mean Opinion Scores with 90% confidence intervals for the overall viewing experience (Q3).

The Irusu device yielded the highest MOS ≈ 4.03 (excl. one outlier), followed by Music Joy (MOS ≈ 3.88, excl. four outliers) and GetCardboard (MOS ≈ 3.61, excl. three outliers). These values are found in the upper part of the ACR scale, close to good. Indeed, their magnitude is in agreement with the immersiveness-related results reported by Di Stefano and Battisti (2017). The confidence interval of GetCardBoard overlaps with the other intervals, which makes a clear distinction towards the other two devices questionable. Yet, the confidence intervals for Irusu and Getcardboard do not overlap, as seen in Table 4. This implies that the overall rating of the Irusu device can be considered significantly better than that of Getcardboard with 90% confidence.

Table 4: Number of outliers, 90% confidence intervals and SOS for the overall viewing experience (Q3).

Device	No. of outliers	90% Conf. Int.		SOS
		From	To	
Irusu	1	3.87	4.20	0.76
Music Joy	4	3.70	4.06	0.80
Getcardboard	3	3.39	3.84	1.03

Table 4 also reveals differences in SOS, representing variations in the ratings. Indeed, the Irusu ratings had the least variations, followed by those of Music Joy and Getcardboard, which obviously had the largest spread of user ratings of the overall QoE.

A complete set of statistics for the three devices regarding Q1–11 are found in the Appendix.

5.2 Percents of Good or Better (%GoB) and Poor or Worse (%PoW)

The N opinion scores $\{OS_1, OS_2 \dots OS_N\}$ per question and device have a discrete density

$$f\colon \sum_{i=1}^{n} f(OSi) = 1 \quad (4)$$

The *Percent of Good or Better* (%GoB; ITU-T P.910, 2008) denotes the share of users that ranked at least "good" on the ACR scale:

$$\%GoB = f(4) + f(5) \quad (5)$$

Likewise, the *Percent of Poor or Worse* (%PoW; ITU-T P.910, 2008) denotes the share of users that ranked at most "poor" on the ACR scale:

$$\%PoW = f(1) + f(2) \quad (6)$$

Table 5 shows the corresponding results. It is obvious that the Irusu device has most users that rated good or better. This share is reduced for Music Joy and Getcardboard, but even in the latter case above 50%. On the other hand, only one user has rated Irusu poor or worse, while that percentage grows for Music Joy and reaches 23% for Getcardboard.

Table 5: Percents of Good or Better and Poor or Worse for the overall viewing experience (Q3).

Device	%GoB	%PoW
Irusu	77%	2%
Music Joy	67%	7%
Getcardboard	57%	23%

Thus, along with the MOS, we can clearly see that the users appreciate Irusu the most, followed by Music Joy and Getcardboard. Most of the unsatisfied users reported issues in handling the device and blurry pictures.

5.3 Correlations

In the sequel, we are investigating *Pearson Correlation Coefficients*

$$r_{kl} = \frac{\sum_{i=1}^{N}(os_i^k - MOS^k)(os_i^l - MOS^l)}{\sqrt{\sum_{i=1}^{N}(os_i^k - MOS^k)^2} \cdot \sqrt{\sum_{i=1}^{k}(os_i^l - MOS^l)^2}} \quad (7)$$

that quantify ties between questions Qk and Ql ($k, l \in \{1, 2 \dots 11\}$, as shown in Table 2).

Figures 3–5 show the correlation matrix charts for the three devices, with fields corresponding to questions Q1–Q11 from left to right, and from top to bottom. While the fields on the diagonal illustrate the distribution of the opinion scores (as used in Section 5.2), the fields above the diagonal (in the upper right triangle) contain the values $r_{kl} = r_{lk}$ and an indication of their significance level (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$) The fields below the diagonal (in the lower left triangle) illustrate bivariate scatter plots with least square fits of polynomials. We will primarily focus on the strongest and most significant correlations.

Starting with the Irusu device (Figure 3), we observe mid-size positive correlations between Q5 (real-world experiences) and Q6 (place visited), as well as between the comfort-related questions Q1/2 and Q7 (being inside the environment). Obviously, comfort and presence features tend to go hand-in-hand. It is also interesting to see a mid-size negative correlation between Q5 and Q11 (adjustment), meaning that the latter interactivity- and handling-related issues had a negative impact on presence.

In the case of Music Joy (Figure 4), we observe mid-size positive correlations within and between the groups of comfort- and presence-related questions (Q1–Q2, Q5–Q7) as well as the overall QoE rating (Q3). Thereby, the strongest positive correlations appeared between Q5 and Q6 and between Q5 and Q3. On the other hand, Q4 (aiming at distraction) correlates negatively with the above questions. Obviously, there are rather strong ties between comfort, overall rating, and presence (focus).

Finally, in the case of Getcardboard (Figure 5), we observe a similar correlation pattern as compared to Music Joy, however with even stronger positive correlations between Q1–Q2 (comfort), Q3 (overall rating) and Q5–Q7 (presence). One potential reason lies in the stronger variations of the (Q3-related) ratings for Getcardboard, pointing at the more dispersed perception of different users, but with a trend to judge above questions Q1–Q3/Q5–Q7 in similar ways, i.e. either high or low.

For all devices, the negative mid-size correlation between these questions and Q11 also provides indications that the need for frequent adjustments reduces the comfort, presence, and overall ratings.

Finally, we are considering the group of weak (and less significant) correlations for any type of device. Questions Q8 (awareness of surroundings), Q9 (use of the control button), Q10 (impact of the control button, only for Irusu) belong to this group. Obviously, the presence of a control button (as provided by Irusu) does not contribute much to comfort, presence, and overall ratings.

5.4 Subjective Feedback

In their answers to Q16, many users appreciated the fidelity of experience compared to real experience in the 360-degree videos. Some users complained about the lens quality. In the Music Joy device, the angle of vision was considered narrow. Some information popups encountered in 360-degree videos do not open at expected locations (which is, however, a typical phenomenon in 360-degree videos, and not specific to these devices).

There was some confusion regarding the interaction interface, where to click, and what information the users would receive. Also, there was some confusion in using the interface (e.g. whether the button needs to be pressed once or twice) for opening popups.

None of the users reported headaches dizziness or nausea.

6 CONCLUSIONS

This study set out to investigate the Quality of Experience of three low-cost VR cardboard devices, through which a user can experience 360-degree videos on a smartphone, running the Google

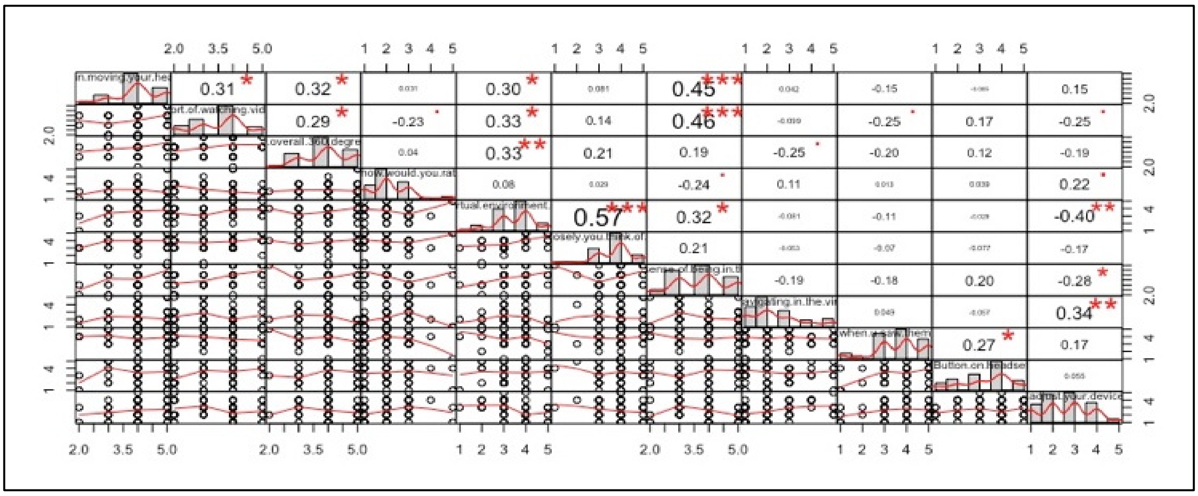

Figure 3: Correlation chart matrix for Irusu, questions Q1–11 (from left to right/top-down).

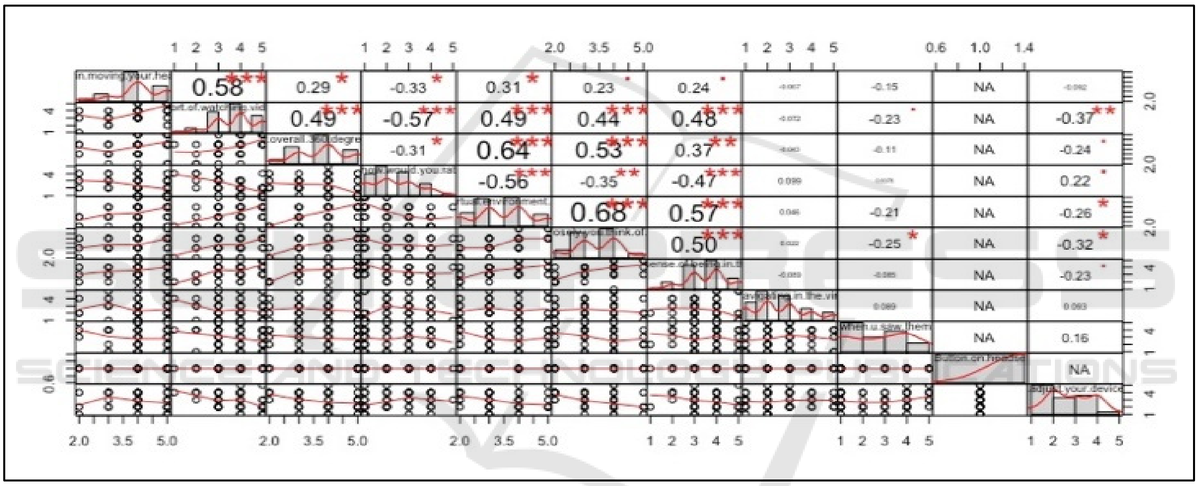

Figure 4: Correlation chart matrix for Music Joy, questions Q1–11 (from left to right/top-down).

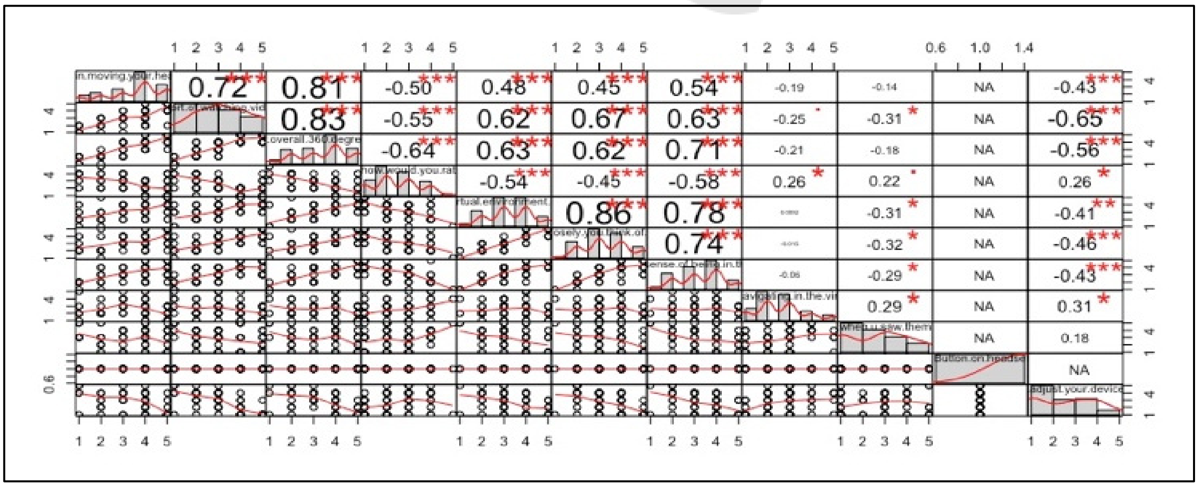

Figure 5: Correlation chart matrix for Getcardboard, questions Q1–11 (from left to right/top-down).

Cardboard app. N=60 users watched a scenic movie for one minute and answered 16 questions (of which 11 were of quantitative nature) per device.

The results in terms of Mean Opinion Scores reveal an overall good(-to-fair) experience, as it was even observed in earlier work by Di Stefano and Battisti (2017), with some partly significant differences between the devices. While the top-ranked device had a majority of Good-or-Better (GoB) ratings, the lowest-ranked device had a significant amount of Poor-or-Worse (PoW) ratings, and more variability in the user ratings as such. Considering the correlations between the 11 quantitative questions, it becomes obvious that comfort, presence and overall assessment go hand-in-hand with each other, while interactivity is of minor relevance.

The factors with high positive correlations with the overall MOS are User Comfort and Presence, which positively boosted the user's QoE. Low scores due to unclear video quality caused by suboptimal lenses were reported by users. Interactivity features were either missed in the devices or reported to be confusing.

We expect that our results can provide interested stakeholders and in particular organizations that are distributing these boxes for educational, entertainment and gaming purposes with a view of the overall quality perception, relationships between key features, and a method of how to evaluate various boxes as a basis for decisions which device to use for a specific task: Upon introducing a user to the cardboard devices of interest, the watching-and-rating task and the questionnaire, the user experiences one (or more) 360-degree video(s) per device. The recorded opinion scores are analyzed with particular focus on MOS, SOS, confidence intervals and correlations, as well as on subjective ratings. This way, we obtain both quantitative and qualitative indications about eventual superiority of devices and impacts of the underlying factors.

Future work may address a study of additional contents, features and factors, leading to further generalization and a deeper understanding of our results and findings.

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APPENDIX

In Tables 6 to 8, a complete set of statistics for the three devices are presented. N_o denotes the number of outliers to be removed, before MOS and SOS are calculated. %GoB and %PoW are merely applicable to questions with the ACR scale, cf. Table 2, and Q10 relates to an interaction feature that only the Irusu device has to offer.

Table 6: Statistics for device "Irusu", Q1–11.

Q#	N_o	MOS and 90% CI	SOS	%GoB	%PoW
Q1	2	4.14 [3.99; 4.28]	0.66	82%	3%
Q2	0	3.58 [3.39; 3.78]	0.91	60%	15%
Q3	1	4.03 [3.87; 4.20]	0.76	77%	2%
Q4	2	2.09 [1.92; 2.25]	0.76	N/A	N/A
Q5	1	3.61 [3.43; 3.79]	0.81	57%	10%
Q6	2	3.88 [3.74; 4.02]	0.65	70%	3%
Q7	4	3.88 [3.70; 4.06]	0.80	62%	7%
Q8	6	2.13 [1.92; 2.34]	0.93	18%	62%
Q9	5	3.86 [3.66; 4.05]	0.85	N/A	N/A
Q10	0	3.32 [3.06; 3.57]	1.19	53%	25%
Q11	2	2.53 [2.31; 2.76]	1.03	N/A	N/A

Table 7: Statistics for device "Music Joy", Q1–11.

Q#	N_o	MOS and 90% CI	SOS	%GoB	%PoW
Q1	3	4.16 [4.01; 4.30]	0.65	82%	5%
Q2	5	3.95 [3.78; 4.12]	0.76	63%	8%
Q3	4	3.88 [3.70; 4.06]	0.80	67%	7%
Q4	1	2.29 [2.07; 2.51]	1.00	N/A	N/A
Q5	0	3.48 [3.28; 3.69]	0.95	50%	17%
Q6	0	3.45 [3.28; 3.62]	0.79	50%	12%
Q7	1	3.61 [3.42; 3.80]	0.87	55%	12%
Q8	5	2.36 [2.14; 2.59]	0.99	22%	52%
Q9	0	2.87 [2.57; 3.17]	1.38	N/A	N/A
Q10	-	N/A	N/A	N/A	N/A
Q11	2	2.83 [2.60; 3.06]	1.04	N/A	N/A

Table 8: Statistics for device "Getcardboard", Q1–11.

Q#	N_o	MOS and 90% CI	SOS	%GoB	%PoW
Q1	5	3.82 [3.60; 4.04]	0.96	63%	20%
Q2	0	3.18 [2.92; 3.44]	1.20	40%	30%
Q3	3	3.61 [3.39; 3.84]	1.03	57%	23%
Q4	1	2.44 [2.23; 2.66]	0.99	N/A	N/A
Q5	2	3.40 [3.19; 3.60]	0.94	45%	22%
Q6	1	3.37 [3.16; 3.58]	0.96	43%	22%
Q7	2	3.41 [3.20; 3.62]	0.96	48%	23%
Q8	4	2.43 [2.23; 2.63]	0.91	18%	50%
Q9	0	2.77 [2.47; 3.06]	1.37	N/A	N/A
Q10	-	N/A	N/A	N/A	N/A
Q11	0	2.62 [2.33; 2.91]	1.34	N/A	N/A