On Head Movements in Repeated 360° Video Quality Assessment for Standing and Seated Viewing on Head Mounted Displays

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Abstract

Watching 360° videos on head mounted displays (HMDs) allows viewers to explore scenes in all directions. In this paper, we focus on investigating the head movements of two participants for standing and seated viewing of a total of 720 360° videos on HMDs. The head movements were recorded in a 360° video quality assessment experiment which was repeated after a long and short break between sessions to study changes in viewing behavior over time. The analysis of the head movement data is provided as histograms of head rotations, head speed, head turns, and head trajectories. It is shown that the participants have their own distinct exploration behavior for standing viewing which becomes less different for seated viewing.

Index Terms: Human-centered computing—Computing methodologies—Virtual reality—Head Movements

1 Introduction

Due to the rapid development of virtual reality (VR) and increased use of head-mounted displays (HMDs), applications such as 360° video streaming have seen an increased interest in the consumer markets. Apart from assessing the subjective quality of 360° videos, which has been extensively studied, it is similarly important to understand the behavior of how users view this type of media on HMDs. For example, head and body motion prediction can be used for predictive pre-rendering of views to cope with the ultra-low latency requirements of mobile VR applications [4].

To study users' behavior of viewing VR on HMDs, head movements are typically recorded and analyzed [1, 7]. In [5], it was shown that the head movements data obtained for watching 360° videos produces information that can identify a user out of a pool of users with high accuracy. Given the increased degrees of freedom in viewing of virtual worlds, different postures also need to be taken into account such as seated, standing, and walking [8]. A novel navigation technique with an in-place locomotion user interface for seated VR experiences is proposed in [3] which allows a smooth transition from virtual standing to virtual seated.

In this paper, we investigate the influence of standing and seated viewing of 360° videos on an HMD regarding head movements and also study if the viewing behavior changes over time. A 360° video quality assessment experiment was used to obtained head movement data from the participants for standing and seated viewing. The experiment was repeated twice with a long and short break between the respective sessions for standing and seated viewing.

2 Experimental Design

The experiments use the setup of our common platform developed for conducting subjective immersive media quality assessment tests. Comprehensive details about the experimental setup of this platform such as test stimuli, test methods, software suite, and technical equipment can be found in [2]. The experimental design is summarized here to the extent needed for the understanding of the reported work.

Four natural scenes of 10 s duration each with different resolutions and quantization parameters were generated resulting in a set of 120 360° videos that cover a wide range of qualities. The stimuli were presented in random order on an HTC Vive Pro HMD with free exploration in a series of sessions for standing and seated viewing on a fixed chair. Each participant joined three sessions for both standing and seated viewing. The participants were asked to rate the 360° video quality on a five-level quality scale according to the absolute category rating (ACR) method. A session lasted around 30 minutes depending on the time needed to cast the quality scores. Fig. 1 shows the session repetition schedule with a long break between Session 1 (S1) and Session 2 (S2), and a short break between S2 and Session 3 (S3). Head movements were recorded for each session and sampled with 90 Hz according to the refresh rate of the HMD.

To study head movements in repeated sessions, we have engaged two participants, referred to as P1 and P2, to keep hygiene related concerns to a minimum. However, each participant viewed a large number of stimuli, i.e., 360 videos over three sessions for both standing and seated viewing (a total of 720 360° videos) with the same set of 120 videos shown in each session but in random order. The ages of the two male participants were 60 (P1) and 31 (P2) years, both were academic staff and familiar with the ACR method.

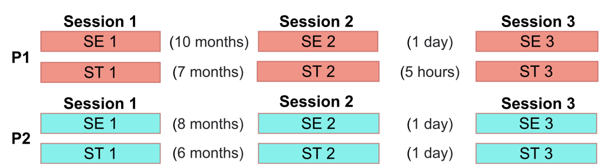

Figure 1: Session repetition schedule (ST: standing, SE: seated).

3 Experimental Results

3.1 Histograms of Head Rotations

The histograms of the head rotations for standing and seated viewing obtained for the three dimensions of rotational movements are shown in Figs. 2-4. The bin widths in these histograms have been chosen as 3° for yaw, 1.5° for pitch, and 1° for roll. The number of occurrences in each bin has been normalized by the total number of samples resulting in relative frequencies that sum to one.

Fig. 2 shows the relative frequency of the yaw angle (head rotation to the left or to the right) for each session and participant for standing and seated viewing. As for standing viewing, it can be seen from Fig. 2(a)-(c) that the viewing behavior is quite different for the two participants in S1. In particular, P1 mainly focuses on the front view while P2 explores the entire 360° yaw-range of turning to the left and to the right. For S2 and S3, P1 shows similar behavior of focusing at the front view while P2 slightly increases the relative frequency toward the front view. Clearly, the two participants have rather different viewing behaviors which are kept consistently throughout the three sessions. On the other hand, for seated viewing, both

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Table 1: Maximum (Max), minimum (Min), and range (Δ =Max-Min) of yaw, pitch, and roll angle for each participant and session.

		Standing									Seated								
		Yaw			Pitch			Roll			Yaw			Pitch			Roll		
		Max	**Min**	**Δ**	**Max**	**Min**	**Δ**	**Max**	**Min**	**Δ**	**Max**	**Min**	**Δ**	**Max**	**Min**	**Δ**	**Max**	**Min**	**Δ**
P1	S1	152.5°	-157.7°	310.2°	45.4°	-35.2°	80.6°	7.6°	-13°	20.6°	53.2°	-73.9°	127.1°	30.4°	-44.9°	75.3°	21.3°	-7.4°	28.7°
	S2	180°	-180°	360°	29°	-20.4°	49.4°	1°	-9.7°	10.7°	40.2°	-64.2°	104.4°	31.9°	-28.3°	60.2°	9.5°	-12.1°	21.6°
	S3	175.2°	-148.6°	323.8°	33.7°	-22.4°	56.1°	2.9°	-9.1°	12°	46.9°	-60.7°	107.6°	33.3°	-40.5°	73.8°	7.3°	-6.9°	14.2°
P2	S1	180°	-180°	360°	82.7°	-80.1°	162.8°	31.3°	-22.8°	54.1°	87.6°	-103.5°	191.1°	34.8°	-39.3°	74.1°	36.3°	-42.8°	79.1°
	S2	180°	-180°	360°	76.9°	-74.3°	151.2°	25.9°	-24.6°	50.5°	77.1°	-92.8°	169.9°	28.5°	-49.3°	77.8°	37.2°	-35.4°	72.6°
	S3	180°	-180°	360°	45.8°	-57.8°	103.6°	15.5°	-9.9°	25.4°	63.7°	-88.5°	152.2°	30.9°	-56°	86.9°	30.7°	-37.8°	68.5°

participants show similar exploration behavior of rather limited range to the left and right as shown in Fig. 2(d)-(f). The histograms of the yaw angle become even more similar in S2 and S3 indicating that there exists a similar natural and comfortable head orientation in seated viewing across the participants.

Fig. 3 depicts the relative frequency of the pitch angles (upward or downward head rotation). The histograms show that the exploration of the 360° videos does not span over the entire pitch range from the south pole ($-90°$) to the north pole (90°) but is rather focused on an area around the equator (0°) for both participants throughout all three sessions as well as for standing and seated viewing. Although P2 tends to utilize a wider pitch range compared to P1, the histograms are similarly symmetric and unimodal with the tails commencing at around $\pm 30°$ for each session in standing and seated viewing. In contrast, the histograms for P1 are bimodal with the two peaks of the relative frequency of the pitch angle near the equator and 27° above. This head rotation behavior becomes more pronounced for seated viewing and with progressing from S1 to S3. P1 becomes more comfortable with exploring the 360° video scenes toward the north pole with the support given by the fixed chair. Similar as for yaw, both participants have their own typical exploration behavior which remains throughout the standing and seated viewing sessions.

Fig. 4 presents the histograms of the roll angle (head tilt toward the shoulders). These histograms are narrow for both participants throughout the three sessions for standing and seated viewing. Note the higher maximum relative frequency obtained for the roll angle compared to yaw and pitch angles. Again, P2 tends to explore a wider range of roll angles than P1. A more distinct feature that differentiates the two participants is the shift of the center of the histogram to the left or right relating to one participant having the head on the average tilted more to the left and the other more to the right. This head rotation behavior is clearly present already in S1 and becomes even more pronounced in S2 and S3 for standing viewing. In contrast, the histograms of the roll angles are almost the same in S1 for both participants for seated viewing and become even more similar with repeated viewing in the two subsequent sessions.

Additional insights on the head rotation behaviour are obtained from the maximum (Max), minimum (Min), and range (Δ =Max-Min) values of yaw, pitch, and roll as shown in Tab. 1. The numerical results confirm that P2 explores the 360° videos to a larger extent than P1 for both standing and seated viewing. As for the pitch and roll in standing viewing, both participants tend to explore the 360° videos less in the repetition of the experiment.

3.2 Head Speed and Head Turns

Head speed quantifies how fast a participant moves the head while exploring a VR scene on an HMD. Head speed was calculated from the head rotation traces for yaw, pitch, and roll in degrees per second (°/s) with the obtained averages over a whole session shown in Tab. 2. Clearly, rotation around the yaw axis is performed with significantly higher speed compared to pitch and roll, especially, for standing viewing where participants are not constrained to a fixed chair. Further, P2 rotates with a higher head speed compared to P1 in standing viewing while head speeds of the two participants become similar for seated viewing. In addition, for each participant, the change of head speeds from S1 to S2 and then S3 become more consistent and vary not as much for seated viewing.

Table 2: Average head speeds around yaw, pitch, and roll axes.

		Standing			Seated		
		S1	**S2**	**S3**	**S1**	**S2**	**S3**
P1	Yaw (°/s)	26.87	19.32	21.84	12.52	10.67	9.46
	Pitch (°/s)	7.37	3.20	4.50	6.21	4.23	4.06
	Roll (°/s)	2.76	1.20	1.53	2.04	1.72	1.51
P2	Yaw (°/s)	48.57	44.66	41.70	14.08	14.20	14.01
	Pitch (°/s)	8.93	10.44	6.96	6.21	6.27	6.40
	Roll (°/s)	3.07	4.01	2.33	3.21	3.25	3.42

Table 3: Number of head turns for yaw and pitch.

		Standing			Seated		
		S1	**S2**	**S3**	**S1**	**S2**	**S3**
P1	Yaw turns	33	19	19	10	17	12
	Pitch turns	12	1	6	15	13	15
P2	Yaw turns	129	96	85	12	17	19
	Pitch turns	21	15	12	12	10	17

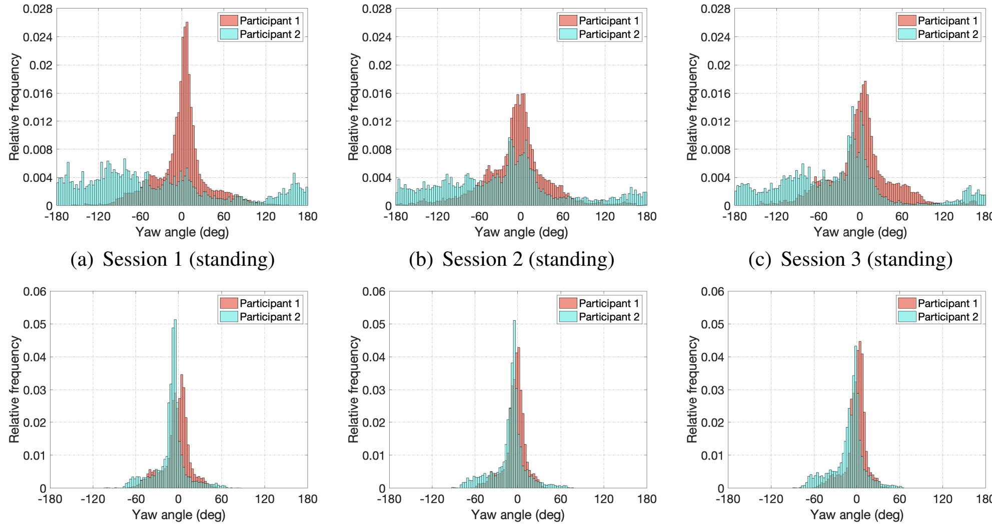
Head turns represent sudden head rotations by taking the difference between two rotational points on two consecutive discrete time instances $n-1$ and n. The following expressions have been used to identify a head turn with respect to yaw and pitch: $|\mathrm{yaw}_n - \mathrm{yaw}_{n-1}| > 4°$ and $|\mathrm{pitch}_n - \mathrm{pitch}_{n-1}| > 2°$. Tab. 3 shows the number of head turns for yaw and pitch for standing and seated viewing for the respective sessions. P1 shows a high number of head turns for standing viewing in S1 but slows down in S2 and S3 as well as during seated viewing. P2 produces a significantly higher number of head turns compared to P1 for standing viewing but also slows down for seated viewing.

3.3 Head Trajectory

Head trajectories were recorded in all sessions carrying information about the rotational and translational head movements that the participants undertook while watching the 360° videos. Fig. 5 shows the polar plot of the top view of the experimental setup revealing the yaw angle and radius of the movements. All participants started each session from the front view, i.e., around 0° yaw angle.

Fig. 5(a)-(c) show the head trajectories of P1 for the three sessions for standing viewing. It can be seen that the rotational movements are similar for all three sessions while the translational movements are rather limited for S1 and clearly increase for the subsequent two sessions. On the other hand, P2 shows a much wider exploration in terms of rotational and translational movements as can be seen from Fig. 5(d)-(f) for standing viewing. In S3, P2 expands the translational movements but neglects the yaw range from 45° to 90°.

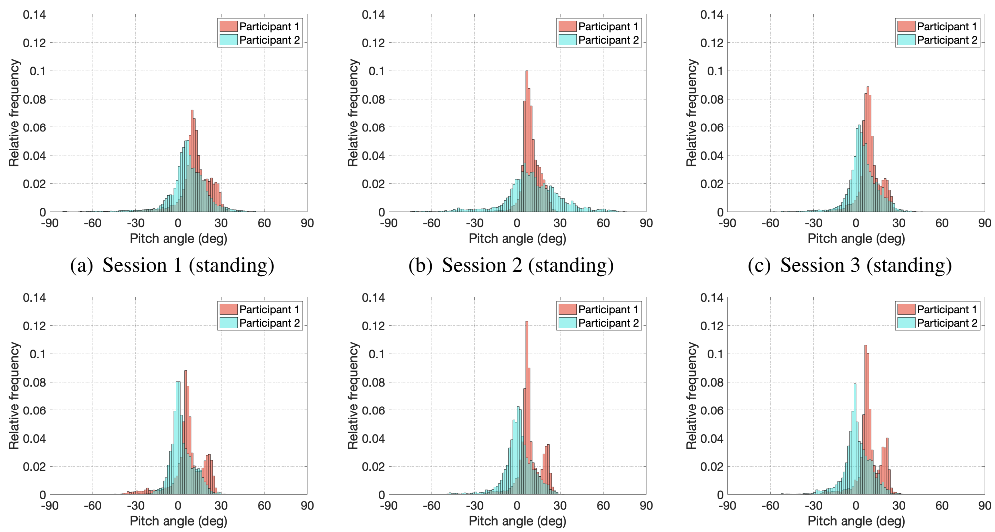
In contrast to the large rotational and translational movements with largely changing trajectory patterns among sessions for standing viewing, the head trajectories for seated viewing are similarly focused for both participants throughout all sessions. A distinctive feature of P1 is the narrow rotational exploration while P2 typically explores a much wider yaw range, see Fig. 5(g)-(i),(j)-(l).



(a) Session 1 (standing) (b) Session 2 (standing) (c) Session 3 (standing)

(d) Session 1 (seated) (e) Session 2 (seated) (f) Session 3 (seated)

Figure 2: Relative frequency of the yaw angles for standing and seated viewing.



(a) Session 1 (standing) (b) Session 2 (standing) (c) Session 3 (standing)

(d) Session 1 (seated) (e) Session 2 (seated) (f) Session 3 (seated)

Figure 3: Relative frequency of the pitch angle for standing and seated viewing.

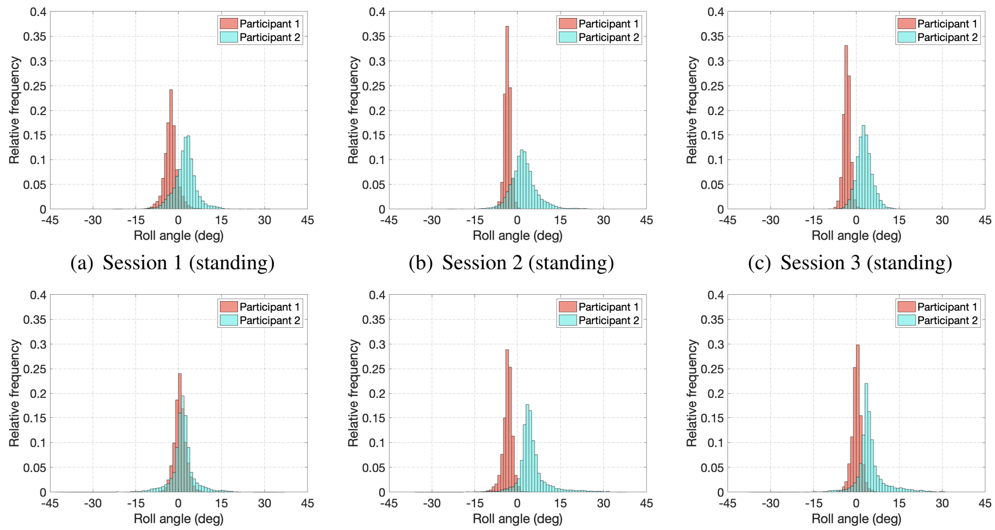
3.4 Qualitative Subjective Feedback

P1 reported feeling somewhat insecure in turning to the left or right during S1 for standing viewing but became more confident in S2 and S3. In seated viewing, P1 noted being more focused on performing the quality task rather than exploring the scenes. P2 expressed a generally large interest in exploring the scenes in both standing and seated viewing irrespective of the given quality assessment task. However, the fixed chair limited the “comfort zone” for turning to the left or right which encouraged P2 to learn more about the scenes by exploring the “sky” (north pole region) and “ground” (south pole region) during S2 and S3 (see pitch ranges in Tab. 1). The feedback indicates that age may have a noticeable impact on the exploration of 360° videos in conjunction with a quality assessment task.

4 Conclusions

In this paper, based on a repeated 360° video quality assessment experiment, we have investigated the head movement behavior of participants for standing and seated viewing. The analysis of the recorded data leads to the following conjectures: (1) Each participant has their own distinct exploration behavior for standing viewing which becomes less different among the participants for seated viewing. (2) Head movements are higher in standing compared to seated viewing with high rotations in yaw followed by pitch and then roll. A similar discovery of little head turns was reported in [6] where participants were seated straddling a motorcycle-style seat. (3) A tendency of reduced rotational exploration of the 360° videos is observed in the repetitions for standing and seated viewing. However, one participant increased the pitch range for the repetitions in seated viewing. (4) Increased translational head movements appear to be encouraged in the repetitions for standing viewing.

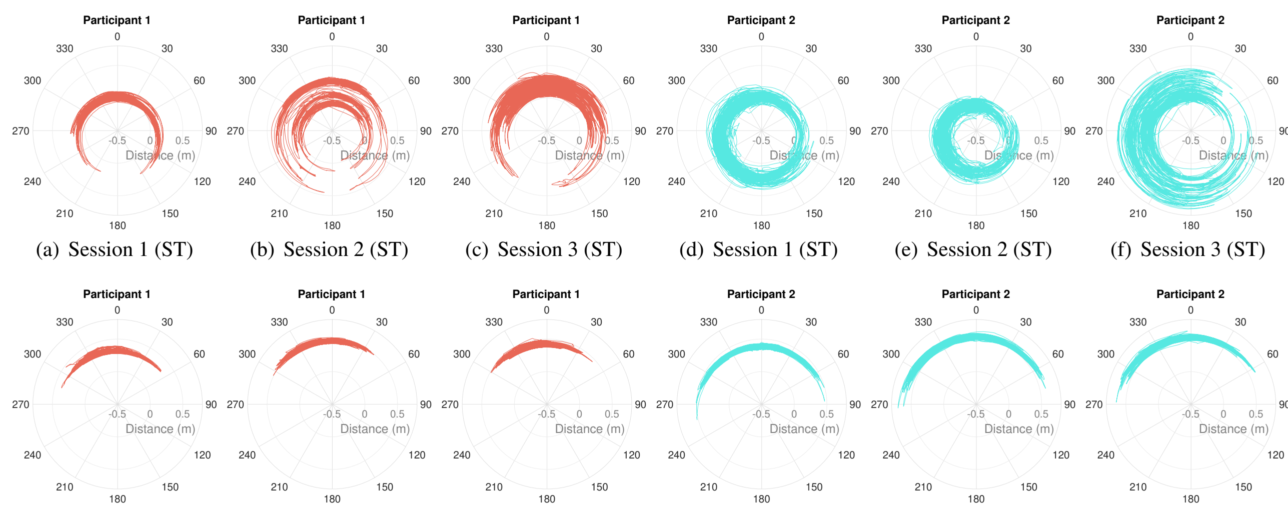
Due to a more focused and similar exploration behavior of participants, seated viewing would better support predictive pre-rendering of views to cope with the ultra-low latency requirements of mobile VR applications. Similarly, 360° video content to be viewed on HMDs would be easier to produce for seated viewing as a rather small rotational range is explored and exploration behavior appears to be more similar between participants.



(a) Session 1 (standing) (b) Session 2 (standing) (c) Session 3 (standing)

(d) Session 1 (seated) (e) Session 2 (seated) (f) Session 3 (seated)

Figure 4: Relative frequency of the roll angle for standing and seated viewing.



(a) Session 1 (ST) (b) Session 2 (ST) (c) Session 3 (ST) (d) Session 1 (ST) (e) Session 2 (ST) (f) Session 3 (ST)

(g) Session 1 (SE) (h) Session 2 (SE) (i) Session 3 (SE) (j) Session 1 (SE) (k) Session 2 (SE) (l) Session 3 (SE)

Figure 5: Head trajectories for standing and seated viewing.

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