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Presence in time: watching live and recorded sports in VR increases spatial, interpersonal, and temporal presence

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Introduction: Little research has explored the experience of viewing sporting events in three-dimensional (3D) virtual reality (VR), whether at the time the sporting events are happening or at a later date.

Materials and Methods: Participants (n = 148) were university students who watched brief segments of a 360° live stream of collegiate volleyball and basketball games, either live, at the time the games were happening, or approximately 1 week later. Participants watched segments of gameplay both while wearing and not wearing a 3D-VR headset, and provided spatial, interpersonal, and temporal presence ratings immediately afterward, as well as ratings of satisfaction with each viewing format.

Results: Viewing the games in 3D-VR, as compared to watching the games on a standard two-dimensional (2D) tablet computer, was associated with greater spatial, interpersonal, and temporal presence, and watching games live was associated with greater temporal presence. Although no differences were seen in overall satisfaction between the 3D-VR and standard 2D-tablet viewing formats, the more participants experienced a sense of presence while watching the games, the more they were satisfied with their sports viewing experience.

Discussion: Sports spectatorship in 3D-VR is associated with a heightening of the feeling of spatial presence ("being there"), interpersonal (i.e., social) presence ("being together"), and temporal presence ("this is happening now"), regardless of whether the games that one is watching are actually occurring in the present, or are instead camera recordings that were captured sometime in the past. Researching the experience of temporal presence in response to recordings of other kinds of public (e.g., music concert) and private events (e.g., family memory) is recommended.

KEYWORDS

virtual reality (VR), sports, presence, 360-degree videos, temporal

Introduction

Prior research details how the experience of presence engendered by three-dimensional (3D) virtual reality (VR) technology could provide a way to simulate the experience of physically attending one's favourite sporting events from the comfort of one's own home (Kim and Ko, 2019; Wilson and Mayhorn, 2019). For example, as compared to watching the

games on a standard two-dimensional (2D) flatscreen display (e.g., television or computer), Vincent and Frewen (2023) found that a majority of participants reported that they felt more spatially, interpersonally, and temporally present when watching live collegiate volleyball and basketball games through a 3D-VR head-mounted display (HMD). Moreover, increased experiences of spatial and temporal presence were associated with an increased preference for watching sports in 3D-VR (Vincent and Frewen, 2023).

While the spatial and social senses of presence are well described in the literature, referring to the respective feelings of "being there" and "being together" at the sports game (e.g., Felton and Jackson, 2022; Skarbez et al., 2018), the notion of a *temporal* sense of presence has only recently been theoretically recognized. Prior study results referring to temporal presence implied that participants, while watching pre-recorded videos, reported that what they were watching: "seemed to be occurring in the present (i.e., now) more so when viewed through HMD . . . even when participants knew fully well that the videos that they were watching had been recorded at an earlier date, thus constituting an illusion of "nowness" in VR" (Vincent and Frewen, 2023, p. 2; see also Frewen et al., 2022; Vincent and Frewen, 2024). This enhancement of temporal presence may increase viewer engagement; the more the viewer feels that what they are watching is happening "now", perhaps the more suspenseful and exciting their viewing experience will be.

Nevertheless, Vincent and Frewen (2023) disclosed several limitations of their prior study, among which included their sole reliance on live streaming of videos, as well as the format of the surveys that they used to assess experiences of presence and satisfaction. First, due to their exclusive use of live-streaming of ongoing sporting events, the authors noted a curious discrepancy between the spatial and temporal senses of presence that was inherent to their research design:

> "while in neither [the VR or non-VR] viewing condition was the participant actually in the same physical space or location as where the sporting activity was taking place (i.e., spatial presence), in both viewing conditions the sporting activity was truly occurring in the present, as is normally the case when people watch sporting events, rather than sometime in the past (i.e., temporal presence), as had been used in prior studies (i.e., Kim and Ko, 2019; Wilson and Mayhorn, 2019). This may have limited the extent to which the experience of temporal presence could be further modulated through VR, in other words, being that all participants knew clearly that the footage they were viewing was being recorded live". (Vincent and Frewen, 2023, p. 6).

As a result, the researchers recommended a future study to investigate spatial and temporal presence in response to both 3D-VR and standard 2D viewing of both live and past (i.e., pre-recorded) sporting events. The authors further reasoned that while cultural norms favour viewing of fuller sports games at the actual time of gameplay, viewing of pre-recorded videos could serve to extend the life of use of prior live streams for subsequent review, such as in watching the highlights of games. As noted, a direct comparison of the experience of presence during live vs. pre-recorded sporting events would allow for a deeper investigation into the power of 3D-VR for engendering not only the familiar spatial and social dimensions of presence but also the more newly recognized temporal dimension.

Further, the use of a forced-choice survey response format in the prior study made it difficult to quantify how strong the perceived differences between 3D-VR and standard 2D viewing formats really were, thus further rendering the results of correlational tests between the experience of different senses of presence uncertain (Vincent and Frewen, 2023). In the latter case, a surprising result of the previous study was that a greater experience of social presence during 3D-VR viewing was not correlated with either spatial or temporal presence, nor with satisfaction-preference ratings for viewing in 3D-VR. As a result, the researchers were forced to conclude that the:

> "increased experience of social presence (accompanying VR in their study) seems unlikely to be mediated through the ability of VR to also induce the sense of being spatially or temporally present, that is, the sense that things are happening in the here and now. The reasons why people experience more social presence in VR while viewing livestreamed sporting events in 360° therefore requires further study". (Vincent and Frewen, 2023, p. 6).

Here, in the least the study results call for an improved measurement approach to investigating associations between the experience of presence in the spatial, interpersonal, and temporal dimensions for the consumer of sports media.

The current study thus sought out to replicate and extend the results of Vincent and Frewen (2023) using a continuous response survey and a comparison of responses to sports games that were originally streamed live and were either watched at that time or were watched approximately 1 week later. The resulting quasi-experimental research design thus allowed for a fuller evaluation of their contextualized "SIT" framework developed for conceptualizing the multidimensional experience of presence in 3D-VR as involving a modulation of the participant's senses of where (Spatial), with whom (Interpersonal) and when (Temporal) events are occurring in relation to a self (i.e., the participant) (Vincent and Frewen, 2023).

We predicted that:

1) 3D-VR would produce more intense experiences of spatial, interpersonal, and temporal presence during viewing of sporting events than would watching the same games on a standard 2D flatscreen device (i.e., tablet computer), irrespective of whether the games were occurring in the present and viewed via live-streaming or were the same games but only viewed 1 week later.
2) Satisfaction with the VR viewing modality would be correlated with more intense experiences of spatial, interpersonal, and temporal presence when viewing the games in 3D-VR.
3) Live-streaming of events, whether viewed in 3D-VR or simply on a standard 2D-tablet, should produce greater experiences of temporal presence when compared with watching previously recorded videos. Note that such a demonstration would serve to provide further construct validity for the otherwise lesser known subjective dimension of temporal presence when compared with the familiar spatial and social senses of the term (e.g., Felton and Jackson, 2022; Skarbez et al., 2018).

TABLE 1 Rating questions.

Theme	Questions		Live		Playback	
	Question 1	Question 2	VR (M, SD)	Non-VR (M, SD)	VR (M, SD)	Non-VR (M, SD)
Spatial	. . .how much did you feel like YOU WERE IN THE SAME LOCATION as where things were taking place in the video?	. . .how much did you feel like YOU WERE "THERE", IN THE SAME PLACE as where things were happening in the video?	6.24 (2.20); r = .77	3.49 (2.66); r = .72	5.88 (2.40); r = .82	2.83 (2.47); r = .85
Interpersonal	. . .how much did you feel like you were INTERPERSONALLY CONNECTED TO what was happening in the video?	. . .how much did you feel like you were SOCIALLY A PART OF what was happening in the video?	5.38 (2.37); r = .69	3.54 (2.20); r = .57	4.89 (2.37); r = .68	2.98 (2.05); r = .68
Temporal	. . .how much did you feel like what you were seeing in the video was HAPPENING IN THE PRESENT, that is, CURRENTLY, rather than being something that had happened sometime in the past?	. . .how much did you feel like what you were seeing in the video was HAPPENING RIGHT NOW, that is, LIVE, as opposed to being a recording from sometime in the past?	6.82 (2.14); r = .66	5.67 (2.55); r = .77	5.83 (2.37); r = .71	4.11 (2.38); r = .78
Satisfaction	. . .HOW SATISFACTORY was this way of viewing the video?	. . .HOW MUCH DID YOU LIKE this way of viewing the video?	6.24 (2.34); r = .85	5.49 (2.02); r = .74	5.86 (2.35); r = .76	5.87 (1.90); r = .68

Notes. Ratings were on 0–10 rating scale anchored by "Not at all" (0) and "Completely" (10) with "Moderately" as the mid-point (5). Questions were prefaced by the statement: "Referring to what was happening in the video . . . ". The value r indicates the correlation observed between the two ratings per theme while the M and SD, reported refers to the averaged response across the two ratings.

Methods

Participants

Participants (n = 148) were university students who were invited to participate from a campus eatery; all participants who were on site were invited to participate, and the acceptance rate was approximately 50%. There were 94 participants who identified as female (64%), 50 who identified as male (34%), and 4 who identified as non-binary or third gender (2%).

Materials

The research equipment used was identical to the prior study (Vincent and Frewen, 2023) including choice of 360° Camera and settings (Kandao QooCam 8K camera set to 7,680 by 3,840 at 30 fps), Samsung Galaxy S21 smartphone (1,080 × 2,400 pixels and refresh rate of 120 Hz), HMD (Skymall 3D-VR headset with 90° FoV), and Samsung Galaxy Ultra S8 2D-tablet computer (14.6″, 1848 × 2,960 pixels and 120 Hz refresh rate).

Survey

Participants answered ten self-report questions via online surveys that were administered in person by 2D-tablet immediately after each viewing modality (i.e., 3D-VR and 2D-tablet). The questions that were asked were an expanded 10-item version of the six that were used by Vincent and Frewen (2023). The first eight questions were presented in a random order and were answered on a 0–10 rating scale anchored by "Not at all" (0) and "Completely" (10) with "Moderately" as the mid-point (5). Two questions asked about each of spatial, interpersonal, and temporal presence and viewing satisfaction as described in Table 1 above; given the moderate-to-high correlations that were observed between each of the four pairs of questions (see Table 1), the ratings obtained in response to each pair were averaged for simplicity of presentation and to address the error inherent in measurements of singular survey items, a decision that was made prior to data collection. The remaining two questions simply asked about gender identification and for an indication of the type of sporting event that had been viewed as an attention check as was similarly conducted by Vincent and Frewen (2023).

Procedure

The study procedures received approval by an institutional research ethics board prior to study commencement, and all participants provided written informed consent prior to taking part in the study procedures. Figure 1 provides an overview of the research design and procedures.

Of the 148 participants, 64 indicated they had viewed a basketball game while 79 indicated they had viewed a volleyball game; acknowledging that there were two persons who indicated "other" and three persons who chose not to answer the question, there were no errors noted in the attention check. As conducted in the prior study by Vincent and Frewen (2023), one researcher recorded the videos live from a front row seating area by the volleyball or basketball court, streaming the footage to YouTube, while the other facilitated the students' viewing of the video footage acquired via HMD (3D-VR condition) and 2D-tablet in counterbalanced order (73 3D-VR condition first, 75 2D-tablet condition first). Near equivalence was achieved simply by

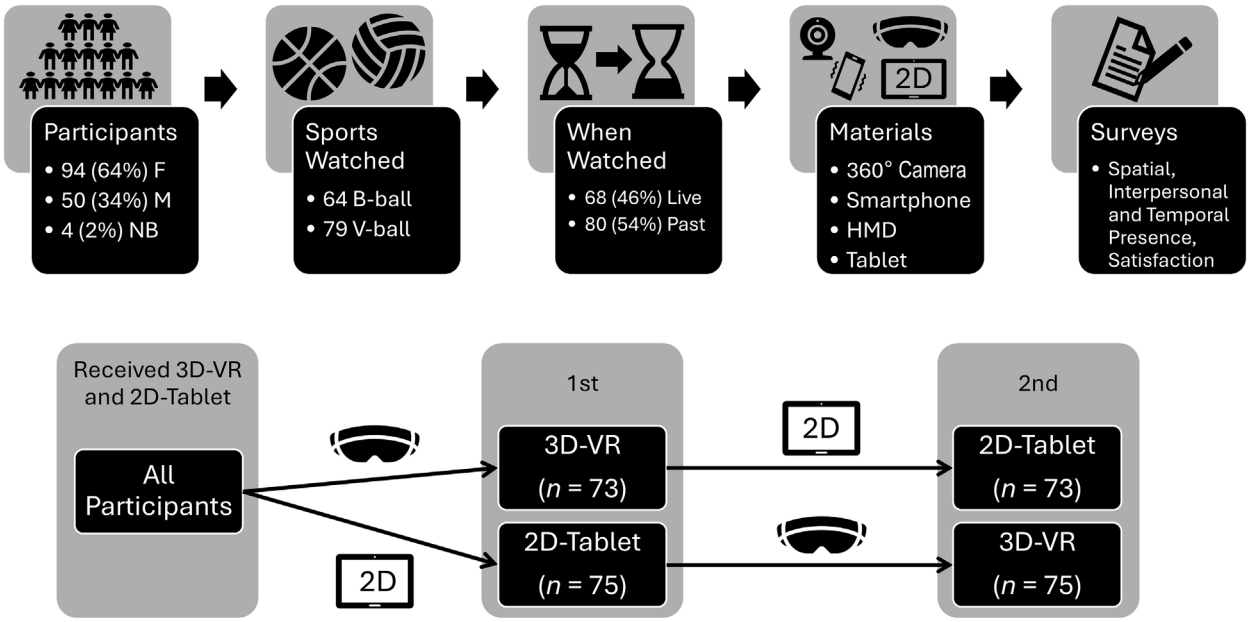

FIGURE 1
Schematic of Research Design and Procedures. *Notes.* F, Female, M, Male, NB, Non-Binary, B-ball, Basketball, V-ball, Volleyball, HMD, Head-Mounted Disiplay. Materials included a 360° Camera ((Kandao QooCam 8K camera; set to 7,680 by 3,840 at 30 fps), smartphone (Samsung Galaxy S21; 1,080 × 2,400 pixels and refresh rate of 120 Hz), HMD (i.e., 3D-VR headset: Skymall VR; 90° FoV), and tablet computer (Samsung Galaxy Ultra S8; 14.6″, 1848 × 2,960 pixels and 120 Hz refresh rate).

administering the ordering in an ABAB design (i.e., if the first participant tested on any particular evening received the 3D-VR condition first, the next participant received the 2D-tablet condition first). Participants were informed of which viewing modality they were to perform first after they had consented to the study.

Of the 148 participants, 68 (46% of) participants viewed a live stream of the sporting events, while 80 (54% of) participants viewed the same videos approximately 1 week later. Here, the 68 participants who watched the live streams marked the target sample size to be matched (or slightly exceeded) by the group who watched the same videos approximately 1 week later.

As a key point, participants were explicitly informed as to whether the video they were watching was a live-stream or a previously recorded video, which is itself also a fact that is clearly apparent on the YouTube user interface itself. Participants' understanding of the same was verified verbally in all cases, and there were no instances of confusion on this essential point.

Participation took place at a campus eatery in the evening when the games were typically originally scheduled, thus keeping constant the time of day of viewing of the live-streamed and pre-recorded videos. Participants were free to move in their chairs or while standing during both 3D-VR and 2D-tablet viewing and encouraged to interact with both technologies as they wished before answering the online rating scale questions. In any case, length of video viewing was usually only about a few minutes.

Statistical analysis

Split-plot multivariate analysis of variance (MANOVA) examined participants' spatial-, interpersonal-, temporal-presence and satisfaction ratings in response to the 3D-VR and 2D-tablet viewing conditions (within-subjects) by the order in which they were administered (between-subjects) and whether participants had viewed the recordings live or 1 week later; effect sizes are expressed as partial η^2. In cases where results were statistically significant at a multivariate level, follow-up univariate ANOVA was undertaken, and independent and paired *t*-tests of mean comparisons were conducted in turn, with effect sizes noted as Cohen's *d* and *d′*, respectively. Further, Pearson correlation coefficients were calculated between each of the three presence and satisfaction ratings referring within and across the 3D-VR and 2D-tablet viewing formats, and a single-step multiple regression equation was calculated with presence ratings as predictors and satisfaction ratings as the outcome, replicating approaches taken by Vincent and Frewen (2023).

Results

Analysis of variance and mean differences

The primary results are illustrated in Figure 2 separately for the participants who watched a live stream of the games versus those who watched the same games approximately 1 week later.

The multivariate main effect for viewing order (3D-VR first or 2D-tablet first) was statistically significant, $F\,(4,141) = 4.01$, $p < .01$, η^2-partial = .10, as was the multivariate main effect of viewing time (live or at a later date), $F\,(4,141) = 5.12$, $p < .01$, η^2-partial = .13, although these two factors did not significantly interact, $F\,(4,141) = 1.30$, $p = .27$, η^2-partial = .04. The multivariate main effect for viewing format (3D-VR or 2D-tablet) was also highly significant, *F*

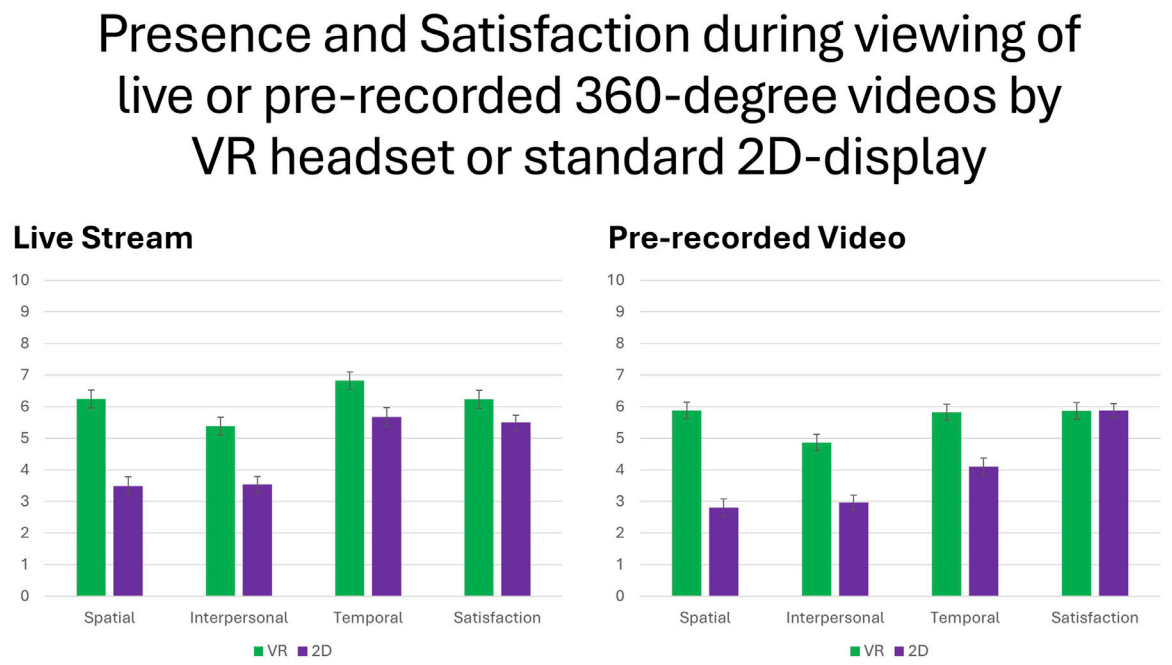

FIGURE 2
Presence and Satisfaction Ratings in response to 3D-VR and standard 2D-tablet viewing of Live-streamed vs. Pre-recorded 360-degree Videos of Collegiate Basketball and Volleyball Games. *Notes.* Ratings were on 0–10 rating scale anchored by "Not at all" (0) and "Completely" (10) with "Moderately" as the mid-point (5). Bar-graphs display the *M* whereas the error bars refer to the *SEM*.

TABLE 2 Univariate ANOVA.

Dependent variable	Format (F) (VR or Non-VR)	Order (O) (VR first or second)	Format (F) x order (O)	Time (T) (live or playback)
Spatial Presence	$F = 147.74$, $p < .01$, η^2-$p = .51$	$F = 7.86$, $p < .01$, η^2-$p = .05$	$F = 6.38$, $p = .01$, η^2-$p = .04$	$F = 2.84$, $p = .09$, η^2-$p = .02$
Interpersonal Presence	$F = 91.92$, $p < .01$, η^2-$p = .39$	$F = 3.31$, $p = .07$, η^2-$p = .02$	*ns*	$F = 2.93$, $p = .09$, η^2-$p = .02$
Temporal Presence	$F = 45.17$, $p < .01$, η^2-$p = .24$	*ns*	*ns*	$F = 15.90$, $p < .01$, η^2-$p = .10$
Satisfaction	*ns*	*ns*	*ns*	*ns*

Notes. Statistics are reported for effects for which $p < .10$; otherwise, *ns* simply refers to non-significant results (i.e., $p > .10$). Multivariate effects for the FxT, TxO, and FxTxO interactions were non-significant, thus univariate analyses were not undertaken.

(4,141) = 40.62, $p < .01$, η^2-partial = .54, but interacted with viewing order, F (4,141) = 3.20, $p = .02$, η^2-partial = .08, while not with viewing time, F (4,141) = 1.76, $p = .14$, η^2-partial = .05; the three-way interaction was also non-significant, F (4,141) = 0.93, $p = .45$, η^2-partial = .03.

Follow-up univariate results are reported in Table 2 above. In short, follow-up mean comparisons showed that participants reported that the main effect of 3D-VR format was associated with greater experiences of spatial-, interpersonal- and temporal presence, independent of the order and time in which videos were viewed. Paired mean comparisons confirmed that this was true in the case of participants who watched the sporting events live (spatial [d' = 1.11], interpersonal [d' = 0.81], and temporal [d' = 0.49]; all p's < .01), replicating the prior results of Vincent and Frewen (2023). Moreover, the same result was seen in the case of participants who watched videos of the same games but at a later date (spatial [d' = 1.26], interpersonal [d' = 0.86], and temporal [d' = 0.72]). In comparison, self-reported satisfaction with the 3D-VR and 2D-tablet viewing formats was not found to significantly differ; satisfaction with both viewing formats was generally in the "moderate" range between 5 and 6 on the 0–10 scale (Table 2).

Referring to the main effect involving order, results were only statistically significant for spatial presence ratings, but this too was the only rating that showed statistically significant results for the interaction between order and viewing format. Further analysis of the latter result showed that while spatial presence in response to 3D-VR did not depend on viewing order, t (146) = 0.71, $p = .48$, d' = 0.12, spatial presence in response to the 2D-tablet condition was reported to be higher when participants experienced the 2D-tablet condition first, t (146) = 3.73, $p < .01$, d' = 0.61.

Finally, referring to the main effect involving time of viewing, results were only statistically significant for temporal presence ratings. In short, live streaming was associated with greater experiences of temporal presence when compared to viewing pre-

TABLE 3 Correlations between presence and satisfaction during VR and Non-VR viewing of sports.

	Satisfaction	
Sense of presence	VR	Non-VR
Spatial	.61	.21
Interpersonal	.61	.27
Temporal	.44	.31

Notes. Sense of presence ratings correspond with the format in which satisfaction was rated. All *p*'s < .01.

recorded videos, both when viewed in the 3D-VR format, t (146) = 2.67, $p < .01$, d' = 0.44, and in the case of viewing in the 2D-tablet format, t (146) = 3.85, $p < .01$, d' = 0.64.

The magnitude of ratings was also compared between each of the three dimensions of presence separately among participants who watched the games live and among participants who watched the games at a later date. Firstly, among those who watched the games live, referring first to the experience of presence in 3D-VR, both spatial (d' = .37, $p < .01$) and temporal (d' = .63, $p < .01$) presence were rated higher than interpersonal presence, whereas differences between spatial and temporal presence failed to reach statistical significance (d' = .26, p = .08). In comparison, referring to the experience of presence while watching sports games in the standard 2D-tablet format, temporal presence was rated higher than both spatial (d' = .83, $p < .01$) and interpersonal (d' = .88, $p < .01$) presence, whereas there was no evidence for differences between spatial and interpersonal presence (d' = .02, p = .83).

Secondly, among those who watched previously recorded games, a similar pattern of findings emerged. Again referring first to the experience of presence in 3D-VR, once again both spatial (d' = .41, $p < .01$) and temporal (d' = .39, $p < .01$) presence were rated higher than was interpersonal presence, while there was again no evidence for differences in the intensity of spatial and temporal presence (d' = .02, p = .83). In comparison, referring to the experience of presence while watching sports games in the standard 2D-tablet format, temporal presence was again rated higher than both spatial (d' = .52, $p < .01$) and interpersonal (d' = .50, $p < .01$) presence, whereas there was no evidence for differences between spatial and interpersonal presence (d' = .07, p = .35.

Correlations and linear multiple regression

Sense of spatial (S), interpersonal (I), and temporal (T) presence was significantly correlated with satisfaction in response to both the 3D-VR and 2D-tablet viewing formats, but the effect sizes were 1.4–2.9 times stronger in the case of the 3D-VR format (see Table 3). The three different senses of presence were also moderately correlated during 3D-VR viewing (all *p*'s < .01): S-I, r = .71, S-T, r = .41, I-T, r = .54. Moreover, very similar findings were seen in response to the standard 2D-tablet viewing format (all *p*'s < .01): S-I, r = .75, S-T, r = .41, I-T, r = .55.

A linear multiple regression equation accounted for 44% of the variation in satisfaction with the 3D-VR viewing condition from experienced presence, F (3,144) = 38.06, $p < .001$, y = 1.59 + .353S + .139I + .281T; the unstandardized beta coefficients were statistically significant in the case of Spatial ($p < .001$) and Interpersonal (p = .003) but not in the case of Temporal (p = .07). However, different results were seen in response to the 2D-tablet viewing condition. While the equation again accounted for 33% of the variation in satisfaction with the 3D-VR viewing condition from experienced presence, F (3,144) = 20.78, $p < .001$, y = 4.42 + .014S + .121I + .174T, only the unstandardized beta coefficient referring to Temporal was statistically significant (p = .016), whereas in the cases of Spatial (p = .87) and Interpersonal (p = .31) these coefficients were non-significant.

Finally, satisfaction ratings *between* viewing formats were not significantly correlated, r = .12, p = .16. Further, corresponding presence ratings were only weakly correlated between response to the 3D-VR and 2D-tablet viewing formats: Spatial, r = .27, Interpersonal, r = .45, Temporal, r = .44.

Discussion

The current results provide further support for the power of 3D-VR to induce increased experiences of spatial, interpersonal, and particularly temporal presence while watching sporting events, both while streamed live as well as when watched at a later date. We conclude that if one wants to feel more like one is in the same time and place as where and when things are happening–or, at least where and when they occurred once upon a time–one may try watching a video of said events by HMD. Doing so appears to render a greater experience not only of being "there", as is well known in the 3D-VR psychology literature in the terms of *spatial* presence, but also that what is happening is happening "now", in the *temporal* sense of the same term (Vincent and Frewen, 2023). Further, the current research showed, in contrast to prior findings, that the *social* feeling of presence, the feeling of "being together" or interpersonally connected to and a part of what was happening in the video, correlated with the spatiotemporal senses, triangulating a simple three-dimensional, contextualized framework for conceptualizing the phenomenology of presence as referring to one's experience of place, person, and time (Vincent and Frewen, 2023).

Perhaps the chief theoretical contribution of the current research is to further substantiate the construct validity of a *temporal* dimension of presence for understanding the subjective experience of 3D-VR (Frewen et al., 2022; Vincent and Frewen, 2023; Vincent and Frewen, 2024). Indeed, the construct of temporal presence is lesser known when compared with the more familiar spatial and social senses of presence referring to experiences of "being there" and "being together", respectively (e.g., Felton and Jackson, 2022; Skarbez et al., 2018). In the current research, temporal presence was not only rated higher for 3D-VR viewing of sports games both while streamed live as well as when watched at a later date, but temporal presence was even rated about as high when viewing a pre-recorded game in 3D-VR as it was when viewing a live-streamed game on a standard two-dimensional display. More, the intensity of experience of temporal presence was about as high as was spatial presence while watching both live-streamed and pre-recorded videos. Collectively, these findings suggest that temporal presence may be a salient dimension of the phenomenology of

presence in 3D-VR, at least as regards the experience of viewing 360-degree videos. In effect, it appears that watching 360-degree videos by HMD makes people feel more like what they are seeing is happening "*now*", regardless of whether that is in fact true, in the case of live-streaming of videos, or is in fact false, in the case of watching pre-recorded videos. Referring to the latter, viewing by HMD may serve to extend the life of media consumption of sporting events, such as even allowing a certain feeling of "reliving" of the thrill of certain significant moments in sporting history.

Further theoretical and experimental research should seek to uncover the psychological mechanisms through which viewing stimuli by HMD intensifies experiences of temporal presence, including stimuli that were recorded at an earlier time. Vincent and Frewen (2023) conjectured that this may be partially due "to the increased spatial presence commonly experienced in 3D-VR, or the unframed or in other terms *externally non-mediated* sense in which one seems to be viewing and aware of media via HMD" (p. 2). In other words, by contrast to a framed screen such as a television or standard computer monitor:

> "Viewing 360-degree videos through HMD simultaneously occludes one's natural surroundings while providing an unframed viewing of the virtual space, thereby creating a false perception that what one is seeing are things that are situated directly in front of one's eyes. But normally when we see things that are happening right in front of our own eyes, and they take up our whole field of view, we will not only be physically located in the place that we are seeing, but we will also consider that the things that we are seeing are happening "right now" (i.e., we do not live in the past). Such normal and logical circumstances thus create the potential for an illusory increased experience of "nowness" when pre-recorded videos are viewed in VR".

Testing of the effects of external non-mediation in influencing temporal presence could be dissociated from viewing by HMD by presenting videos within a frame within the immersive environment viewed by HMD; one would predict that doing so should reduce the intensity of temporal presence, perhaps even to the degree experienced when watching 2D videos. Similarly, accentuating the viewer's awareness of their wearing of the HMD should decrease perceived intensities of temporal presence.

Nevertheless, if practical user satisfaction is of chief concern, our results also suggest that viewing of sports games through 360-degree videos was on average only moderately enjoyable, with no clear differences in satisfaction between the 3D-VR and standard (2D-tablet) viewing modalities. However, the more participants reported a sense of presence in 3D-VR, the more satisfied they were with 3D-VR as a sports viewing technology; by comparison, satisfaction with the standard two-dimensional (tablet) viewing modality was less strongly correlated with the experience of presence. Accordingly, and consistent with prior findings (Vincent and Frewen, 2023), it may be advisable for media vendors to record sporting events in 360-degrees when possible. Doing so presents media consumers the choice between immersive (3D-VR) and non-immersive (2D) viewing options.

Tailoring of content to more strongly enable feelings of social presence may also be advantageous to increase satisfaction with 3D-VR viewing, given that the interpersonal sense of presence was generally rated lower than the spatiotemporal senses in the current research. In any case, interpersonal presence correlated with the spatiotemporal senses of presence in the current research, a set of results divergent from a previous investigation, perhaps owing to the use of a quantitative, continuous rating scale as compared with the use of a forced-choice, categorical metric in the prior study (Vincent and Frewen, 2023).

Nevertheless, it must be noted that all rated means for presence and satisfaction levels experienced were below seven on the 11-point (0–10) scale, suggesting that there is still considerable room for improvement in engendering presence and satisfaction beyond the capabilities of the 3D-VR technology studied here. Other research has investigated the predictions of quality of experience during viewing of 360-degree videos of other themes and found that the overall interest of the user in the video content is a strong predictor (Anwar et al., 2020), which is consistent with prior research in 3D-VR sports spectatorship (Kim and Ko, 2019), while the experience of cybersickness reduces overall satisfaction, and is especially prevalent among females (Anwar et al., 2020). Further, participants who have more prior familiarity with 3D-VR can be expected to be more critical of the perceptual quality of the videos depicted (Anwar et al., 2020); unfortunately, the current study did not inquire about participants' prior familiarity with 3D-VR technology, although it was our impression that most participants had no prior exposure with the technology.

Further in this regard, in the current research, as in the prior study (Vincent and Frewen, 2023), we relied on the use of smartphone-mediated 3D-VR, which is of demonstrable lower quality than more technologically sophisticated 3D-VR equipment. Importantly, Anwar et al. (2020) showed that better quality HMDs lead to higher quality user experiences (e.g., comparing the HTC Vive to a smart-phone mediated HMD such as used herein). That said, prior to conducting the current investigation, we piloted and found that another HMD to which we had access–the *Meta Quest 3 HMD*, among the most popular and technologically sound consumer-grade HMDs currently available–appeared to render *poorer* quality livestreams on YouTube than did the standard smartphone HMD enclosure that was opted for in the current research, whether via the Quest YouTube application or via its native internet browser. While technological improvements to both recording and viewing devices will likely enable more immersive experiences of presence and satisfaction while viewing 360-degree videos by HMD in future years, this must be considered a limitation of the current research.

Additional notable limitations of the current research are shared with those of the prior investigation of Vincent and Frewen (2023), owing to the use of a quasi-experimental design and the specificity of our participant demographic. Regarding the former, participants were not randomized to live streaming vs. pre-recorded viewing times. Furthermore, the live streaming sessions were conducted in a public place (i.e., a university campus eatery) and therefore lacked the experimental control that is possible through a 3D-VR psychology laboratory. Overall, while our approach may afford a high degree of external validity, it is unclear how unmeasured aspects of the setting might have facilitated or hindered the strength of the research findings we have reported. Further, limitations include that we only studied university students

whose experience of 3D-VR may not generalize to other participant groups; for example, sports fans who are at a later life stage may be more reluctant to trial newer viewing technologies, being comfortable enough with the two-dimensional viewing modalities with which they are already familiar. As previously noted, research is needed to identify the source of individual differences in preference for viewing sports and other forms of entertainment media via HMD vs. standard two-dimensional flatscreen displays (Vincent and Frewen, 2023).

It is worth noting that applications for increasing temporal presence as a result of viewing video by HMD likely extend beyond sports media consumption to other forms of entertainment and personal domains of life. For example, viewing 360-degree videos of personal events by HMD may enable reliving of a cherished memory with a qualitatively new form of nostalgia, or a novel form of immediacy in witnessing life events that one had otherwise regrettably missed (e.g., a child's birthday party), making the events seem more like they are happening in the here-and-now even when viewed at a later date. For example, considering 3D-VR applications for virtual attendance at music concerts, Charron (2017) considered that:

> "even if [conventional 2-dimensional] digital mediation maintains the time dimension (now) of live [music] performances, it ultimately loses its space dimension (here). In that sense, regardless of technological developments, live performances retain some elements of uniqueness that cannot be reproduced, such as being there . . . On the other hand, fueled by the development of immersive technologies such as spherical videos and VR goggles, virtual concerts are rapidly growing in popularity online". (Charron, 2017, p. 2–3)

In fact, among 44 concert goers in one survey study who reported having previously viewed a music concert via HMD, 70% considered the medium to be the "the future of music industry" (Onderdijk et al., 2023, p. 2,391). Surprisingly to the researchers, however, such affections had less to do with a motivation for enhanced social presence, and more to do with other aspects of the 3D-VR viewing experience such as its general novelty and the ability to alter visual perspective (Onderdijk et al., 2023). Unfortunately, however, participants' sense of spatial and temporal presence were not directly assessed in the study, while Charron's (2017) interpretation would appear to assume that 3D-VR might primarily affect the spatial but not the temporal experience of presence as was found in the current research; what role each of these dimensions may have played in concert goers' overall level of satisfaction with the experience in the study by Onderdijk et al. (2023) will therefore have to be investigated in future research. Further, other research using a graphical simulation of a 1983 Dire Straits performance (rather than 360-video recordings of the original concert) showed that, particularly among females, participants often experienced unintended social anxiety relating to the presence of other depicted concert attendees (i.e., avatars) (Slater et al., 2023). Here, while temporal presence was again not explicitly assessed in Slater et al.'s (2023) research, it seems likely that the engendered plausibility of the scenario suggested to participants that the concert was somehow really happening in the present rather than merely depicting events that had occurred more than four decades prior; the psychological construct of temporal presence may help explain these and similar effects in future 3D-VR experiments. Finally, Scorolli et al. (2023) compared response to live concert attendance in person to previously-recorded musical performances when viewed through higher-vs. lower-quality 3D-VR headsets and found that while notable differences in social presence emerged, the higher-quality 3D-VR experience produced a more intense emotional experience statistically equivalent with attending a live musical performance, excepting that it was not rated quite as beautiful. Again, however, spatial and temporal aspects of presence were not directly measured. Moreover, from the perspective of the current research, the spatial and temporal aspects of attending would have been confounded in their research design with regard to the comparison between physically attending a live performance and virtually attending a pre-recorded performance; while the former afforded an experience of both spatial and temporal presence, the latter conceivably offered neither.

As our opportunities for immersive media consumption are expected to increase dramatically in the coming years, such as during travel automated by autonomous vehicles, it is important that we design experiences based on a well researched taxonomy to ensure a high degree of user satisfaction (Anwar et al., 2024). One thus hopes for wider, creative applications of the contextualized experience of presence in future 3D-VR research. Ideally, this would be investigated in both the context of viewing of 360-degree videos as well as graphical environments, and combine research design elements that independently seek to modulate the spatial and social but also the temporal dimensions of presence. At the current juncture it seems likely that we are only scratching the surface of the kinds of immersive experiences of presence that the future of 3D-VR may have to offer.

Conclusion

Researching the experience of virtual-online attendance at sporting events through the viewing of 360-degree videos online by HMD remains an understudied endeavor. Here, using an improved survey methodology, we replicated our prior findings from a study of live-streaming of collegiate athletics programming that showed that, even through the use of inexpensive smartphone mediated 3D-VR, people experience more spatial, interpersonal, and temporal presence while watching the games via HMD than when watching the games on a standard two-dimensional flatscreen (tablet) display (Vincent and Frewen, 2023). Further, we newly found that the same can be said of the experience of watching sports games that were previously recorded (i.e., are not being viewed live); it appears that the 3D-VR viewing medium still maximizes spatial, interpersonal, and temporal presence in comparison with viewing the same sports games on a tablet computer. Interestingly, the 3D-VR viewing medium appears to facilitate a greater experience that what one is watching is occurring in the present, in the here and now, regardless of whether this is logically or factually the case. Practical applications of this research therefore continue to be consistent with the recommendation for media vendors to offer 3D-VR viewing of sports as a novel method for enhancing sports fans' experience of virtual presence at games. Study results are also in keeping with the notion that a dimension of temporal presence can

be defined insofar as the experience of viewing live-streams and pre-recorded videos could be distinguished on this dimension; further studies of the construct validity of temporal presence are recommendable not only with viewing of sports media but also with viewing in 3D-VR of video recordings of other life experiences.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Western University Canada, Non-Medical Research Ethics Board (#121880). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

PF: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing–original draft, Writing–review and editing. AV: Data curation, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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